EVALUATION OF THE SOCIO-ECONOMIC IMPACT OF CLIMATE CHANGE IN BELGIUM

STUDY COMMISSIONED BY THE NATIONAL CLIMATE COMMISSION

Final Report

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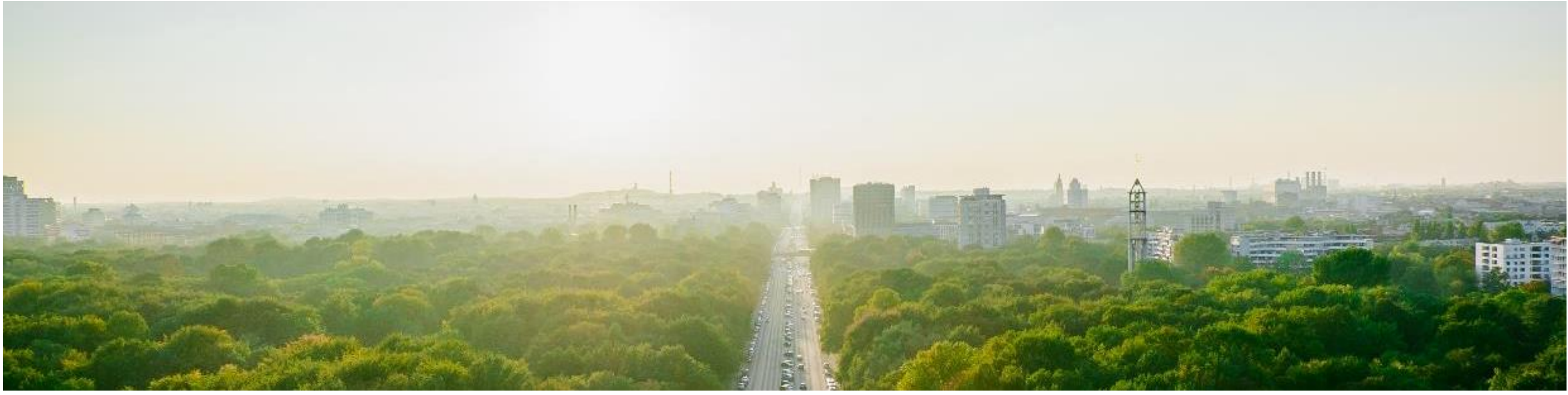

Table of Contents

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LIST OF ACRONYMS

AM	Adapted Management
AR5	Assessment Report 5 (published by the IPCC)
B€	Billion (10^9) euro
CDD	Cooling Degree Days
CF	Capacity Factor
CMIP5	Coupled Model Intercomparison Project 5
CORDEX.	Coordinated Regional Climate Downscaling Experiment
CPI	Consumer Price Index
DJF / JJA	December-January-February (Winter) / June-July-August (Summer)
FWI	Fire Weather Index
GCM	Global Climate Model
GDP	Gross Domestic Product
GVA	Gross Value Added
ha	Hectare
HDD	Heating Degree Days or Heatwave Degree Days (depending on context)
IPBES	Intergovernmental Science-Policy Platform Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre of the European Commission
M€	Million (10^6) euro
Mtoe	Megaton of Oil Equivalent
NCC	National Climate Commission
NDVI	Normalised Difference Vegetation Index (~ Amount of green biomass)
NDWI	Normalised Difference Water Index (sensitive to plant water content)
NWFP	Non-Wood Forest Products
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RMI	Royal Meteorological Institute
SSP	Shared Socio-economic Pathway
TAW	Total Available Water
TM	Traditional Management
TWh	Terra Watt hour
WBGT	Wet Bulb Globe Temperature

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1. INTRODUCTION

Today, the average global temperature has increased by more than 1°C compared to pre-industrial values (Figure 1-1); atmospheric CO_2 concentrations have risen from 280 to more than 400 ppm. At the current pace of emissions, the carbon budget that is left for staying below the 2°C target of the Paris Agreement will be depleted in a few tens of years. For the 1.5°C target, this budget will be exhausted before the decade is out.

At the same time, the impacts of climate change are becoming increasingly apparent. In recent years Belgium has experienced persistently mild winters, recurring drought episodes and a succession of hot summers, culminating in the unprecedented temperature extremes recorded during the summer of 2019. These phenomena have already affected agricultural yield, mortality figures and labour productivity loss, among other.

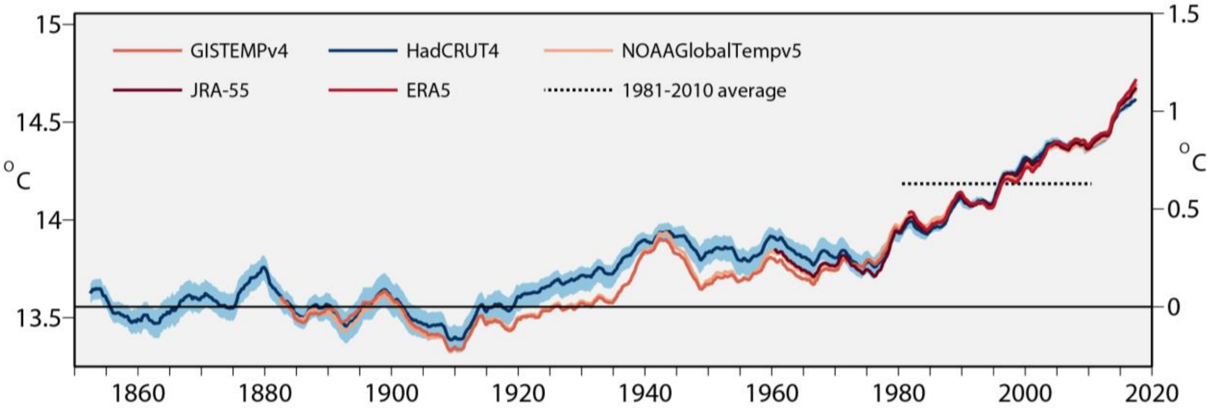

Figure 1-1. Annual average, global 60-month average near-surface air temperature relative to the pre-industrial period. Source: Copernicus Climate Change Service.

Realising that some level of climate change has become unavoidable, it is now important to direct considerable actions and resources towards adaptation, apart from pursuing efforts towards the reduction of greenhouse gas emissions.

To develop relevant and effective adaptation plans and measures, it is of paramount importance to gain insight into the physical climate risk that is expected to affect society. Moreover, to be able to compare climate risk and the associated damage across sectors, it is useful to quantitatively express damage in a harmonized fashion by expressing it as a monetary value.

This report provides an overview of the socio-economic impact of climate change in Belgium, resulting from a literature-based study conducted between November 2019 and July 2020. While working from an existing body of literature has the advantage of allowing to quickly collect and process large amounts of information, it also comes with its limitations.

One such limitation is related to the fact that, most of the time, the available information pertains to regions outside Belgium or for a portion of Belgium only; converting impacts and costs to the Belgian situation has shown to be far from straightforward, often requiring a large number of (strong) assumptions. Another limitation resides in the fact that use of 'the literature' as a main source of (abundant yet scattered) information precludes the development of a fully coherent framework. Indeed, ideally one would follow a bottom-up approach, starting from e.g. consistent land use change scenarios and common methodologies to all sectors considered; and using a fixed set of time horizons and climate scenarios. In our study, we were at the mercy of whatever information was available in scientific papers and reports, each with its own approaches, scenarios and time horizons, making it sometimes hard to ensure an appropriate level consistency.

At the start of the study, an attempt was made to list expected climate change impacts for Belgium as completely as possible, giving rise to a 'climate hazard – sector' matrix in which the matrix cells describe potential impacts; this matrix has been reproduced in the Appendix. Given that the available

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resources were finite, a selection was required regarding the climate impacts to be covered. In the end, our choice was guided by discussions with the Steering Committee, by the expertise available within the consortium, and by the availability of suitable source material.

The remainder of this report is organised as follows. Section 2 presents the main characteristics of climate change scenarios for Belgium in terms of standard climatic indicators such as temperature and precipitation. In Section 3 a detailed account is given of the expected physical impacts of climate change for a number of different sectors, as much as possible employing information for Belgium, but converting information and data from studies conducted elsewhere whenever required. Section 4 describes the effect of transboundary climate impacts to the situation in Belgium, through the mechanisms of international trade. Section 5 continues with a description of analysis methods and indicators developed and employed abroad and within the Belgian Regions, and which have served as an inspiration for the present study. Constituting the core of the study, Section 6 presents results of economic cost estimates by sector at a macroscale level and Section 7 addresses social impacts of climate change in Belgium. Section 8 describes a few concrete case studies, meant to make the impacts of climate change more tangible as compared to the macro-economic approach used in Section 6. Conclusions are presented in Section 9.

Finally, readers who prefer to first read a more digestible version of the present full report are referred to the companion *Summary for Policymakers*, which presents the main highlights of this study.

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2. CLIMATE SCENARIOS

2.1. INTRODUCTION

This chapter summarizes the information about future climate change regarding temperature (extremes), precipitation (extremes), droughts and sea level rise for the Belgian context throughout the 21st century. It takes the CORDEX.be[1] high-resolution climate scenarios for Belgium (Termonia et al., 2018) as a basis, which were recently developed through a collaboration of Belgian research institutions (RMI, KU Leuven, VITO, UC Louvain, Ulg). These scenarios are translations of the Representative Concentration Pathways (RCPs, van Vuuren et al., 2011) from the Intergovernmental Panel on Climate Change (IPCC), Assessment Report 5 (IPCC, 2014a) towards the Belgian territory for which more detail in the meteorological parameters is provided through various climate modelling and techniques.

For this report, the following RCP scenarios are considered (see also Figure 2-1):

- the RCP8.5 scenario, a high-end baseline pessimistic scenario that assumes no policy and a further increase in greenhouse gas emissions towards the end of the 21st century. It should be noted that RCP8.5 is not a business-as-usual scenario. Instead, it should be regarded as a high-end (90th percentile) scenario out of all no-policy baseline scenarios, or as a worst-case (95th percentile) scenario out of all RCP scenarios.
- the RCP4.5 scenario, a middle scenario that assumes an emissions peak around 2040, and a decrease afterwards.
- The RCP2.6 scenario, an optimistic scenario that assumes the emissions peak around 2020 (today), and a decrease afterwards.

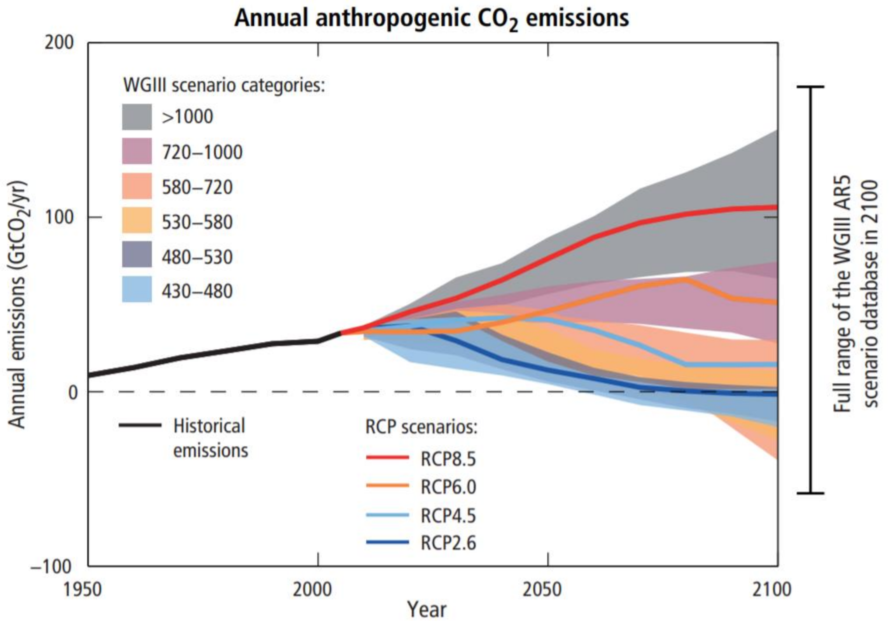

Figure 2-1. Emissions of carbon dioxide (CO_2) in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used by the IPCC's Working Group III (WGIII) (coloured areas show the 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined based on CO_2-equivalent concentration levels (in ppm) in 2100. Here, only CO_2 concentrations are shown, while other greenhouse gas emissions are also taken into account in the establishment of the RCPs. Figure adapted from IPCC (2014a).

Additionally, the following future representative timeframes are considered with respect to the

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reference timeframe 1976–2005, also in line with the IPCC:

- near-future: 2016–2045 (change over 40 years)
- mid-century: 1936–2065 (change over 60 years)
- end-century: 2071–2100 (change over 95 years)

Because of limited data availability and the variety of literature sources used, some information can only be provided in approximation to these scenarios or for similar (alternative) scenarios and/or timeframes, which will then be explicitly mentioned throughout the text.

2.2. TEMPERATURE

In line with the global trends of climate change, an increase in the average temperature is observed for Uccle, as shown in Figure 2-2. Since the 1970s, the rate of change amounts to 0.24 ℃ per decade (Brouwers et al., 2015). It is expected that this will continue to increase towards the end of the 21st century according to the different simulations in the 5th Climate Model Intercomparison Project (CMIP5) and the magnitude largely depends on the emission scenario, see Figure 3. For the high-resolution climate scenarios for Belgium under RCP8.5, the winter temperature in Uccle for the End-Century (2071–2100) is expected to increase by 3.0°C compared to the reference timeframe (1976–2005), and the summer temperature by 3.6°C. For the scenarios RCP4.5 and RCP2.6, the expected temperature rise is lower, respectively 1.6 and 0.4°C for the winter and 2.1 and 0.8°C for the summer.

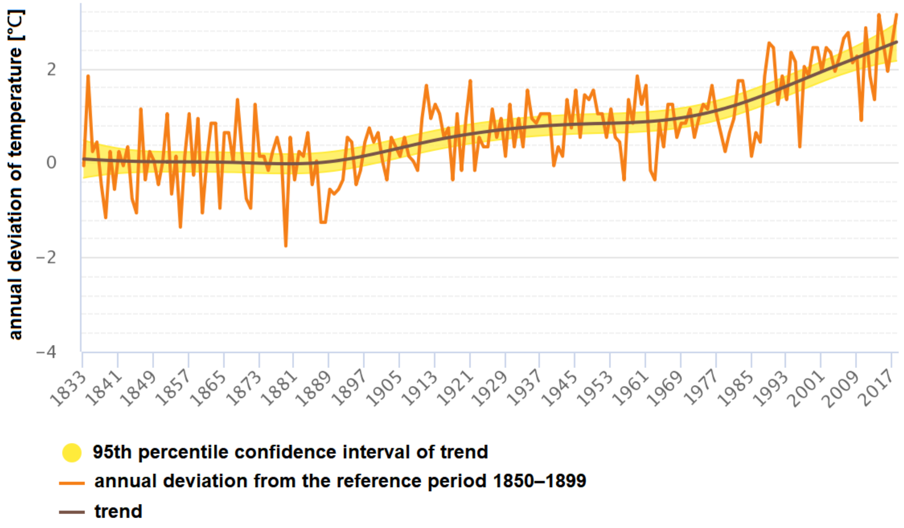

Figure 2-2. Evolution of the annual temperature deviation from the reference period 1850-1899 in Belgium (Uccle). Source: Brouwers et al. (2015).

The high-resolution projections are an average of three independent climate models at very high resolution, considering local effects such as the influence of the North Sea, the hilly landscape and urbanization in Belgium. The uncertainty on each of these values is approximately 1°C (estimated from the interquartile range of the CMIP5 climate model ensemble shown in Figure 2-3 and arises from uncertainties on physical parameters as well as on global and local feedback effects of the climate system. Furthermore, for the near-future (mid-century), an average summer warming of 1.9 (1.3), 1.0 (0.67) and 0.25 (0.17)°C is expected for the scenarios RCP8.5, RCP4.5 and RCP2.6, and a winter warming of resp. 2.3 (1.5), 1.3 (0.88) and 0.51 (0.34)°C.

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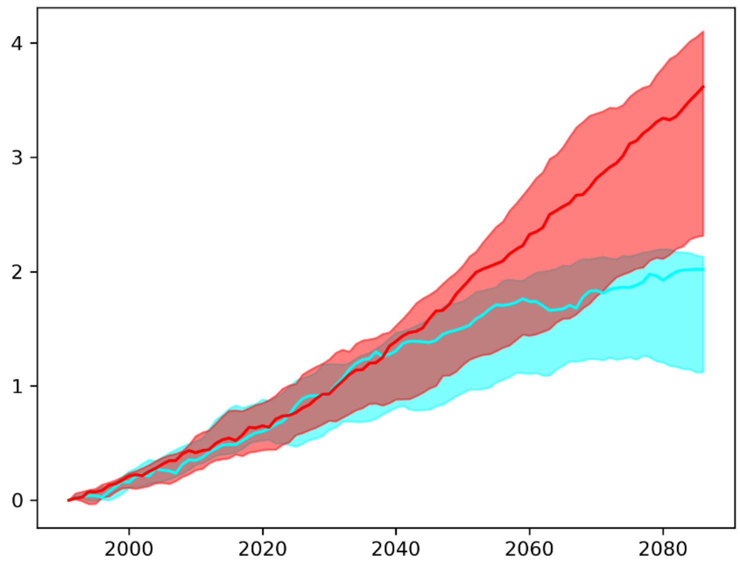

Figure 2-3. Projected temperature change (°C) for Uccle towards the end of the 21st century with respect to the reference period (1976–2005) averaged with a 30-year moving window. The median (lines) and interquartile ranges (shades) are shown from the different simulations in the 5th Climate Model Intercomparison project (CMIP5) under the 'Representative Concentration Pathways' with a radiative forcing of 4.5 W m^{-2} (RCP4.5, cyan) and 8.5 W m^{-2} (RCP8.5, red). Data from CMIP5 essential climate variables on cds.climate.copernicus.eu.

Table 2-1 gives an overview of the projected temperature changes for Belgium for different scenarios and time horizons. Note that temperature of the RCP8.5 for the end-century horizon are estimated by the average of the three high-resolution model simulations for Belgium (Termonia et al., 2018). For RCP2.6 and RCP4.5 only one high-resolution model realization was available.

However, projections of climate change primarily depend on the forcing scenario (Collins et al., 2013). Hence, temperature change of the three-model ensemble for RCP2.6 and RCP4.5 towards the end of the century is estimated by calculating the ratio of mean temperature change for these scenarios with respect to the RCP8.5 in the one-model realization, and subsequently applying these ratios on the average values of the three-model ensemble for RCP8.5. Furthermore, assuming that (decadal) temperature statistics are changing at a constant rate on the decadal time scales, the temperature changes for the near-future and mid-century timeframes are derived from the corresponding changes for end-century timeframe according to the ratios in time shifts between each timeframe and the reference period. The assumption of time invariance in temperature change has been applied in previous studies and validated based on transient climate model runs (Wouters et al., 2017).

Table 2-1. Temperature change (in °C) for winter (December, January, February) and summer (June, July, August) in Belgium, for the periods 2016–2045 (near-future), 2036–2065 (mid-century), 2071–2100 (end-century) compared to 1976–2005 (reference period).

		Temperature change [°C]		
		RCP2.6	RCP4.5	RCP8.5
winter **(ref. Uccle: 3.63°C)**	near-future	+0.17	+0,67	+1.3
	mid-century	+0.25	+1.0	+1.9
	end-century	+0.40	+1.6	+3.0
summer **(ref. Uccle: 17.3°C)**	near-future	+0.34	+0.88	+1.5
	mid-century	+0.51	+1.3	+2.3
	end-century	+0.8	+2.1	+3.6

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2.3. PRECIPITATION

The amount of precipitation shows a very high variability from year to year. Still, the historical record of annual precipitation in Uccle (Figure 2-4) shows a slow but statistically significant and steady increase in annual precipitation (Brouwers et al., 2015) at a rate of 0.5 mm per year. As a consequence, annual rainfall is currently about 92 mm higher than at the start of the measurements in 1833.

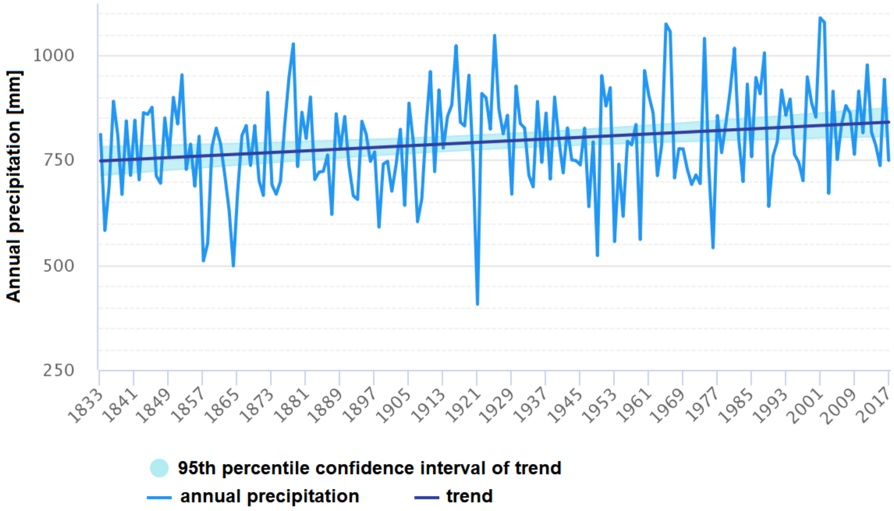

Figure 2-4. Observed annual precipitation change for Belgium. Source: Brouwers et al. (2015).

According to ensemble model climate simulations, precipitation is expected to increase further towards the end of the century (Figure 2-5).

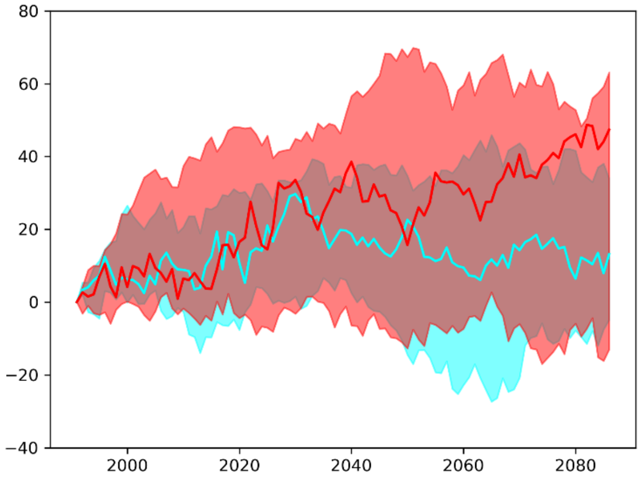

Figure 2-5. Same as in Figure 2-3 but for annual precipitation (in mm). Source: based on CMIP5 essential climate variables on cds.climate.copernicus.eu.

The high-resolution climate scenarios indicate a seasonal dependence: winter (December, January, February) precipitation is expected to increase by about 18% by the end of this century for the RCP8.5 scenario, whereas for summer (June, July, August), a decrease of 10% is expected (Table 2-2). It needs to be noted that the uncertainty on the projected precipitation changes (as estimated by the interquartile range among the climate model simulations) relative to the magnitude of the change is higher than it is for temperature (compare Figure 2-5 with Figure 2-3). Also Tabari et al. (2015) find this seasonal dependence for Belgium with drier summers and wetter winters.

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Table 2-2. Precipitation change (in %) for winter (December, January, February) and summer (June, July, August) in Belgium, for the periods 2016–2045 (near-future), 2036–2065 (mid-century), 2071–2100 (end-century) compared to 1976–2005 (reference period).

		Precipitation change [%]		
		RCP2.6	RCP4.5	RCP8.5
winter (ref. Uccle: 21.9 mm)	near-future	+1.0	+4.0	+7.6
	mid-century	+1.5	+6.1	+11.4
	end-century	+2.4	+9.6	+18.0
summer (ref. Uccle: 22.8 mm)	near-future	-1.0	-2.5	-4.3
	mid-century	-1.4	-3.8	-6.5
	end-century	-2.3	-6.0	-10.3

Indeed, precipitation is prone to substantial internal climate variability due to the stochastic nature of the climate system but also due to the representation (and associated uncertainty) of precipitation physics as a process in the climate models. Because of this, the average value cannot be rescaled according to one available model realization, as was done for temperature above. Disregarding uncertainty related to internal climate variability and physics, (extreme) precipitation changes are expected to be proportional to warming (Fischer et al., 2014). As such, the precipitation values for other RCPs are rescaled from RCP8.5 according to the change of average temperature in Table 2-1.

2.4. EXTREME HEAT

Observations evidence that extreme heat episodes are on the rise, becoming both more intense and more frequent (Klein Tank et al., 2005; Della-Marta et al., 2007; Horton et al., 2015). Global climate projections that consistently point towards an increase in the number, frequency, and intensity of heatwaves (e.g., Diffenbaugh and Giorgi, 2012; Fischer and Schär, 2010; Schär et al., 2004; Vogel et al., 2017; Meehl and Tebaldi, 2004) have shown that extremely hot summers such as in 2003 in Europe are likely to become fairly common towards the end of the century. In fact, such an increase is to be expected simply from the increase in average temperature, as illustrated in Figure 2-6, because of the shift in the rightmost tail of the temperature distribution.

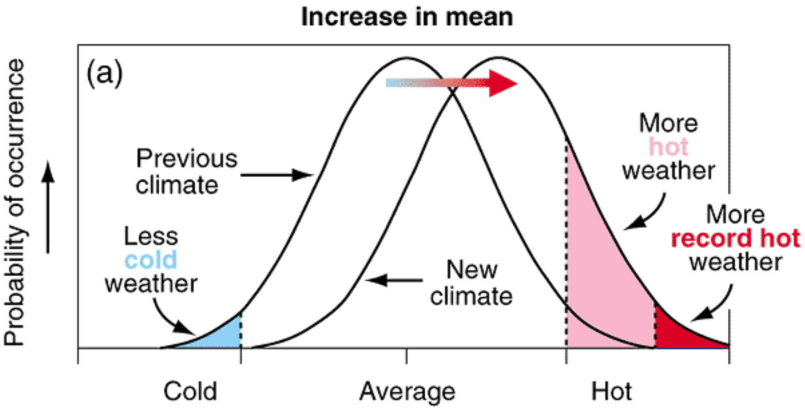

Figure 2-6. The effect of mean temperature increase on extreme temperatures, for a normal temperature distribution. Source: IPCC.

Of course, this representation in Figure 2-6 is overly simplified as in reality the extremes may change more, or less, strongly than the average temperature. Indeed, as for other areas in Eurasia and North America, high temperature extremes in Belgium are expected to increase more strongly than the

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average summer temperature (see Table 2-3 versus Table 2-1), as a result of enhanced temperature variability at inter-annual to intra-seasonal time scales (Collins et al., 2013). The enhanced variability can be further related to increasing trends in high pressure anticyclonic circulation (Horton et al. 2015) and the additional land desiccation during heatwaves under global warming (Rasmijn et al. 2018; Zhou et al. 2019; Miralles et al. 2014). Hence, it is expected that the frequency, length and intensity of heatwaves will increase even more.

Table 2-3. Change of daily mean temperature extremes (in °C), considering return periods of 1 and 5 years, for winter (December, January, February) and summer (June, July, August) in Belgium, for the periods 2016–2045 (near-future), 2036–2065 (mid-century), 2071–2100 (end-century) compared to 1976–2005 (reference period).

		Extreme temperature change [°C]					
		1-year return period			5-year return period		
		RCP2.6	RCP4.5	RCP8.6	RCP2.6	RCP4.5	RCP8.5
summer – ref. Uccle: 26.3°C (1-yr) and 28.1°C (5-yr)	near-future	+0.38	+1.00	+1.71	+0.43	+1.12	+1.92
	mid-century	+0.57	+1.50	+2.56	+0.64	+1.68	+2.88
	end-century	+0.90	+2.37	+4.06	+1.01	+2.66	+4.56

2.5. URBAN HEAT ISLAND

Cities experience air temperatures in excess of rural values, especially at night, night-time temperatures being higher by a few °C on average, but increasing to 7-8°C and more under favourable conditions. In addition, recent studies (e.g., Li and Bou-Zeid, 2013; De Ridder et al., 2016) present evidence that the urban heat island intensity itself may increase during heatwaves. In an analysis covering several European cities, Hooyberghs et al. (2015) and Wouters et al. (2017) found that urban areas experience about twice as many heatwave days as their rural surroundings.

In the past years, VMM and VITO have been monitoring the urban-rural temperature increment with pairs of climate stations deployed in and around Antwerp, Bruges, Brussels, Gent, Hasselt and Lier (Lauwaet et al., 2018a). Observed 2-m temperature values are processed to yield an indicator named ‘heatwave degree days’ (HDD) (De Ridder et al., 2015a),

$$HDD = \sum_{i} \left[(T_{\mathrm{min},i} - 18.2^\circ\mathrm{C})^{+} + (T_{\mathrm{max},i} - 29.6^\circ\mathrm{C})^{+} \right],$$

where the index *i* in the sum runs over all days in a year, and $T_{\mathrm{min},i}$ and $T_{\mathrm{max},i}$ are the daily minimum and maximum temperatures occurring within a year on day *i*; the ‘+’ symbol featuring as a superscript means that only positive values are retained. In fact, this formula defines the heatwave degree days indicator as the annual sum of daily minimum and maximum temperatures over the thresholds of 18.2°C and 29.6°C specified by the FPS Public Health (Brits et al., 2010). This way, the indicator contains both the duration and the intensity of a heatwave episode.

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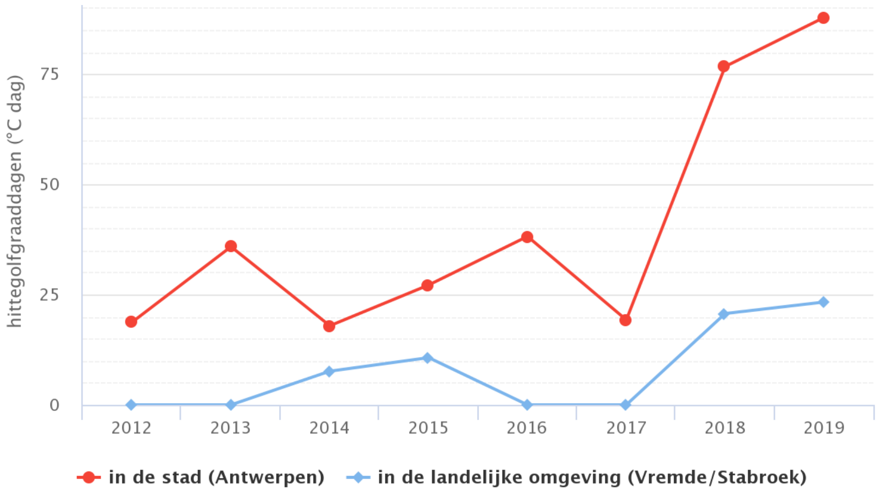

Figure 2-7. Number of observed heatwave degree days for the city centre of Antwerp (red) as compared to nearby rural locations (blue). Source: Milieurapport Vlaanderen[1].

The annual number of heatwave degree days for Antwerp and a nearby rural location for the period 2012-2019 is shown in Figure 2-7, clearly presenting the consistently higher levels of heat stress occurring in the city. While the tendency in this figure is clearly upward, the time series is too short to draw conclusions regarding a long-term trend.

City size does matter for urban heat island strength, but limited so. Aertsens et al. (2012) present an analysis of the UHI intensity (the urban-rural temperature difference) as a function of population density, for a diverse (in terms of city size) sample of cities (Brussels, Antwerp, Lier, Mechelen, Leuven, St.-Niklaas, Aalst, and Heist-op-den-Berg). While from their analysis it emerges that urban heat island intensity strongly correlates with population density, they also concluded that relatively small cities in this sample still exhibit a fairly strong heat island effect in comparison to their size.

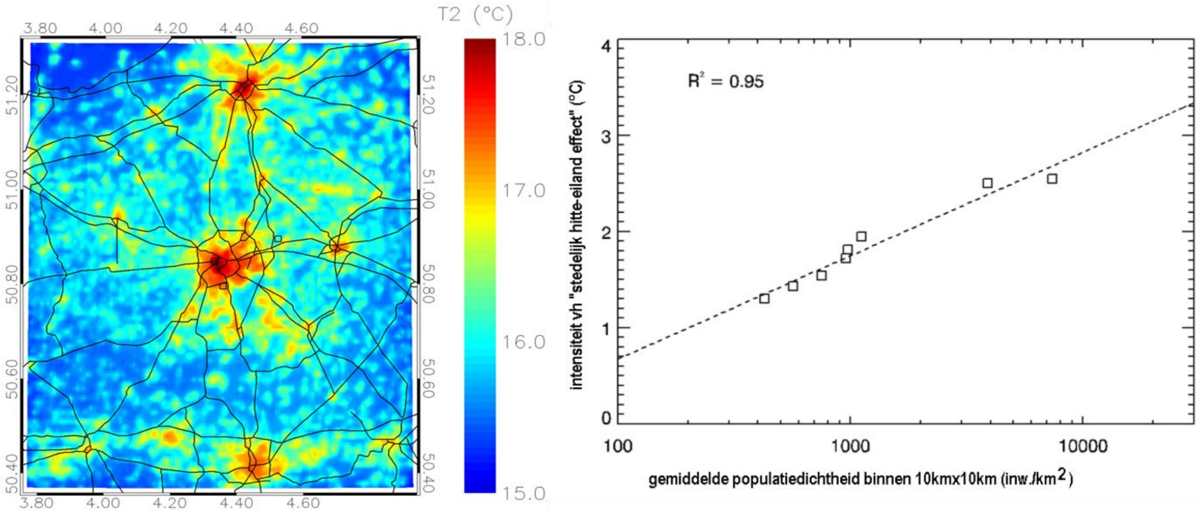

Figure 2-8. Urban heat island for a central portion of Belgium, derived from satellite imagery. The left panel shows background air temperature at 00:00 GMT, averaged over the period May-September 2008, with Brussels in the centre of the domain. The right panel shows average urban-rural temperature difference as a function of mean population density in the 10 km × 10 km area surrounding the city core, for the cities mentioned in the main text. Notice the logarithmic scale in the horizontal axis. Source: Aertsens et al. (2012).

Wouters et al. (2017) studied the combined effect of the urban heat island phenomenon and climate

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[1] https://www.milieurapport.be/milieuthemas/klimaatverandering/temperatuur/hitte-eilanden-in-steden

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change by means of regional climate model simulations. They found that, for a 'middle[1]' scenario (see Table 2-4 and Figure 2-9) the number of heatwave days[2] per year is expected to increase from 5.1 to 16.8 in the cities for a mid-century time horizon, while for the countryside this will 'only' increase from 0.9 to 7.1 heatwave days (Wouters et al., 2017). When considering the worst-case scenario, which in Wouters et al. (2017) exceeds RCP8.5 in severity, it is found that cities are projected to experience 41.5 heatwave days per year on average by the end of the century.

Table 2-4. Current and future number of heatwave days, mean intensity[3] of heatwaves and heatwave degree days (HDD), the latter as defined above. Source: Wouters et al. (2017)[4].

		1981–2014 (~ baseline)	**2041–2074 (~ mid-century)**		
			best case (< RCP2.6)	middle case (~ RCP4.5)	worst case (> RCP8.5)
rural areas	heatwave days [day]	0.9	1.6	7.1	26.9
	intensity [°C]	2.7	2.9	3.5	5.4
	HDD [°C day]	2.4	4.6	24.9	145
urban areas	heatwave days [day]	5.1	6.4	16.8	41.5
	intensity [°C]	3.3	3.5	5	6.2
	HDD [°C day]	16.8	22.4	84	254

In addition to the number of heatwave days, the intensity of the heatwaves is also increasing. As a result, heat stress (as expressed through the heatwave degree days indicator) is 2-3 times higher in cities than in rural areas (Table 2-4). Finally, Wouters et al. (2017) found that, while the overall warming associated with global climate change contributes most to the overall increase in heat stress, a large additional heat stress may be attributed to (projected) urban growth scenarios (Figure 2-10).

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[1] Note that, while the scenarios in Wouters et al. (2017) differ from the RCP scenarios, it is possible to loosely establish a correspondence between both classifications: the 'low' scenario corresponds to the lower end of RCP2.6, the middle scenario is within the range of RCP4.5 and the high scenario is at the higher end of RCP8.5 (Wouters et al., 2017, see their Figure S7).

[2] In Belgium, a heatwave – according to the (health related) definition of Brits et al. (2010) – is a period of at least 3 consecutive days with daily maximum and minimum temperature exceeding 29.6°C resp. 18.2°C.

[3] The heatwave intensity is calculated as the average exceedance of temperature values above the 18.2°C and 29.6°C thresholds (for minimum resp. maximum daily temperature) during the heatwave days (see above).

[4] https://nieuws.kuleuven.be/nl/2017/steden-puffen-vaker-onder-extreme-hitte-als-gevolg-van-klimaatverandering)

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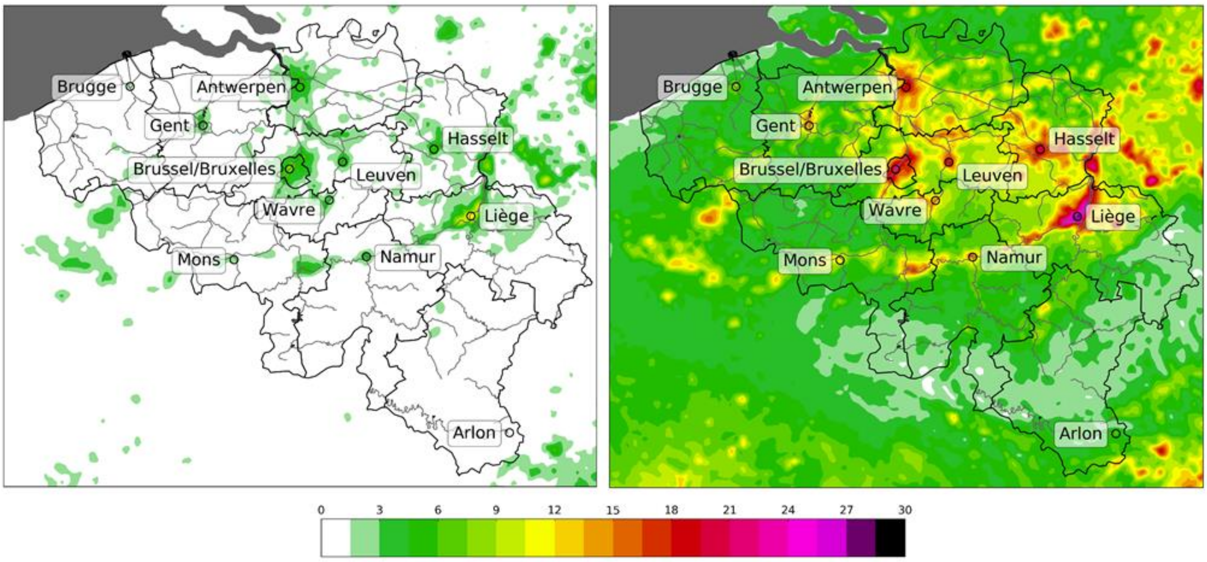

Figure 2-9. Simulated number of annual heatwave days for the periods 1981–2014 (left) and 2041–2074 (right) according to a 'middle' climate scenario that approximates RCP4.5. Source: Wouters et al. (2017).

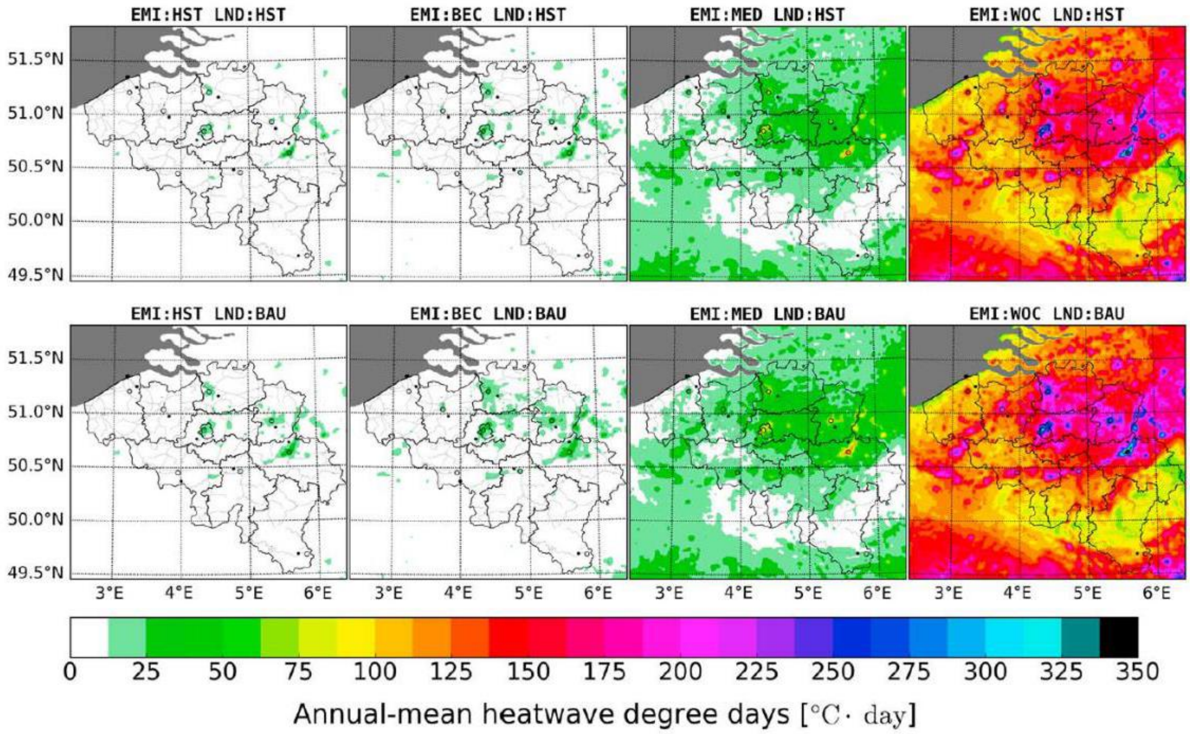

Figure 2-10. Simulated number of heatwave days per year for 1981–2014 and considering different urban growth and climate change scenarios for 2041–2074. The climate scenarios (historic, and best-middle-worst case) go from left to right. The upper panels show simulation results obtained by keeping urban land cover as it is today; the lower panels are from simulations in which urban areas were allowed to grow (business-as-usual scenario), which is reflected in slightly higher urban temperatures (related to larger city size) in the lower panels. Source: Wouters et al. (2017).

The comparison of the climate scenarios used in Wouters et al. (2017) with those employed in the present study (which is based on the RCP scenarios as explained above) is not entirely straightforward. However, studies that do use the RCP scenarios draw a similar picture of a strongly increasing heat burden in and around cities. For instance, Hooyberghs et al. (2015), simulating with VITO's *UrbClim* model (De Ridder et al., 2015b) the number of heatwave days for Antwerp (Figure 2-11) at the end of

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the century under RCP8.5, and using the same definition of 'heatwave days' as used in Wouters et al. (2017), find an increase from a few heatwave days per year up to 25 and more in the urban portion of the domain, the value in rural areas being of the order of 15. (Note that in this study no account was made of urban growth scenarios.) Overall, it is fair to say that urban climate projections point towards an approximately tenfold increase in the number of heatwave days towards the end of the century, when considering a high climate scenario.

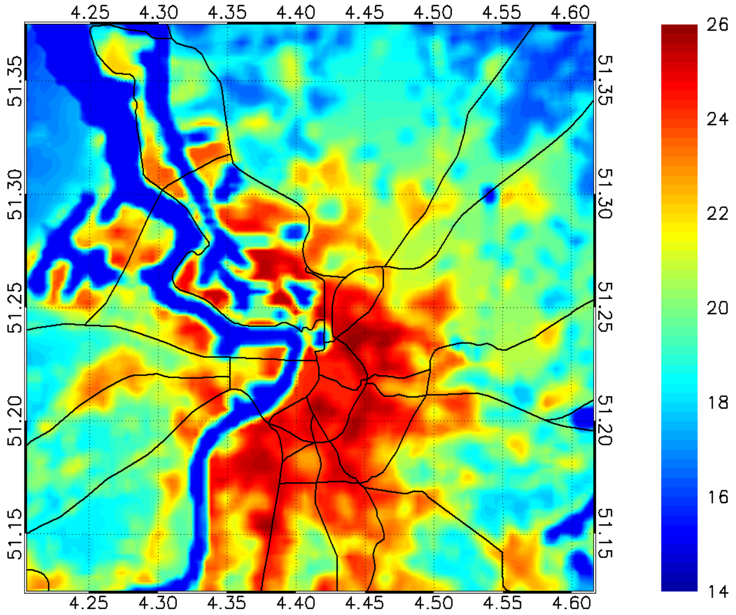

Figure 2-11. Mean annual number of heatwave days simulated for the Antwerp area for the period 2081-2100 under scenario RCP8.5. Source: Hooyberghs et al. (2015).

To end this urban section, we would like to point out that – while local measures (e.g. urban green) surely can help to combat the excess heat in cities – even the most drastic infrastructure-based urban adaptation strategies can bring only marginal relief to global warming (Krayenhoff et al., 2018). At the same time, even if aspirations to avoid dangerous climate change such as the Paris Agreement are realized, large increases in the frequency of deadly heat episodes should be expected (Matthews et al., 2017).

2.6. COLD EPISODES

Global warming is expected to reduce wintertime cold episodes. Table 2-5 and Figure 2-12 show the projected trends in the mean of the wintertime daily minimum temperatures compared to the value of 1980.

Table 2-5. Average values of the daily minimum temperature for the time horizons and climate scenarios shown in Figure 2-12, together with their uncertainty. Note that the source where these data were taken from does not include scenario RCP2.6.

	RCP4.5	**RCP8.5**
2031-2060	(1.5 ± 0.4)°C	(1.8 ± 0.4)°C
2071-2100	(2.2 ± 0.4)°C	(3.5 ± 0.4)°C

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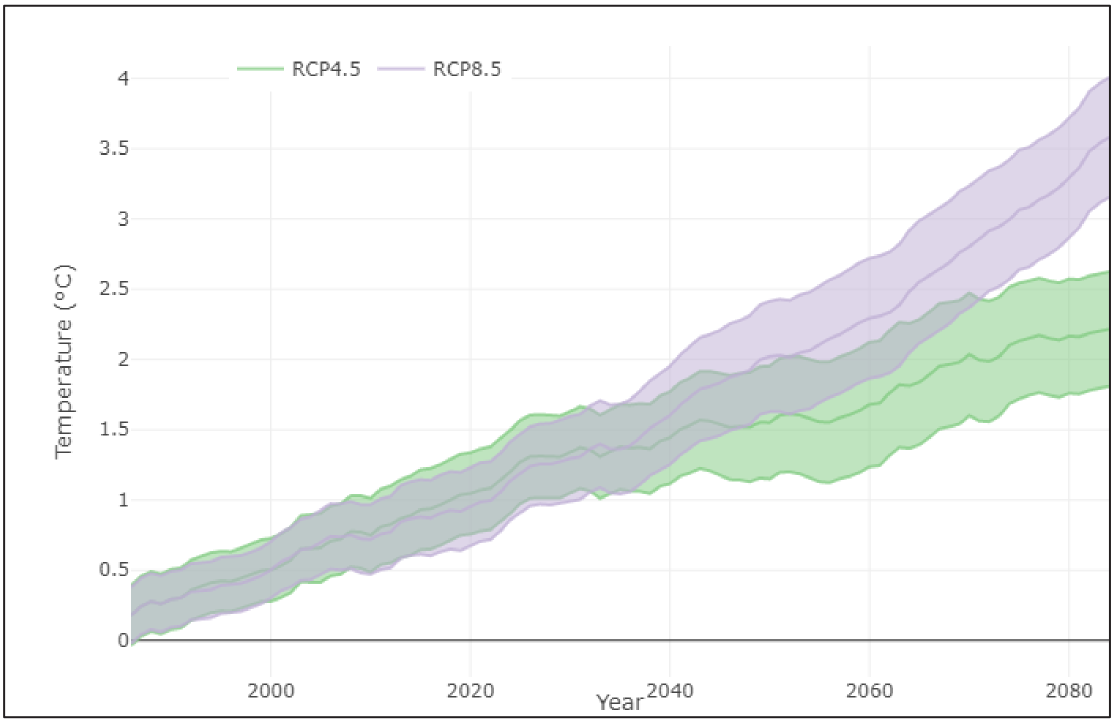

Figure 2-12. Projected average of the daily minimum winter temperature for Belgium, considering the RCP4.5 and RCP8.5 scenarios, compared to the 1980 value. Source: Copernicus Climate Change Service, 'Climate projections of European temperature exposure'[1].

2.7. EXTREME PRECIPITATION AND STORMS

Where extreme temperatures are causing the highest proportion of deaths, floods (38%) and storms (30%) accounts for most of the global economic losses during the 1970–2012 period (334 billion Euros in economic damages), see Golnaraghi et al. (2014). For Belgium (Uccle), the number of days with heavy precipitation of at least 20 mm per day shows a statistically significant increasing trend for Uccle. A year currently counts an average of 5 to 6 days with heavy rainfall, whereas this number was only 3 in the early 1950s (Brouwers et al., 2015), see Figure 2-13.

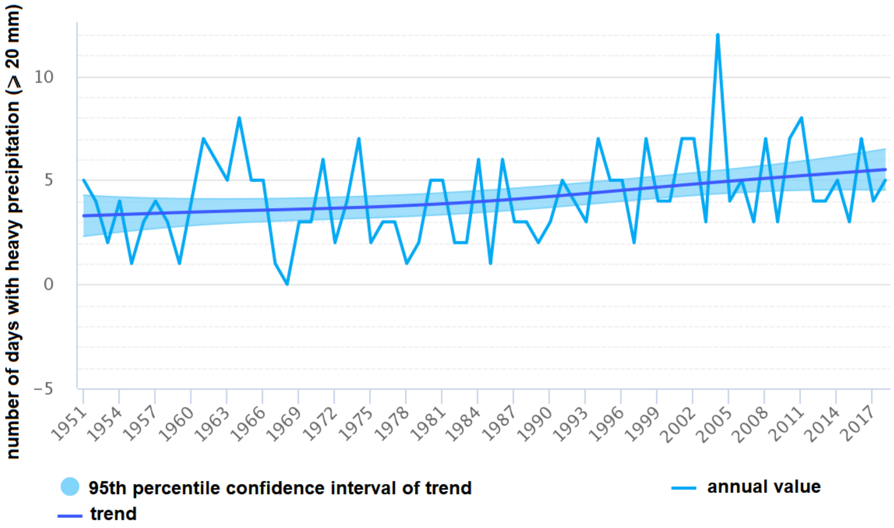

Figure 2-13. Evolution of heavy precipitation since 1951 for Uccle. Figure adapted from Brouwers et al. (2015).

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[1] https://cds.climate.copernicus.eu/cdsapp#!/software/app-health-temperature-exposure-projections?tab=app

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The Belgian high-resolution climate models employed in CORDEX.be have revealed that the increasing trend for heavy precipitation is expected to continue, and the probability of heavy precipitation — both on a daily and hourly basis — will become more extreme in the future in both the North and South of the country (Vanden Broucke et al., 2017; Helsen et al., 2019), see Table 2-6 and Table 2-7.

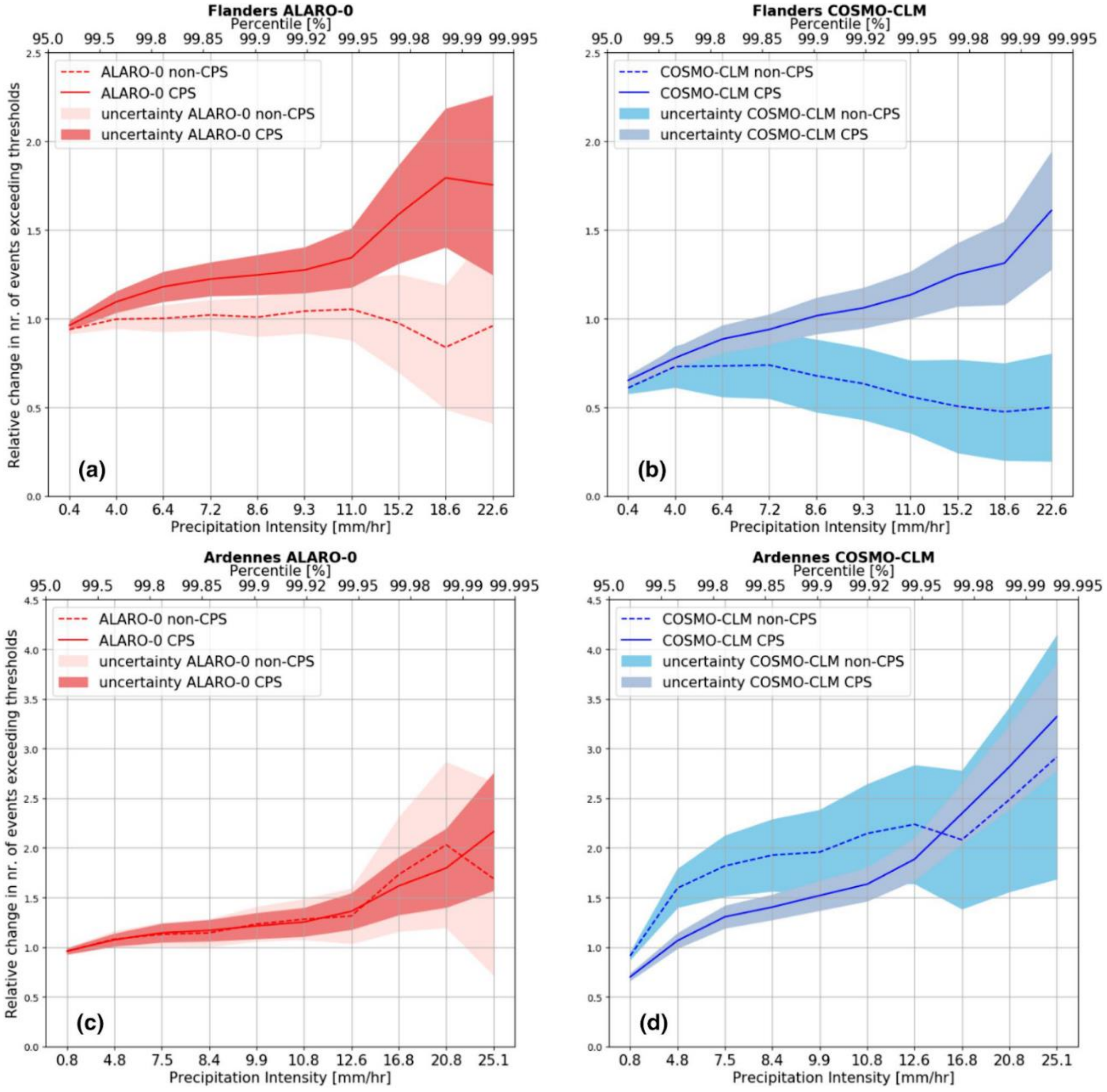

Figure 2-14. End-of--century (2070–2100) relative change (future/present) in the exceedance frequency of extreme hourly precipitation intensities during summer (JJA) for Flanders (upper panels) and the Ardennes (lower panels) for the day-time period (12–18 UTC) for two high-resolution climate models ALARO-0 (left panels) and COSMO-CLM (right panels). Values higher than one indicate an increase in extremes, while one means no change. Note that the precipitation intensities labelled on the horizontal axes correspond to the mean of the intensities of all CPS[1] models corresponding to the percentiles indicated at the top of the figure. Note that the scale of the y-axis differs between the upper and lower panels. Note also that all changes were found to be statistically significant, except for P95 of ALARO-0. Results are shown for both low-resolution (non-CPS) and high-resolution (CPS) climate resolution model setups. Figure source: Helsen et al. (2019).

Moreover, the increase in occurrence of heavy precipitation events (Figure 2-14) is higher than that of

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[1] Convection Permitting Simulations (CPS) are conducted with models that allow the direct physical simulation of convective processes, i.e., the processes that drive thunderstorms, which may give rise to local shortlived extremely high precipitation amounts.

more mild precipitation (Vanden Broucke et al., 2017; Helsen et al., 2019). For the high-end emission scenario RCP8.5, the daily (hourly) intensity of the extreme precipitation with 1-year and 5-year return periods in summer — currently 27 mm/day (42 mm/day) at Uccle, respectively — increase by 37% (7.3%) and 10% (15%), whereas those in winter — currently 19 mm/day (29 mm/day) — by 34% (32.0%) and 26% (45%). The changes are expected to be lower for the other emission scenarios. For example, for summer, the increase in daily (hourly) intensity of extreme precipitation with 5-year return period is 21.6% (8.8%) for RCP4.5 whereas it is 8.2% (3.3%) for RCP2.6. The results for the other combinations of representative timeframes, variables and scenarios can be found in Table 2-6 and Table 2-7.

With respect to hail, climate projections conducted within CORDEX.be (Termonia et al., 2018) for the end of the century under IPCC scenario RCP8.5 point towards a reduced number of hail events but an increase of the main hailstone size.

Table 2-6. Change in extreme daily precipitation (in %) occurring with a return period of 1 and 5 years, for winter (December, January, February) and summer (June, July, August) in Belgium, for the periods 2016–2045 (near-future), 2036–2065 (mid-century), 2071–2100 (end-century) compared to 1976–2005 (reference period). Values are derived from Termonia et al. (2018).

		1-year return period			**5-year return period**		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
winter	near-future	+1.5	+5.8	+10.9	+1.9	+7.6	+14.3
	mid-century	+2.2	+8.8	+16.4	+2.9	+11.5	+21.5
	end-century	+3.5	+13.9	+26.0	+4.5	+18.1	+34.0
summer	near-future	+0.9	+2.5	+4.2	+3.5	+9.1	+15.6
	mid-century	+1.4	+3.7	+6.3	+5.2	+13.6	+23.4
	end-century	+2.2	+5.8	+10.0	+8.2	+21.6	+37.0

As for mean precipitation, extreme precipitation statistics are also highly variable among climate model members, hence the values cannot be rescaled according to one available model realization as well. Changes in extreme temperature also expected to be proportional to warming (Fischer et al., 2014), hence the values for other RCPs are rescaled from RCP8.5 according to the change of average temperature in Table 1.

Table 2-7. As Table 2-6, but for extreme hourly precipitation. Values are derived from Termonia et al. (2018).

		1-year return period			**5-year return period**		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
winter	near-future	+1.8	+7.2	+13.5	+2.5	+10.1	+18.9
	mid-century	+2.7	+10.8	+20.2	+3.8	+15.2	+28.4
	end-century	+4.3	+17.1	+32.0	+6.0	+24.0	+45.0
summer	near-future	+0.7	+1.8	+3.1	+1.4	+3.7	+6.3
	mid-century	+1.0	+2.7	+4.6	+2.1	+5.5	+9.5
	end-century	+1.6	+4.3	+7.3	+3.3	+8.8	+15.0

2.8. URBAN FLOODING

Urban sprawl leads to an additional share of impervious surfaces that inhibits penetration of water into the soil, which will further increase risks related to extreme precipitation (Brouwers et al., 2015; OECD, 2018). However, tools and assessments still need to be developed further for quantifying the societal impacts of increasing extreme precipitation under the joint effects of climate change, land-use change, and adaptation strategies (Arnbjerg-Nielsen et al., 2013).

2.9. EXTREME WIND

Observations from the past 30 years (Figure 2-15) do not show a clear trend in the occurrence of extreme wind speed values in Belgium. Also, projections for the daily average wind speed in Europe do not show a clear trend towards the future (see, e.g. Dantec and Roux, 2019). This appears to be also the case for Belgium, although it is expected that the wind speed during the most intense storms may increase by up to 30% (Brouwers et al., 2015).

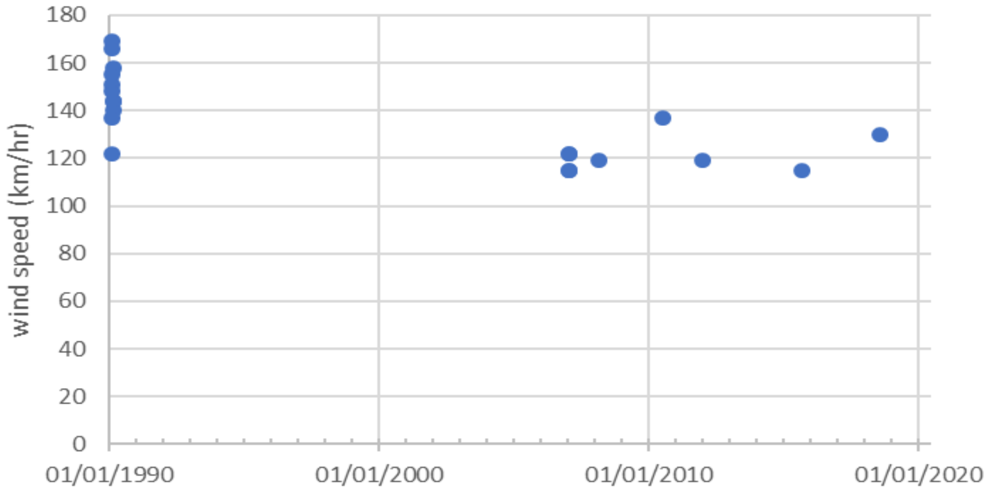

Figure 2-15. Wind speed extremes observed over the past 30 years. Based on data from RMI[1].

2.10. DROUGHTS AND WATER SCARCITY

Droughts cause water scarcity for agriculture, industry and households and is also detrimental for natural ecosystems and recreation. The occurrence and severity of droughts depends on both the total precipitation (either annual or seasonal) and its dispersal in time. The consequential water scarcity is balanced further by the fraction of precipitation that evaporates back to the atmosphere (e.g., due to higher temperature) or that is lost run-off to sewerage and river systems (e.g., due to more intense rainfall), and the water use. Because of the intensive water use in a dense population and industry, Belgium is a hot spot for risk of water shortage and is currently ranked 22 out of 164 countries (ahead of e.g. Spain and Greece) for the water stress indicator (the Water Exploitation Index or WEI) employed by the World Resources Institute (WRI)[2], and characterized with high water stress, hence highly vulnerable to droughts.

It should be noted that, even though the WEI is still widely used, currently a transition towards a new indicator (the WEI+) is taking place. The latter accounts for the effect of cooling water being taken and subsequently discharged, resulting in a much lower effective water usage, hence putting Belgium in a much less adverse water stress-situation. Still, as also noted by Tabari et al. (2015), future summer water availability is expected to decline with climate change.

A comprehensive study on drought in Europe was performed by Spinoni et al. (2017). They found that,

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[1] Available from https://www.datawrapper.de/_/s9r7n/

[2] https://wri.org/applications/aqueduct/country-rankings/

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under the moderate emission scenario (RCP4.5), droughts are projected to become increasingly more frequent and severe in the Mediterranean area, western Europe, and northern Scandinavia, whereas the whole European continent, with the exception of Iceland, will be affected by more frequent and severe extreme droughts under the most severe emission scenario (RCP8.5), especially after 2070. Seasonally, drought frequency is projected to increase everywhere in Europe for both scenarios in spring and summer, especially over southern Europe, and less intensely in autumn; on the contrary, winter shows a decrease in drought frequency over northern Europe. For the macro-region of northern France and the Benelux they found a moderate increase in drought frequency in the past and a strong increase under the different climate scenarios. Dantec and Roux (2019) mention extreme drought stress as one of the most worrisome future climate impacts, largely caused by enhanced evapotranspiration, also in the northern parts of France, i.e., the regions bordering Belgium.

In Belgium, recent years have been characterized by increasing drought. In particular in the years 2011, 2017, 2018 and 2019, Belgium was confronted with extreme drought during summer. Nevertheless, as indicated above, total annual precipitation is increasing in Belgium under climate change. There is no clear trend yet in the severity of droughts (expressed as the longest dry period either during the whole year or during the growing season) from past records for Uccle, see Figure 2-16 (Brouwers et al., 2015). However as mentioned above, projections indicate that the precipitation during summer, when droughts and water scarcity are the most likely, is declining. At the same time, projections indicate a decrease in number of wet days with 16% in summer for RCP8.5 towards the end of the century. For winter, a slight increase of 1.7% in wet days is expected for the same scenario (Table 8). As for temperature and precipitation changes, these projected changes in wet days are estimated by the averages of the high-resolution micro-ensemble reported in Termonia et al. (2018). The changes for the missing RCP scenarios are also rescaled from RCP8.5 according to the change of average temperature in Table 1. From the trends in summer, droughts in Belgium are expected to be more frequent and severe under climate change.

Moreover, water scarcity during droughts will be aggravated further by higher levels of evaporation and run-off (overland water flow after precipitation, reducing water infiltration into the soil hence reducing water availability). Since the temperature increases, the atmosphere can retain more water, hence the amount of water that can potentially evaporate from the surface (potential evaporation) also increases, as is clear from Figure 2-14 (Brouwers et al., 2015). The trend in potential evaporation is also significant with a rate of 32 mm/yr per decade, or — expressed as a function of the simultaneous temperature trend since 1981 — 87 mm/yr per °C temperature change. Hence, more precipitation is evaporated back into the atmosphere which in turn decreases the water supply. Since the temperature will increase further, the capacity of the atmosphere to retain water also increases, and this leads to a further increase in evaporation of the water from the ground to the atmosphere. Assuming that, since 1981, the ratio between temperature change and potential evaporation change remains 87 mm/yr per °C temperature change (see above), the potential evaporation will increase by about 261 mm/yr for end-century in the case of RCP8.5. It should be noted, however, that the further trend in evaporation also depends on other meteorological parameters than temperature, including air humidity levels and cloudiness. At the same time, more water is getting lost to run-off because precipitation occurs in more intense events (see previous section) resulting in less time for the precipitation to drain into the soil. Moreover, the increase in urban sprawl increases the vulnerability to drought, because the increasing amount of impervious surfaces leads to more run-off. Finally, the higher temperature during summer in the future may increase the water usage (e.g., for cooling applications) by energy, industry and households, hence also increases the vulnerability to droughts.

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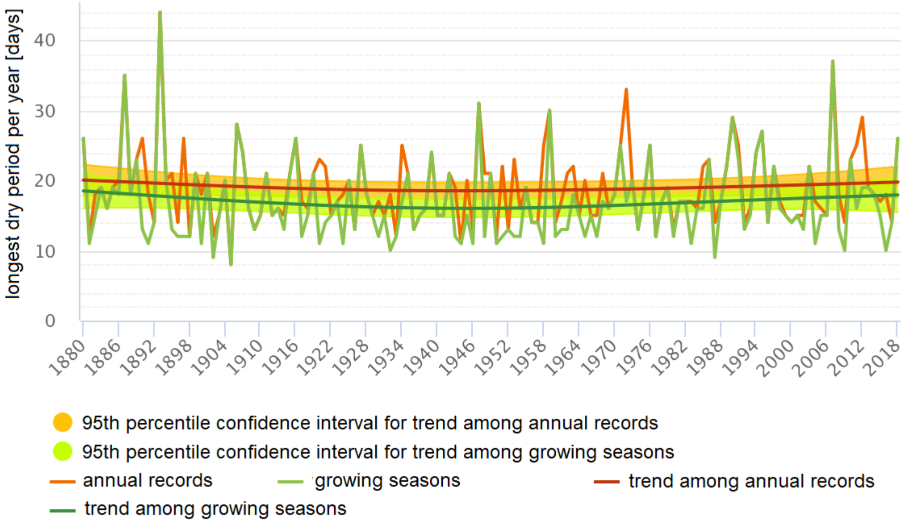

Figure 2-16. Longest dry period among years and among growing seasons. Adapted from Brouwers et al. (2015).

From the above tendencies, it is expected that there will be more frequent and more severe droughts, a reduction in (ground)water supply from rainwater. Hence in the case of unchanged water management, one can expect episodes of more severe water scarcity for Belgium, affecting agriculture, industry and households. In addition, the desiccation of the natural areas is expected to cause an increasing danger in forest fires (Bedia et al., 2013) and to impact habitat suitability of fauna and flora. Different adaptation measures need to be considered, including the increase in water-use efficiency and (winter) storage capacity of storm water for bridging droughts during summer.

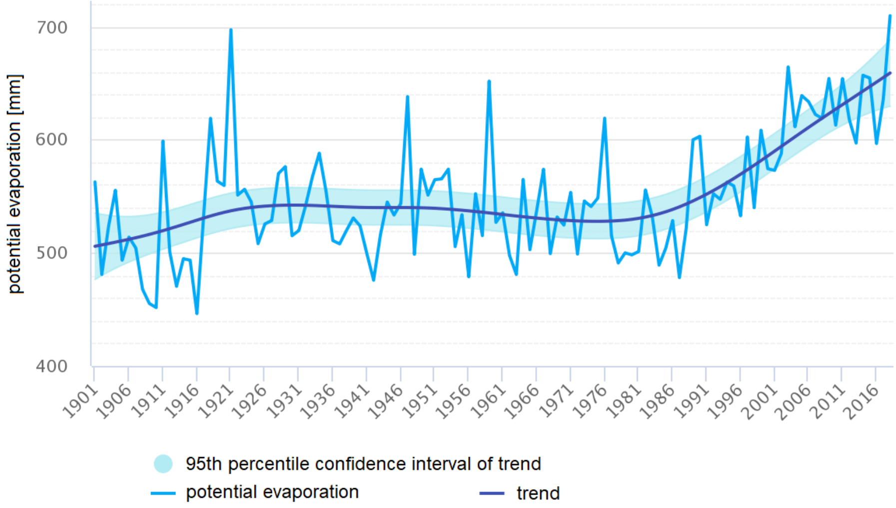

Figure 2-17. Observed evolution of potential evaporation. Adapted from Brouwers et al. (2015).

Finally, it should be noted that the above analysis only offers a qualitative description for future droughts and water scarcity based on trends in the available climate parameters. More research is needed for a more quantitative description of droughts and water shortage, e.g., by employing more comprehensive future hydro-climate indicators.

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Table 2-8. Projected average annual number of wet days for winter and summer. Percentual changes are expressed with respect to the 'current' (1976-2005) number of wet days in the summer/winter month, which are shown on the left. Numbers are derived from Termonia et al. (2018).

		Number of wet days		
		RCP2.6	RCP4.5	RCP8.5
winter (current: 48 out of 90)	near-future	+0.1%	+0.4%	+0.7%
	mid-century	+0.1%	+0.6%	+1.1%
	end-century	+0.2%	+0.9%	+1.7%
summer (current: 38 out of 92)	near-future	–1.5%	–3.9%	–6.7%
	mid-century	–2.2%	–5.9%	–10.1%
	end-century	–3.6%	–9.3%	–16.0%

2.11. SEA LEVEL RISE

Sea level rises with global warming due to the expansion of seawater, the melting of glaciers and small ice sheets and the steady shrinking of the large ice sheets in Greenland and Antarctica. The rapid erosion on the edges of the Greenland and West Antarctic ice sheets also contributes to sea level rise. Sea ice, such as in the Arctic, makes no contribution. It floats at sea and moves just as much water as its own weight according to Archimedes' law. The melted water from sea ice replaces the displaced water and does not change the level of the sea level. Up to now, during the period 1901–2010, global sea level has risen by about 190 mm (Oppenheimer et al., 2019), and the current rate has been 3.24 mm/year since 1993 (WMO, 2019). Sea level rise is non-uniform across the globe which is driven by geographical variations in ocean heat content and processes involving the atmosphere, geosphere and cryosphere (WMO, 2019). However, sea level rise for the North Sea coast closely follows the global average trend Attema et al. (2014). At Ostend, sea level has risen by 115 mm between 1951 and 2013 (van Lipzig and Willems (2015); see Figure 14), which agrees well with the global trend of about 125 mm for the same timespan (likely range: 75-155 mm; Oppenheimer et al., 2019).

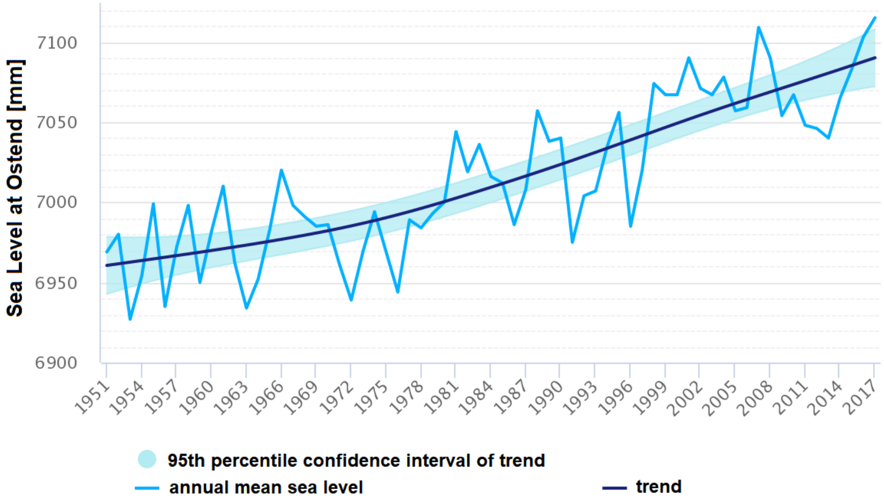

Figure 2-18. Evolution of sea level rise at the Belgian coastline (Ostend), expressed above 'Revised Local Reference'. Figure adapted from Brouwers et al. (2015).

According to Oppenheimer et al. (2019), sea level will continue to increase, the rate strongly depending on the emission scenario. The local sea level rise is shown in Table 2-9, and remains similar to the global level rise (Figure 2-19). For the high-end baseline scenario RCP8.5, the sea level is expected to increase

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with 69 cm (likely range: 43–99 cm) in 2091–2110 (~end-century) compared to 1991–2010, whereas for the RCP4.5 and RCP2.6, a sea level rise of resp. 50 cm (likely range: 31–73 cm) and 39 cm (likely range: 20–63 cm) is expected.

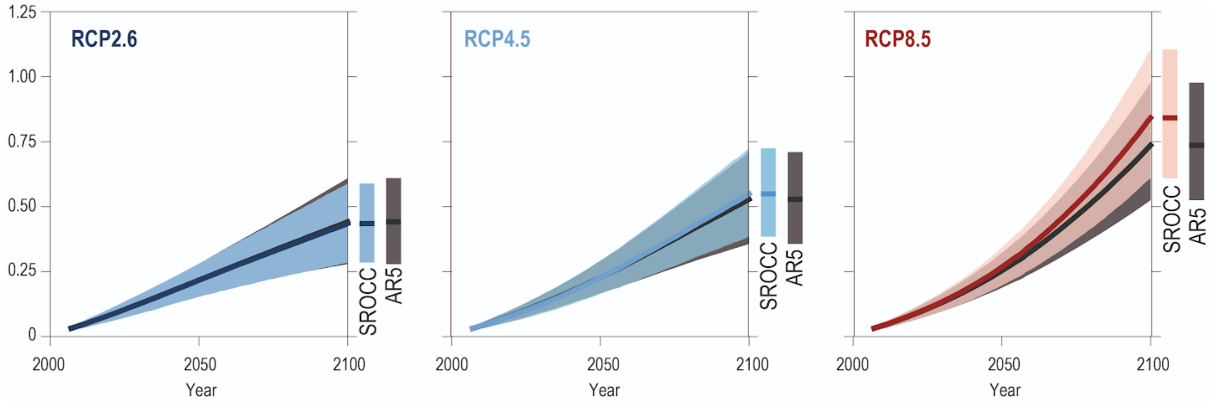

Figure 2-19. Future Global Mean Sea Level (GMSL – vertical axis) for Representative Concentration Pathway (RCP), i.e., RCP2.6, RCP4.5 and RCP8.5, as used in IPCC Special Report on Ocean and Cryosphere in a Changing Climate (Oppenheimer et al., 2019) and, for the IPCC 5th Assessment Report (AR5) results (Church et al., 2013). Results are based on AR5 results for all components except the Antarctic contribution. The shaded region is considered to be the likely range (5th to 95th percentile range). Source: Oppenheimer et al. (2019).

The values for other timeframes, i.e., 2021–2040 (~near-future), 2046–2065 (~mid-century), 2081–2100 (~end-century), are provided in Table 2-9. Beyond 2100, sea level will continue to rise for centuries due to continuing deep ocean heat uptake and mass loss of the Greenland ice sheet and Antarctic ice sheet even in case of no emissions, and will remain elevated for thousands of years (Oppenheimer et al., 2019). From these trends in sea level rise, it is expected that the surface area, the water depth and number of dangerously floodable vulnerable facilities for a millennial storm surge will increase under climate change towards the end of the century (Figure 2-20).

Table 2-9. Global sea level rise at Oostende with respect to 1991–2010 for different time horizons and climate projections, according to Kopp et al. (2014).). The 66% uncertainty ranges are indicated by the values in brackets. Source: http://localslr.climateanalytics.org/location/Oostende.

	sea level rise [cm]		
	RCP2.6	RCP4.5	RCP8.5
2021–2040 (~near-future)	13 [7–19]	13 [8–19]	14 [9–19]
2041–2060 (~mid-century)	23 [13–33]	23 [15–33]	27 [17-38]
2091–2110 (~end-century)	39 [20–63]	50 [31-73]	69 [43-99]

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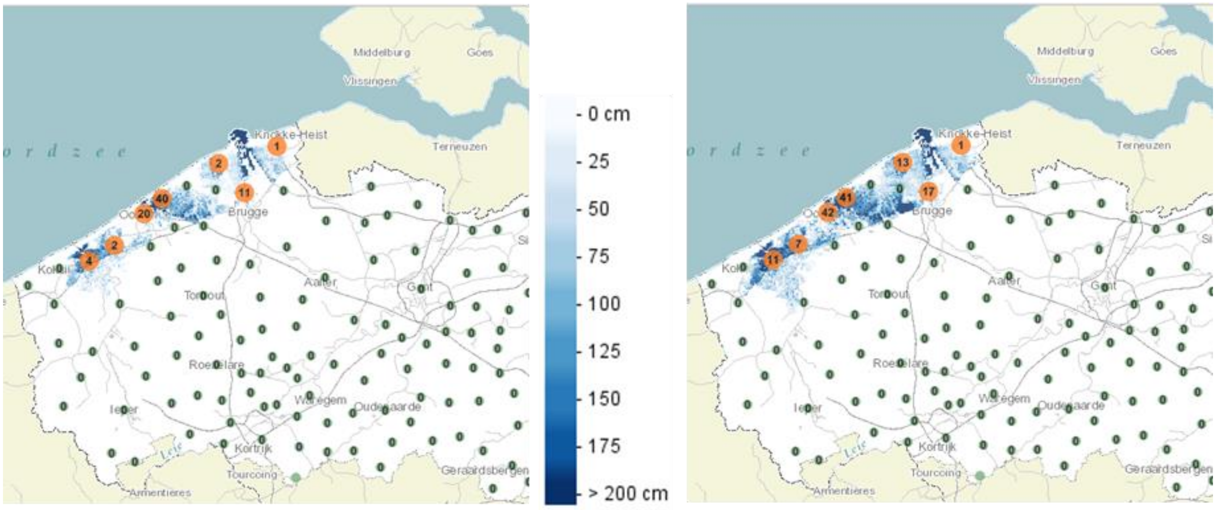

Figure 2-20. The surface area, the water depth and number of dangerously floodable vulnerable facilities in case of a millennial storm surge for the reference year 2017 (left) and 2075 (right). Figure adapted from Brouwers et al. (2015).

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3. PHYSICAL IMPACTS OF CLIMATE CHANGE

3.1. HEALTH

3.1.1. Temperature-related mortality and morbidity

Mortality

Recent heatwaves have raised death tolls worldwide (Mora et al., 2017). Heatwaves give rise to an increased morbidity and mortality, especially in vulnerable population groups such as the elderly, young children, and persons suffering from cardio-vascular disease. In temperate climate zones heatwaves claim more victims than any other weather-related disaster (Borden and Cutter, 2008; WMO, 2014). A striking illustration of this is found in the comparison of the death toll attributed to Hurricane Katrina in 2005 (amounting to approximately 1500, see Beven et al., 2008) versus that of the European heatwave occurring in 2003 (70,000 reported heat-related deaths according to Robine et al., 2008). Also, the European (2003) together with the Russian (2010) mega-heatwaves contributed to more than 80% of all deaths caused by natural disasters in Europe between 1970 and 2012 (Golnaraghi et al., 2014).

Often, the mortality impact of heatwaves is minimized by invoking the "harvesting" phenomenon, i.e., the displacement of mortality by days or weeks. Stated otherwise, frail people die prematurely but not by much, as they would have died soon afterwards anyway. However, whereas minor heatwave episodes do induce a fair share of harvesting, this effect decreases with heatwave strength (Saha et al., 2014). In particular, for the European heatwave of 2003, it was found that the harvesting effect was modest (Toulemon and Barbieri, 2008). Indeed, while of the 15,000 excess deaths occurring in France some 4,000 would have died before the end of 2004 in any event, in the absence of the disaster the remaining 11,000 would have lived statistically 8-11 years longer, thus amounting to an estimated 100,000 lost life-years in France alone (Keller, 2015).

Estimates for the number of excess deaths during the summer of 2003 in Belgium vary, depending on the precise method and periods considered, but they roughly range between 1200-2000 extra death, see Table 3-1.

Table 3-1. Excess mortality (in number of persons) associated with extreme heat during the summer of 2003 in Belgium. The differences in the figures cited between the sources are explained by the different baseline (statistical reference) periods used as well as by the periods considered (e.g., only the heatwave itself versus the extended summer).

source	excess mortality
Robine et al. (2008)	1175
Sartor (2004)	1258
Kovats and Hajat (2008)	1297
Bustos Sierra et al. (2019)	1742
Cox et al. (2008)	2052

In the period 2000-2018, the highest excess mortality in Belgium has been reported for the years 2003, 2006 and 2010 (Bustos Sierra et al., 2019a). Not surprisingly, these years were characterized by high temperatures and high levels of atmospheric pollution (ozone and particulate matter). The causality is not always very clear, though, as e.g. the summer of 2018, despite high temperatures and ozone peaks, did not cause any excess mortality at all. Among other things, this can be related to the high mortality in the 2017/18 winter period, during which a larger number of people succumbed to influenza (Nielsen et al., 2019), many of those people typically being at a higher risk to also die from summertime excess

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heat (Bustos Sierra et al., 2019a).

The summer of 2019 was extraordinary in its record observed temperatures, exceeding 40°C at several locations and shattering previous highs by several degrees. Yet, while a full analysis was not available at the time of writing, a first examination yields a rather 'modest' (e.g., compared to 2003) excess mortality of 716[1], though this figure only relates to excess death that occurred during the heatwave periods themselves, excluding excess mortality in the ensuing weeks. It should be noted, though, that during the second heatwave at the end of July, a very high excess mortality of 35% was registered in the Brussels Region, a possible explanation being the temperature increment associated with the urban heat island of the city.

Of course, the relatively low mortality in 2019 could be the result of preventive measures (e.g., heat-health action plans) that have been taken as a reaction to the high mortality occurring in 2003. Indeed, in France a comparison of the hot summers of 2003 and 2006, and the associated expected number of deaths, suggest that measures taken following the 2003 heatwave have reduced mortality in 2006 (Fouillet et al., 2008).

One of the most certain impacts of global climate change is that of an overall increasing temperature, including also extreme temperatures. Forzieri et al. (2017), using historic mortality statistics for Belgium together with projected temperatures under a business-as-usual scenario (RCP8.5), estimate that the number of heat related deaths in Belgium will increase from a current average of 70 persons per year (1981-2010 baseline period) to more than 2800 towards the end of the century.

Morbidity

Apart from an enhanced mortality, high ambient temperature also causes heat-related illnesses such as heat exhaustion and heat stroke, and aggravates several common cardiovascular and pulmonary conditions (Borden and Cutter, 2008), potentially leading to an increased number of hospital admissions and ambulance calls (Li et al., 2015; Wondmagegn et al., 2019).

A large number of studies associating heat with enhanced hospital (emergency department) admissions has been conducted in the US and Canada (Ordon et al., 2016; Isaksen et al., 2015, Liss et al., 2017; Fuhrman et al., 2016),

- showing heat related increase of renal colic, nephritis and nephrotic syndromes, acute renal failure, ischemic stroke and intestinal infections;
- some studies pointing out the importance of considering human thermal comfort indicators that account for humidity alongside temperature;
- revealing that heat related hospital admissions of elderly persons are high, particularly during the first heatwave occurring in a season, declining with subsequent heatwave episodes;
- showing a particular vulnerability also of a much younger group, adolescents, caused by enhanced exposure associated with the timing of organized sports during summertime.

A study conducted in Italy (Ghirardi et al., 2015) also pointed to (young) children as being vulnerable to heat related illness and emergency department admissions.

Apart from increased hospital admissions, heat also triggers an increased number of ambulance calls during heat episodes, by up to 50% as found in studies conducted in Australia by Williams et al. (2012) and Turner et al. (2013). Interestingly, the former study found an increase not only for 'regular' heat related illness but also for mental health disease, also see below.

Little information appears to be available regarding the impact of heat stress on morbidity for the specific Belgian situation. Cox et al. (2016) found that in Belgium high ambient temperature may trigger preterm delivery (i.e. premature child birth), which is not only one of the main causes for infant

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[1] https://www.sciensano.be/nl/pershoek/3-perioden-van-oversterfte-tijdens-de-zomer-van-2019

mortality but also affects health at later stages in life.

During the summer of 2019 newspapers reported[1] excess heat-related emergency department admissions of around 15-20 persons per day in each of the hospitals of Genk, Hasselt and Sint-Truiden during extremely hot days. Especially the elderly were concerned, and they generally sought help for dehydration and cardiac and respiratory difficulties. Extrapolating these figures to the whole of Belgium – and considering that the country counts 105 hospitals with an emergency department[2] – yields an approximate 2000 daily extra hospital admissions country-wide on heatwave days. Obviously, this is, at best, a very rough order-of-magnitude guess that completely ignores regional differences, among others.

Mental health

Extreme heat also affects mental health: it has been associated with a higher incidence of mood disorders, attempts to commit suicide, increased aggression and violence, and overall negative consequence for mental health (Bourque and Willox 2014; Noelke et al. 2016; Thompson et al. 2018). A study conducted in Belgium by Linkowski et al. (1992) indicates that high temperatures, together with sunlight duration, is related to the probability of violent suicide. Indirectly, extreme temperatures, through their adverse impacts on, e.g., crop yield (Carleton, 2017) or health impairment (Berry et al. 2010) can lead to enhanced mental health problems including increased suicide rates.

Patients with mental disorders are more sensitive to high temperature exposures (Almendra et al. 2019). Antipsychotics can interfere with regulatory temperature functions and decrease the body’s capacity to shed heat, by adversely affecting the parasympathetic nervous system, i.e., by suppression of perspiration. This, in turn, can induce alterations in pharmacokinetics of other psychotropic drugs, increasing the risk of drug toxicity (Martin-Latry et al., 2007). In addition, a reduced autonomic nervous system functioning owing to antipsychotic medicine intake has been found to contribute to heat stress and development of depression, especially in the elderly (Chen et al. 2019). Moreover, some schizophrenic patients manifest cognitive impairment that can affect their ability to evaluate the environmental temperature and act adequately (Zhao et al. 2016).

More information regarding the impact of heat and other climate indicators is available in Ščasný et al. (2020).

Urban heat exposure

As outlined in Section 2.5, urban areas exhibit additional heat stress because of the urban heat island effect. Because of this UHI increment, cities are particularly exposed to heatwaves. Moreover, urban residents are particularly vulnerable to extreme heat, not only because of the extra temperature increment in cities, but also because of the high concentration of vulnerable people living in cities, such as elderly isolated persons, or people living in poor housing conditions.

In a study on Berlin, it was found that during heatwaves, mortality rates were higher in the city, especially in the most densely built-up districts (Gabriel and Endlicher, 2011). In a study on Paris (Dousset et al., 2011), it was concluded that, during the heatwave of the summer of 2003, areas exhibiting the highest remotely sensed nighttime infrared surface temperature suffered the highest excess mortality. Again considering the hot summer of 2003, Vandentorren et al. (2004) found that heat-related excess mortality was especially high in cities, Paris featuring on top with an excess mortality of nearly 140% during the period 1-19 August 2003. Even though this enhanced excess mortality can, at least partly, be attributed to the vulnerability of the urban population (e.g., a larger

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[1] https://www.hln.be/in-de-buurt/genk/-twintig-patienten-per-dag-extra-op-spoed-door-hitte-ziekenhuizen-zien-aanmeldingen-stijgen~ab944dbb/

[2] https://www.health.belgium.be/nl/gezondheid/organisatie-van-de-gezondheidszorg/delen-van-gezondheidsgegevens/gezondheidszorginstellingen

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share of isolated elderly people), increased mortality has been associated with the urban temperature increment itself (Keller, 2015).

In Belgium, accounting for urban effects is particularly important given that the share of people living in cities and towns amounts to 87% (situation of 2015; see Lavalle et al., 2017), putting the country among the top urbanized regions in Europe. Considering mortality data for Belgium presented in Bustos Sierra et al. (2019a) by region, it emerges that Brussels has a higher excess mortality (when expressed as a percentage, not in absolute numbers) than the Flemish and Walloon Regions. Also here, this has been attributed to the excess temperature increment occurring in Brussels, caused by the urban heat island phenomenon.

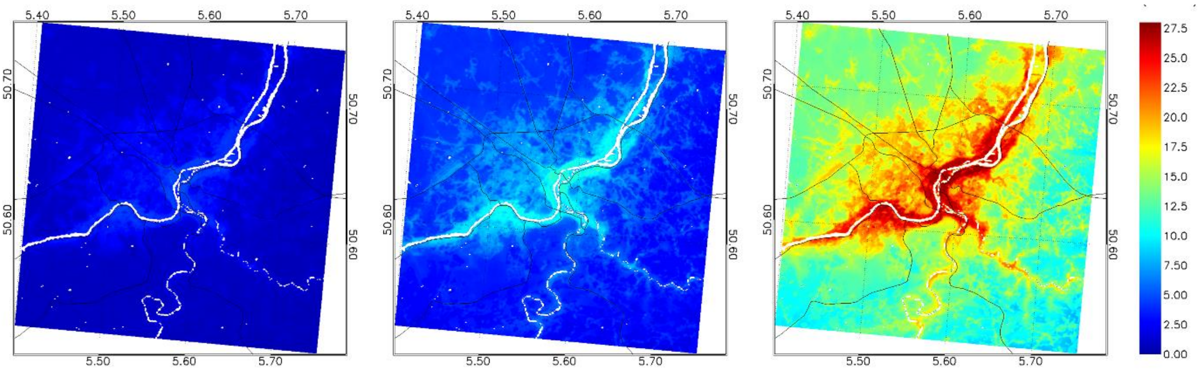

Figure 3-1. Evolution of the annual average number of heatwave days under the RCP8.5 scenario for Liège, for the present (1996-2015, left), near future (2026-2045, middle) and end of the century (2081-2100, right). Source: Poelmans et al., 2018.

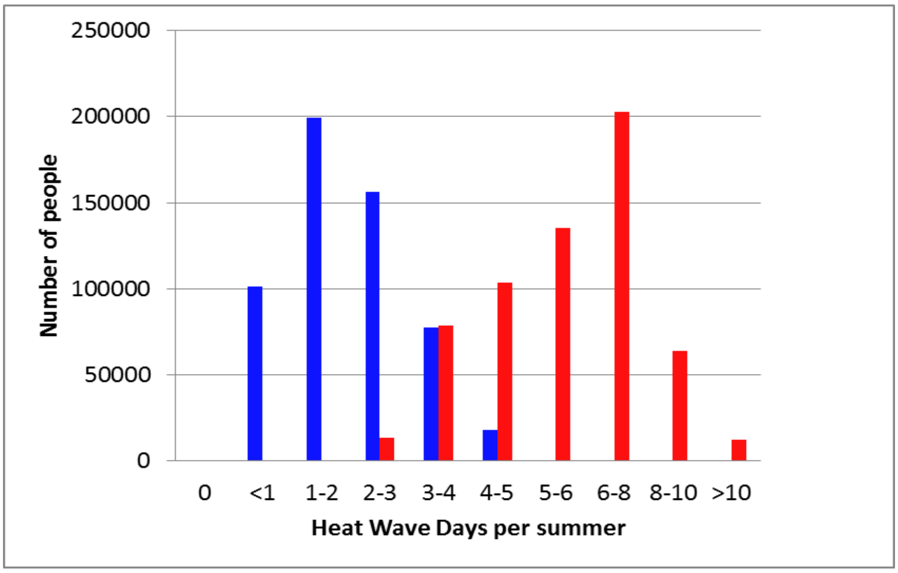

Figure 3-2. Statistical distribution of the number of persons in Liège that are exposed to a given number of heatwave days each summer, for the years 1996-2015 (blue) and 2026-2045, RCP8.5 (red). Source: Poelmans et al. (2018).

A few studies have considered heat exposure in Belgian cities. The SMARTPOP[1] project considered, among other things, exposure to excessive heat stress in the city of Liège. The calculation of heatwave days used in this assessment is based on the definition of the Belgian Federal Public Service for Health, which defines a heatwave day as a day for which the 3-day mean maximum temperature exceeds 30°C and the 3-day mean minimum temperature exceeds 18°C[2]. Figure 3-2 shows the evolution of the

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[1] http://www.smartpop.be/

[2] Note that these temperature thresholds are rounded off from the threshold values of 18.2°C and 29.6°C that

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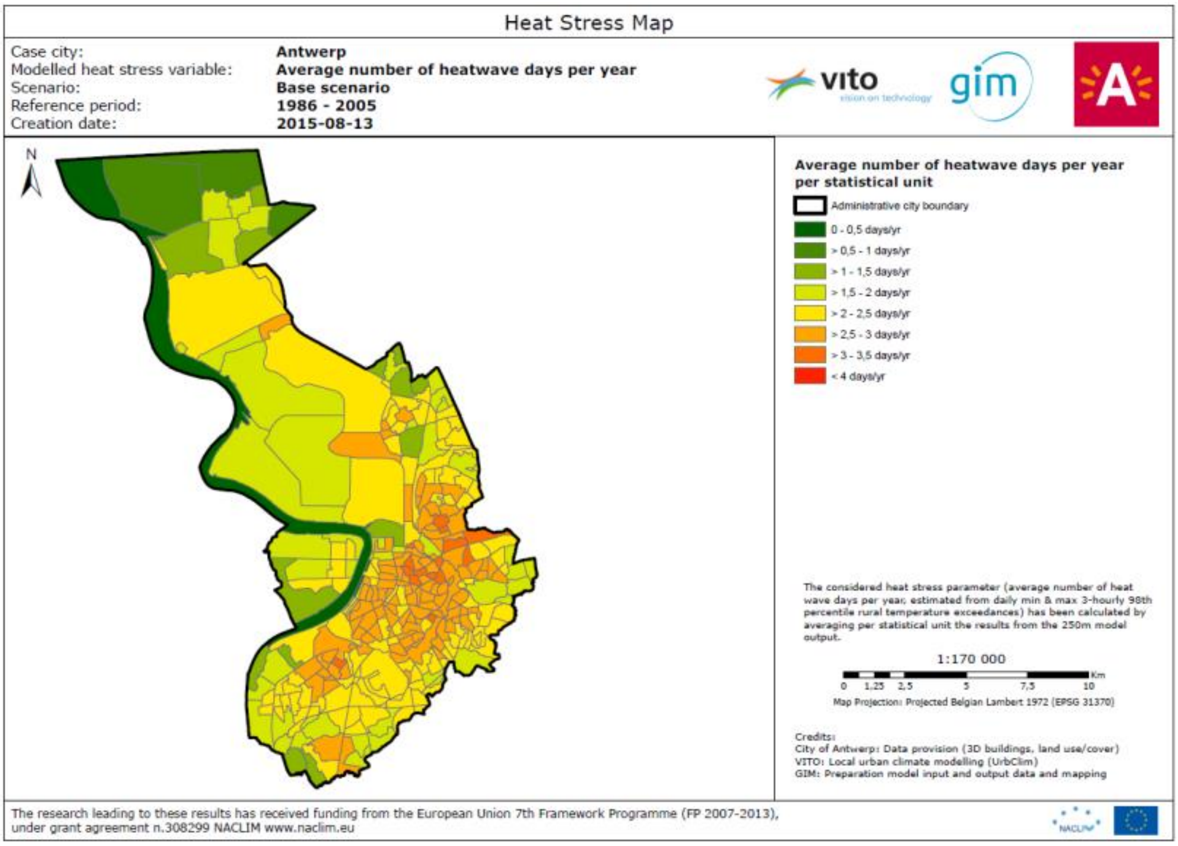
number of heatwave days for Liège and surroundings over the next century under the RCP8.5 scenario. Where nowadays people in the city centre experience up to 5 heatwave days per year (compared to 1 to 2 days for people living in rural areas), these numbers double before mid-century and are more than 5 times larger by the end of the century. This means that if the world continues on the current 'business as usual' track, almost 30% of summer days (the summer being taken here as June-July-August) will be a heatwave day by the end of the century, on average. While some years will experience less, natural interannual variability will cause years with many more heatwave days.

Overlaying (1) the population density in 2008 and the projected values in 2050 as predicted by a population scenario with (2) the heatwave maps allows to calculate the exposure of the population in the Liège area to excessive heat now and in the future. Figure 3-2 shows that, while currently the main share of the population is exposed to 1-2 heatwave days on average each summer, this exposure will increase to 6-8 days already by 2026-2045.

Another study carried out in the EU-FP7 NACLIM[1] project, considered the city of Antwerp, linking excessive heat patterns with the spatial distribution of population density and socio-economic assets at the level of the statistical units composing the area. Figure 3-3 shows the annual mean number of heatwave days for Antwerp for the period 1986-2005, clearly featuring the urban heat island effect in the city core as compared to the surrounding areas. Figure 3-4 and Figure 3-5 show the same quantity but then for the near (2026-2045) and far (2081-2100) future under the RCP8.5 scenario. The picture arising from this is very consistent with the situation depicted above for Liège.

Figure 3-6 gives the number of hospitals per statistical sector in the Antwerp area, showing that most are exposed to the warmer urban heat island portion of the domain. Likewise, Figure 3-7 shows that the urban heat island of Antwerp comprises a large number of elderly stay homes.



The considered heat stress parameter (average number of heat wave days per year, estimated from daily min & max 3-hourly 98th percentile rural temperature exceedances) has been calculated by averaging per statistical unit the results from the 250m model output.

Map Projection: Projected Belgian Lambert 1972 (EPSG 31370)

Credits:
City of Antwerp: Data provision (3D buildings, land use/cover)
VITO: Local urban climate modelling (UrbClim)
GIM: Preparation model input and output data and mapping

The research leading to these results has received funding from the European Union 7th Framework Programme (FP 2007-2013), under grant agreement n.308299 NACLIM www.naclim.eu

Figure 3-3. Average annual number of heatwave days in Antwerp for 1986-2005 (Stevens et al., 2015).

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have been used in several other studies (Brits et al., 2010; Brouwers et al., 2015).

[1] www.naclim.eu

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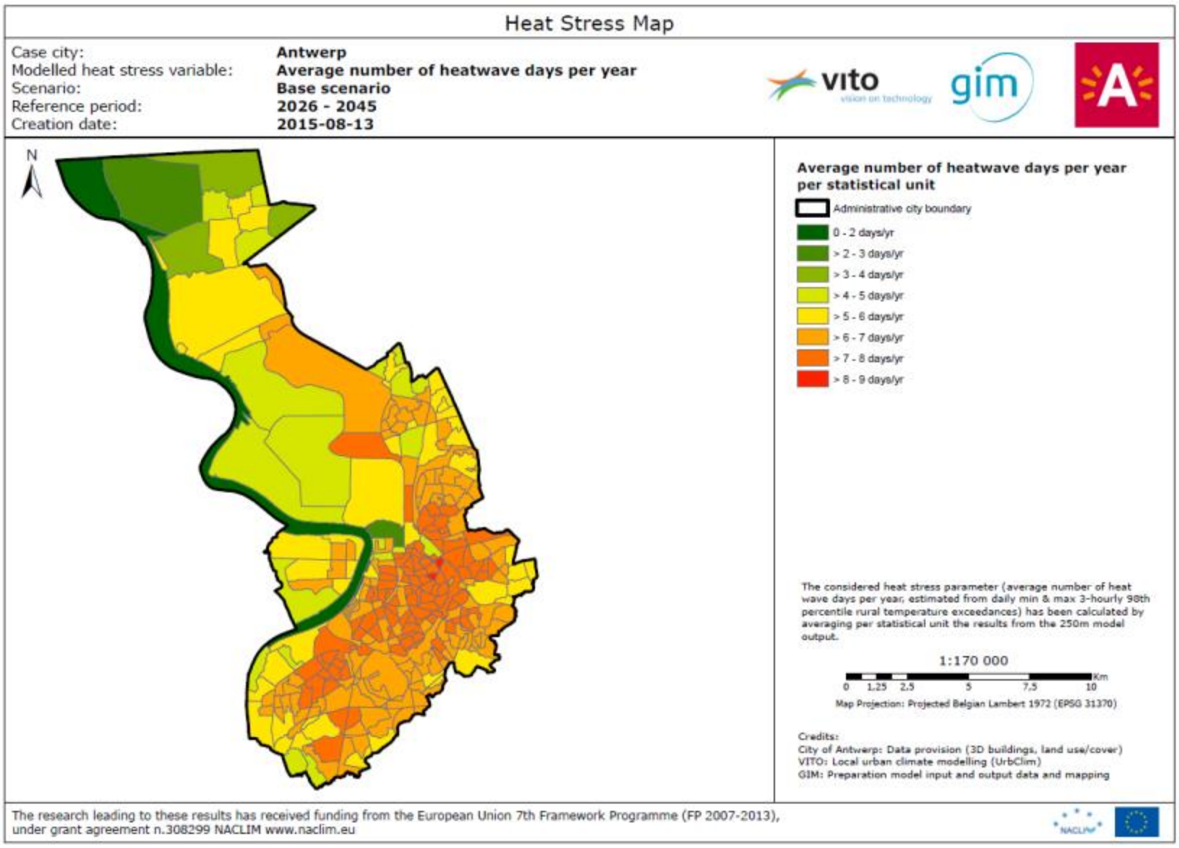


Figure 3-4. As in Figure 3-3 but for the years 2026-2045 under climate scenario RCP8.5.

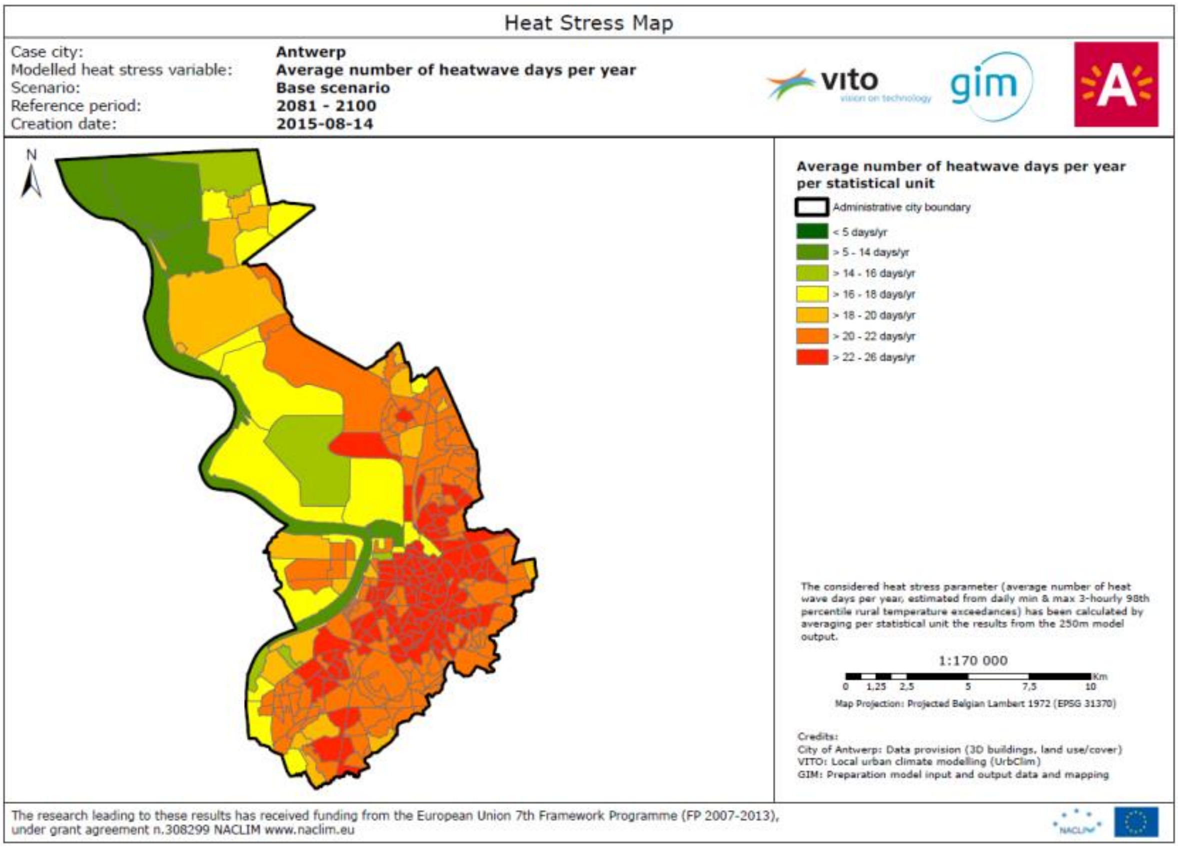
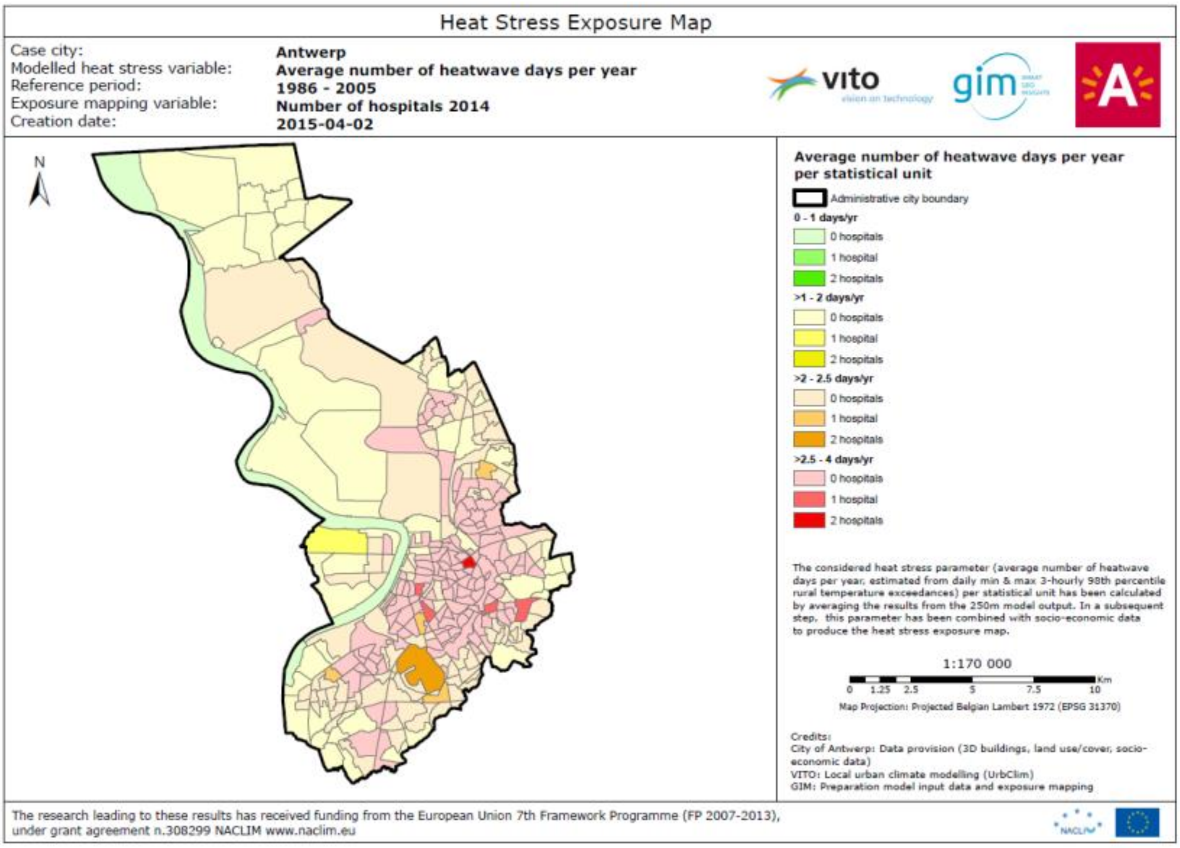


Figure 3-5. As in Figure 3-3 but for the years 2081-2100 under climate scenario RCP8.5.



Heat Stress Exposure Map

Case city: **Antwerp**
Modelled heat stress variable: **Average number of heatwave days per year**
Reference period: **1986 - 2005**
Exposure mapping variable: **Number of hospitals 2014**
Creation date: **2015-04-02**

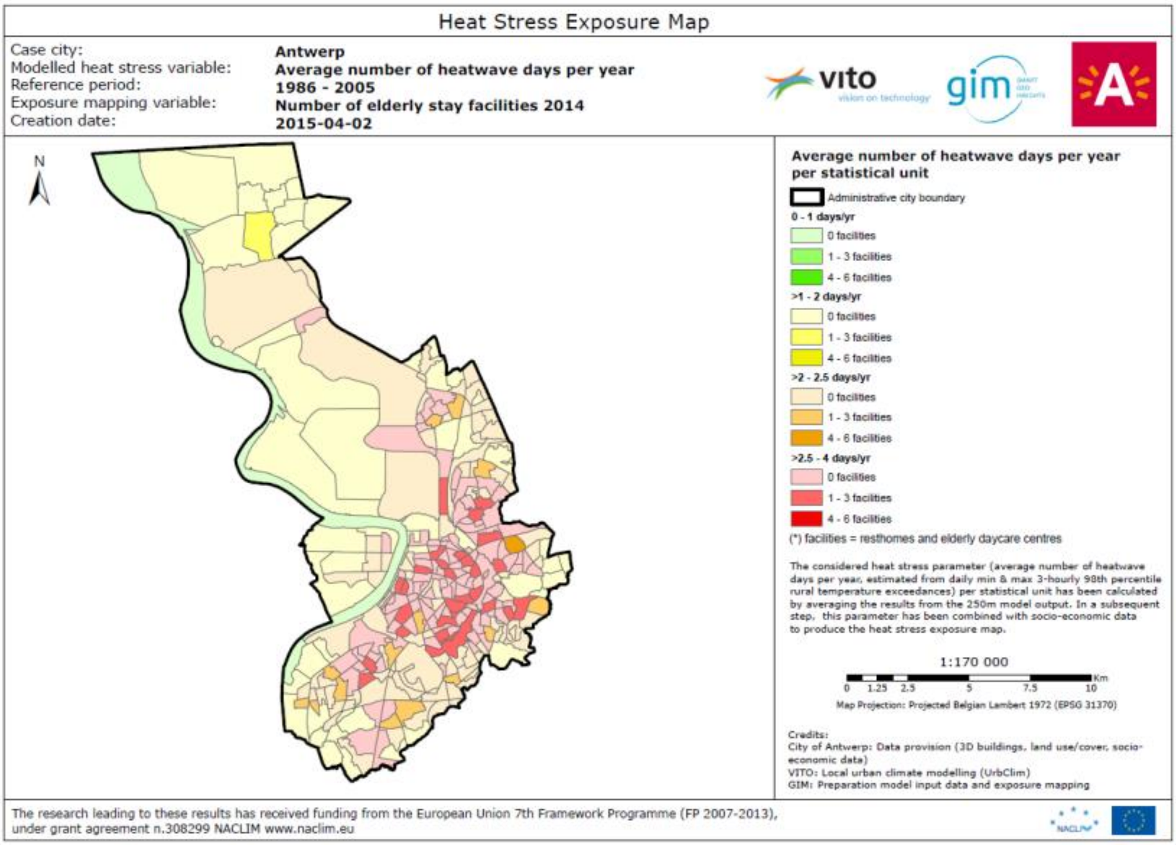
The considered heat stress parameter (average number of heatwave days per year, estimated from daily min & max 3-hourly 98th percentile rural temperature exceedances) per statistical unit has been calculated by averaging the results from the 250m model output. In a subsequent step, this parameter has been combined with socio-economic data to produce the heat stress exposure map.

Map Projection: Projected Belgian Lambert 1972 (EPSG 31370)

Credits:
City of Antwerp: Data provision (3D buildings, land use/cover, socio-economic data)
VITO: Local urban climate modelling (UrbClim)
GIM: Preparation model input data and exposure mapping

The research leading to these results has received funding from the European Union 7th Framework Programme (FP 2007-2013), under grant agreement n.308299 NACLIM www.naclim.eu

Figure 3-6. Average number of heatwave days in Antwerp for 1986-2005 overlaid with number of hospitals occurring per statistical unit (Stevens et al., 2015).



Heat Stress Exposure Map

Case city: **Antwerp**
Modelled heat stress variable: **Average number of heatwave days per year**
Reference period: **1986 - 2005**
Exposure mapping variable: **Number of elderly stay facilities 2014**
Creation date: **2015-04-02**

(*) facilities = resthomes and elderly daycare centres

The considered heat stress parameter (average number of heatwave days per year, estimated from daily min & max 3-hourly 98th percentile rural temperature exceedances) per statistical unit has been calculated by averaging the results from the 250m model output. In a subsequent step, this parameter has been combined with socio-economic data to produce the heat stress exposure map.

Map Projection: Projected Belgian Lambert 1972 (EPSG 31370)

Credits:
City of Antwerp: Data provision (3D buildings, land use/cover, socio-economic data)
VITO: Local urban climate modelling (UrbClim)
GIM: Preparation model input data and exposure mapping

The research leading to these results has received funding from the European Union 7th Framework Programme (FP 2007-2013), under grant agreement n.308299 NACLIM www.naclim.eu

Figure 3-7. As in Figure 3-6 but considering the number of elderly stay facilities.

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Finally, a study with relevance for Belgium was conducted recently within the framework of the FP7 RAMSES project[1], considering the relation between heat and mortality in the city of Antwerp (Sanchez et al., 2018). It was concluded that, while in the time frame 2009-2013 an average of 13.4 deaths per year in the city could be attributed to heat, under scenario RCP8.5 this figure would rise to 32 per year in 2026-2045, and to 86 per year in 2081-2100.

Extrapolating this to the Belgian territory, considering that the city of Antwerp is home to approximately 0.5 million inhabitants against around 11 million in the entire country, this would yield a heat attributable mortality of almost 1900 per year. Obviously, this naïve approach ignores any regional or urban-rural differences. Nevertheless, the resulting estimate is nearly of the same order as the earlier cited number of 2800 deaths per year that was found by Forzieri et al. (2017) using a completely independent approach. Following the same procedure, the number of excess heat related death in the near future (time frame 2026-2045) can be estimated for Belgium to be 707 per year.

Comparing this number of 1900 death per year to figures in Table 3-1, it is fair to conclude that, towards the end of the century, under scenario RCP8.5 and assuming that no physiological adaptation will take place, one should expect a 'summer of 2003' scenario in terms of mortality every year, on average. It is of course uncertain to what extent physiological adaptation to heat will occur in the Belgian population, and how fast this will take place, so the estimated heat attributable death figures could be an overestimate. On the other hand, the increasing share of elderly persons in the population was not accounted for in this study, which would probably have an effect in the opposite sense (i.e., an increase in mortality).

Impacts of cold

Exposure to cold can lead to direct effects such as hypothermia, or indirect pathologies such as cardiovascular disorders (hypertension, thrombosis) or respiratory infections (influenza, pneumonia) (Ballester et al., 2011). People with pre-existing cardiovascular and respiratory diseases and the elderly are the most vulnerable (Ryti et al., 2015; Hajat et al. 2017). In fact, in temperate climates as in Belgium, it is not the direct impact of (extreme) cold that claims most victims. Indeed, most of the mortality during the cold season can be attributed to diseases that flourish in conditions of cold weather, such as influenza.

Currently, the death toll associated with winter cold still far exceeds that of death figures related to summer heat. To put things in perspective, consider the number of 152,000 death attributed to influenza in the 2017/18 winter season in Europe (Nielsen et al., 2019), compared to the death toll of 70,000 attributed to the (exceptional) European heatwave of 2003 (Robine et al., 2008). Also, in Belgium, the expected all-cause daily mortality is up to around 320 in winter and 250 in summer (Cox et al., 2010).

It is expected that, with climate change, cold-related mortality will be considerably reduced (Ciscar et al., 2011). Yet, climate models also predict that extreme cold weather events are still likely to occur over European continental areas and other mid- and high-latitude regions under 21st-century warming scenarios (Kodra et al. 2011).

While Ballester et al. (2016) found strong associations between interannual variability in winter mean temperature and mortality (with higher seasonal cases during harsh winters) for most European regions, this was not the case for Belgium (together with the United Kingdom and the Netherlands). Nevertheless, they conclude that warmer winters should contribute to the decrease in winter mortality everywhere in Europe, hence also in Belgium.

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[1] www.ramses-cities.eu

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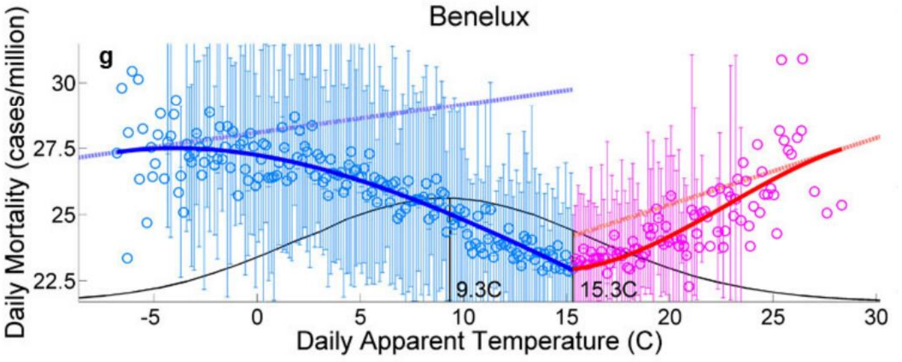

Figure 3-8. Observed relationship between daily mean apparent temperature and mortality for the Benelux. Note that the apparent temperature (definition provided in Ballester et al, 2011) is a combination of air temperature and humidity and represents the perceived heat stress better than air temperature alone. Source: supplementary material from Ballester et al. (2011).

Also, Ballester et al. (2011), estimating future temperature related mortality in Europe based on outcomes of regional climate model projections (and using the A1B climate scenario), found a shift in the seasonality of mortality from winter to summer. They also found that the rise in heat-related mortality will start to completely compensate the reduction of deaths from winter cold during the second half of the century, amounting to an average drop in human lifespan of up 3–4 months in 2070–2100. This can be understood from Figure 3-8, realising that the health gain from increasing winter temperatures will be offset by the health loss associated with increasing summer temperatures. An important element is that Figure 3-8 shows that the warm tail of the temperature-mortality curve is steeper than the cold tail.

Finally, considering all the above, it is also important to realize that quality of housing and the ability of people to protect themselves against cold constitutes an important element to reduce vulnerability to cold.

3.1.2. Climate change impacts on air quality

Belgium, and especially the Flemish Region, exhibits among the highest pollution levels in Europe. Apart from pollutant (precursor) emissions, meteorological conditions have a strong impact on these pollution levels. Wind speed and atmospheric turbulence affect the way pollutants are dispersed, and shortwave radiation, temperature and humidity influence the chemical reaction rates that are involved in, e.g., the production of ozone and secondary particulate matter. Precipitation and the lack of it (drought) affect the way certain pollutants (particulate matter) are washed out of the atmosphere.

Projections of air quality including climate change impacts are difficult to establish given the very high uncertainty regarding the pollutant (precursor) emissions, especially from traffic, but also from residential and other sources, because of unanticipated technological developments and the unknown degree of market acceptance of new technologies (electric car, district heating, among others).

Still, a few studies have been conducted for Belgium. Deutsch et al. (2010) used the year 2003 as a proxy for future climate change conditions, while the year 2007 – after a detailed analysis – was taken as representative for average present-day climatological conditions. From a comparison of observed values of PM_{10} (fine particulate matter with an aerodynamic diameter below 10 µm that can penetrate deep into the lungs and cause adverse health effects, it emerges that the year 2003, with its hot and dry summer, exhibited a considerably larger number of days with PM_{10} values in exceedance of standard health limit values (50 µg/m^3) than the 'average' year 2007, as shown in Figure 3-9. A very similar picture emerges for $PM_{2.5}$, the finer fraction contained within PM_{10} and assumed to induce stronger adverse health effects still.

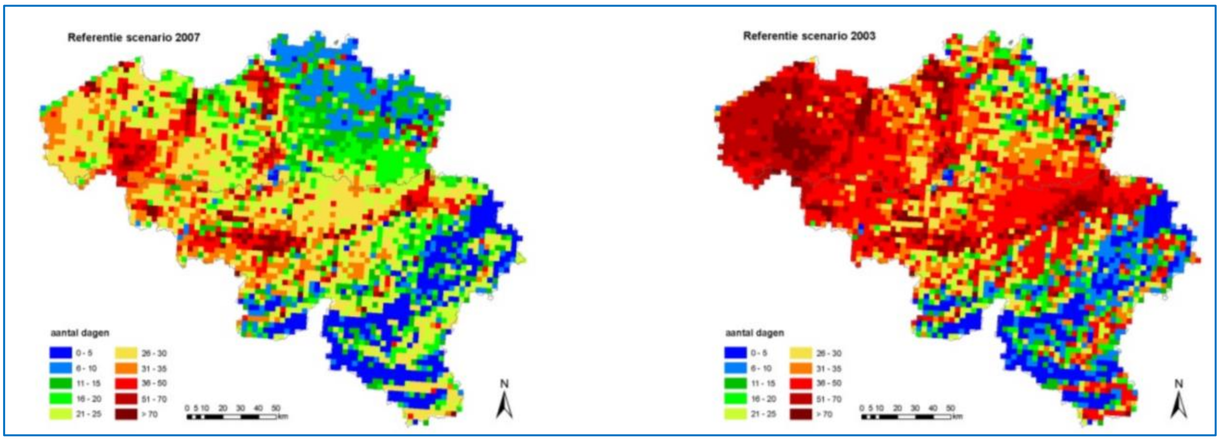

Figure 3-9. Observation-based (i.e., observed values interpolated with land-use based regression) number of days exceeding a PM10 concentration value of 50 µg/m3 for Belgium, during the years 2007 (left) and 2003 (right) (from Deutsch et al., 2010).

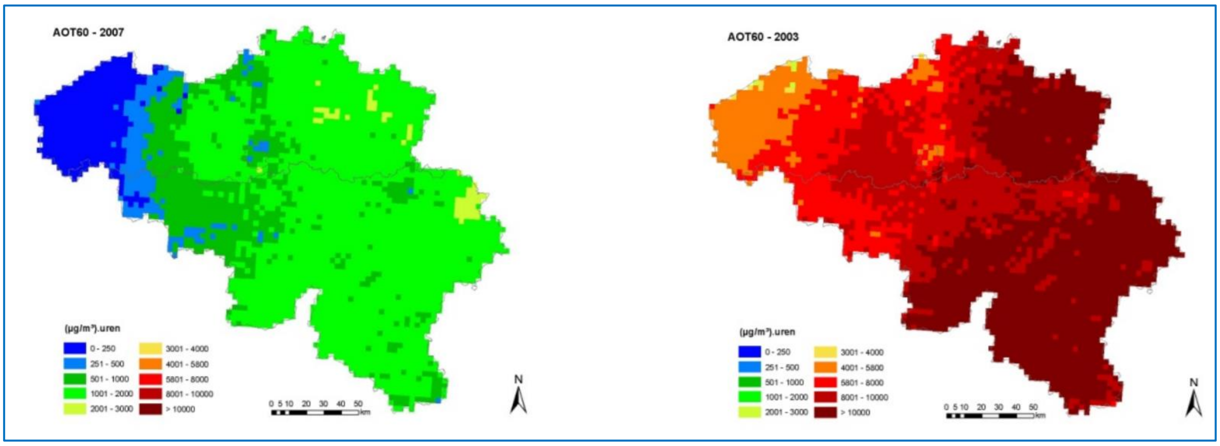

Figure 3-10. As in Figure 3-9 but considering the AOT60 for O_3 (from Deutsch et al., 2010).

Apart from particulate matter the Deutsch et al. (2010) study also considered photochemical pollution, i.e., ozone (O_3), in particular the AOT60, which is the accumulated ozone exposure above a threshold of 60 ppb (= 120 µg/m³) and which relates to the effects of ozone on the population. Here also, the effect of the 'anomalous' year 2003 on this indicator is rather drastic, featuring values around five times higher than those of the 'regular year 2007 (Figure 3-10).

In addition to these observation-based analyses, numerical simulations were conducted using different scenarios of projected pollutant and precursor emissions for the year 2030, and using the meteorological data of the years 2003 and 2007 as drivers representing present-day and future-climate (time horizon 2030) conditions.

From this exercise, the main conclusion in Deutsch et al. (2010) was that climate change has the potential to partially or completely undo the beneficial effects of anticipated pollutant emission reductions, among others because of the higher temperatures (enhanced atmospheric chemical reactions) and the occurrence of drought spells (reduced washout from precipitation).

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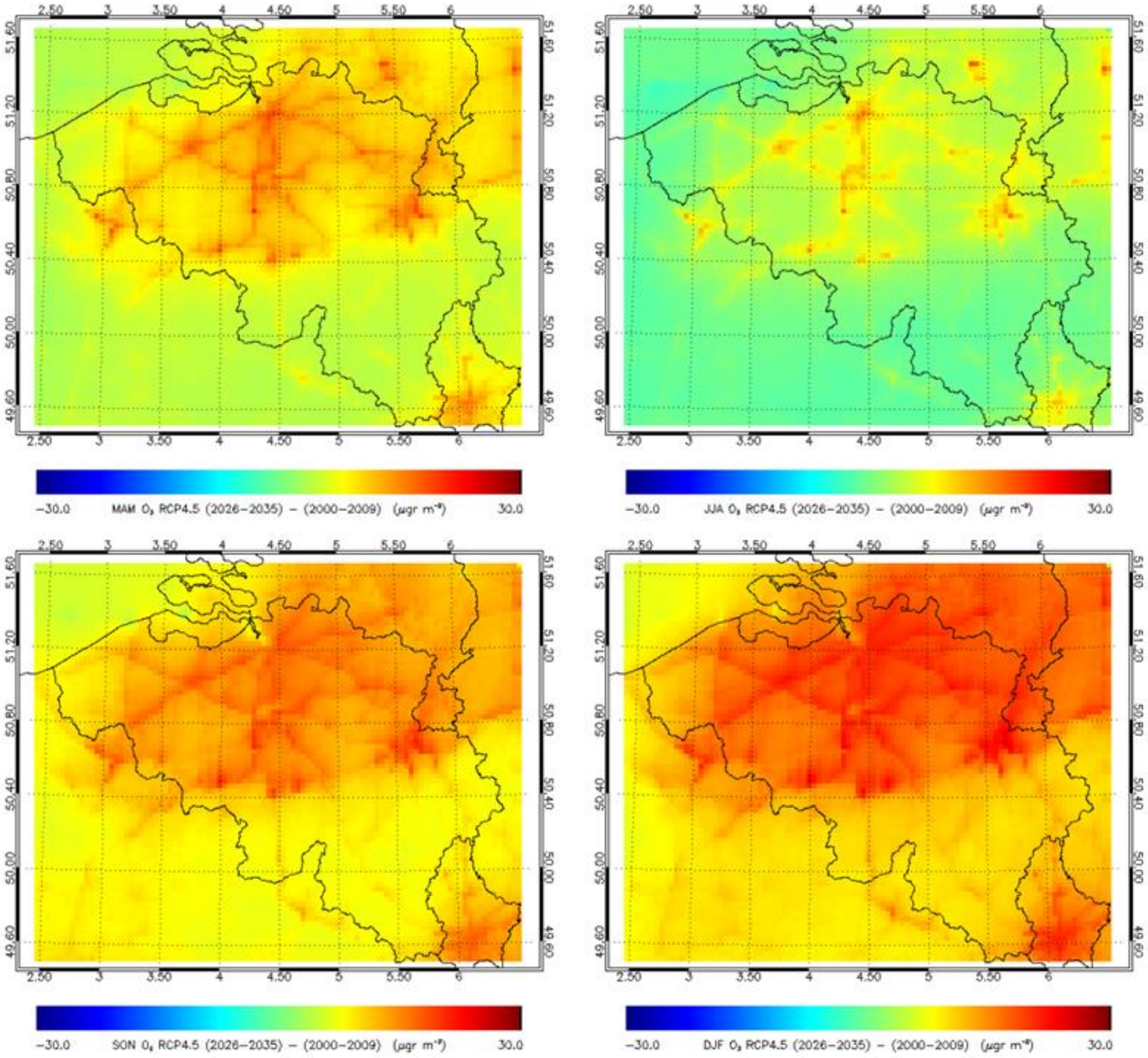

Figure 3-11. Estimated changes (2025-2036 vs 2000-2009) of daily mean ozone concentrations over Belgium by season, showing (starting from the top left figure and rotating in a clockwise sense) the results for spring, summer, fall and winter (from Lauwaet et al., 2014).

In another study, by Lauwaet et al. (2014), an atmospheric pollution model for ozone was forced by present-day (2000-2009) as well as future (2025-2036, RCP4.5) climate data, and considering scenarios for pollutant precursor emission reductions. Figure 3-11 shows that towards 2030 we can expect up to 30 µg/m^3 higher average ozone concentrations. Most of these increases are, however, related to the imposed emission reductions, in particular the reduced NO_x concentrations lead (somewhat paradoxically at first sight) to a reduced ozone destruction hence higher resulting ozone concentration. Yet, when keeping the emissions constant (in order to isolate the climate impact), while changing the climate forcing from today's values to those of the near future, showed an increase by 10% of the O_3 concentrations.

3.1.3. *Advance of tropical disease vectors*

Vector-borne diseases are infectious diseases, caused by pathogenic agents transmitted from an infected individual to another individual by an arthropod, other invertebrate or rodent. Intermediary hosts such as domesticated or wild animals often serve as a reservoir for the pathogen until susceptible populations are exposed (Brits, 2010). Advance of tropical (disease) vectors is a concern, but more research is needed to assess the potential consequences in terms of health impacts and associated costs. The transmission cycles of vector-borne diseases are sensitive to climatic factors, but disease

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risks are also affected by factors such as land use, vector control, human behaviour, population movements and public health capacities (EEA, 2017). Medlock and Leach (2015), referring to IPCC (2014a), state that it is generally accepted that direct effects of a temperature rise on vector-borne disease risk cannot be predicted with any real confidence, because of the complexities of the transmission cycles and the behavioural, ecological, and societal factors that cannot be captured directly within climate models.

The most frequently discussed disease vectors that are relevant in Belgium are ticks and different species of tropical mosquitos and we will therefore focus on those vectors. Other vector/disease pairs worth mentioning but not considered here are sand flies/Leishmaniasis, rodents/Hantavirosis and mammals/Leptospirosis. As to the former, according to EEA (2017) the current risk for sand-fly-transmitted diseases for central Europe has been estimated to be low owing to temperature constraints on pathogen growth.

Ticks as a disease vector

Ticks (*Ixodes ricinus*) are responsible for the spread of Lyme disease, caused by the bacterium *Borrelia burgdorferi*. It should be noted that at present only about 14% of ticks are infected with *Borrelia*, and that, once bitten, the risk of transmission by an infected tick is only 1 to 3%. Studies in the Netherlands indicate that the former number has remained stable even as tick populations have increased. The Institute of Tropical Medicine in Antwerp states that there is no infection risk if the tick is removed within 24 hours. Ticks can also spread a form of encephalitis, but occurrence of this specific disease in Belgium is extremely rare. There is limited evidence that other tick-borne diseases (e.g., Crimean–Congo haemorrhagic fever, *Rickettsia*) may be sensitive to climate change (EEA, 2017).

Lyme disease is the most common vector-borne disease in the EU, with a reported incidence of approximately 65,000 cases per year. However, there is no standardized case definition or diagnosis for Lyme disease in Europe, so this number represents only a best estimate.

Occurrence of tick species carrying Lyme disease is limited by climatic conditions, and annual or seasonal variations in climate conditions influence tick prevalence within its natural range (the pathogen itself is not sensitive to ambient climatic conditions). Ticks can survive cold winters but become active when the ambient temperature increases above 4-5°C, below which they are in a chill coma. Higher temperatures are needed for metamorphosis and egg hatching, i.e. between 8°C and 10-11°C respectively. The optimum activity range is between 18 and 25°C (WHO, 2006).

Populations could thus expand or have a longer activity period as a result of an increase in daily minimum temperatures in a warming climate, thus increasing the probability that humans are bitten and that the disease is transmitted. It should be noted that not only the adults but also the larvae and nymphs can transmit the disease.

Figure 3-12 shows the number of tick bites in recent years as reported through the Belgian TickNet self-reporting website. Although even in winter some bites have been reported it is clear that there is more activity in the warmer months, with a peak in June (also related to the ticks' lifecycle). One can imagine that if especially the spring months become warmer, more activity and hence more bites may be expected in this period. However, very hot months can have a negative effect on tick survival, which seems to explain the lower values for May/June 2017 as compared to 2016.

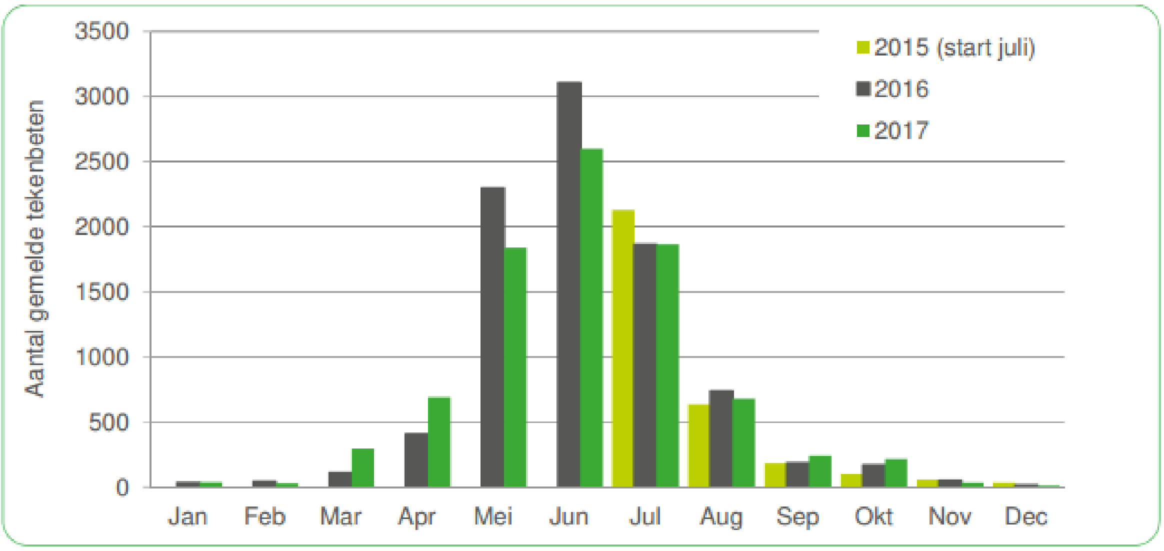

Figure 3-12. Number of tick bites in 2015, 2016 and 2017 as reported through the Belgian TickNet self-reporting website. Source: Sciensano, 2018.

An increase in the number of cases of Lyme disease since the start of the 1990's has indeed been observed in Belgium (42 reported cases in 1991 vs. 722 reported cases in 2003), although other factors than climate change (such as better reporting or changes in human behaviour) may be at play. In the Netherlands (RIVM, 2014), the number of reported cases of Lyme disease has tripled between 1999 and 2014. It is interesting to note that according to WHO (2006) the number of reported cases was 6500 in the Netherlands and only 500 in Belgium. This difference may at least partly be due to differences in awareness and reporting.

Analyses of long-term trends in the Netherlands indicate that both the length of the tick season and the area of suitable tick habitat have increased; as have the densities of tick hosts (small mammals, birds). As a result, as indicated by field studies, tick density and activity seem to have increased between 2006 and 2009.

It should be noted that according to data collected by Sciensano, the number of Lyme infections in Belgium has remained relatively stable over recent years, with the yearly incidence in the period 2015-2017 being comparable to the incidence in the period 2008-2009. Other studies also point to the fact that there has not been an increase in Lyme disease over the past 10 years. Figure 3-13 shows the evolution of the number of cases reported by the sentinel laboratories network per week in recent years. The seasonal pattern is clearly visible but there does not appear to be a clear trend in average counts.

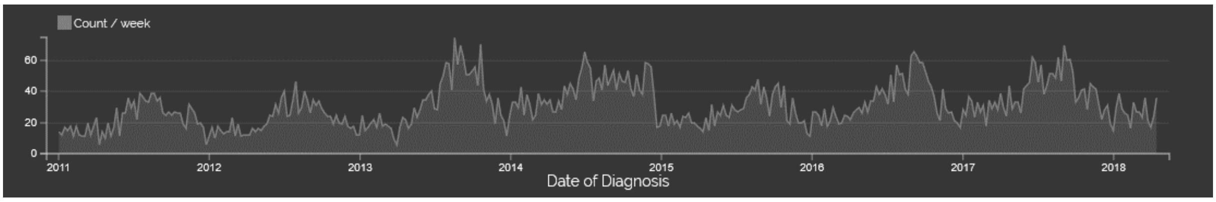

Figure 3-13. Number of reported Lyme infection cases per week over the period 2011-2018. Source: Epistat/Epilabo – Sentinel Laboratories Network[1]).

According to Geebelen et al. (2019), incidence of Lyme disease in Belgium (all manifestations combined) is in the order of 103.5 per 100,000 inhabitants, or about 11,690 cases per year. Sciensano (2018) reports, on the basis of reporting by a general practitioners network, an incidence of *Erythema*

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[1] https://epistat.wiv-isp.be/dashboard/

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migrans (an indicator for *Lyme borreliosis*) of 9 per 10,000 for Belgium. According to the same report, about 52% of Lyme cases were reported in Flanders, 38% in Wallonia and the rest in Brussels (based on positive serology reports in a network of laboratories). Based on reporting by a network of general practitioners, incidence of Lyme disease in Belgium over the period 2011-2018 was highest in the provinces of Antwerp, Limburg and Luxembourg. The lowest incidences appeared in the (forest-poor) provinces of West and East-Flanders and Hainaut. The other provinces have intermediate prevalence.

This is in agreement with the reporting of tick bites via a dedicated platform[1] which for 2017 (Sciensano, 2018) yields a proportion of reported bites of 58.3% in Flanders and 40.5% in Wallonia. When taking into account differences in population density frequency is higher in Wallonia than in Flanders though (96 vs 76 bites per 100,000 inhabitants, for a national average of 75), with the highest relative figures applying to the provinces of Luxembourg, Brabant Wallon, Namur and Limburg. In Luxembourg for instance, the number of reported bites per 100,000 inhabitants was 205 in 2017, i.e. 2.7 times the national average.

Prevalence of ticks (and hence of Lyme disease) is not only influenced by warmer winters but also the humidity of the environment, as ticks prefer microclimatic conditions with high humidity. In their prolonged nonparasitic phases, they require a microclimatic relative humidity of at least 80% to avoid fatal desiccation (Gray et al., 2008). More ticks will be present after a wet winter and spring than after a dry one. The prevalence was lower in the dry summers of 2017 and 2018. Annual weather-related fluctuations may thus partly mask longer term climatic effects on populations, although it should be noted that as a result of their multi-annual life cycle, tick prevalence in a given year is also determined by the meteorological conditions in the preceding years. As Gray et al. (2008) point out, in areas where lowered summer precipitation coincides with raised summer temperatures (which may well be the case in Belgium), the survival, activity, and distribution of *I. ricinus* are likely to be reduced because of their vulnerability to desiccation.

The impact of climate change on prevalence of Lyme disease is thus not a simple linear one related only to temperature, which makes it hard to predict whether occurrence of the disease will increase as a result of climate change, and to what extent. It should be noted that small mammals (shrews, hedgehogs, hares, …) and birds (including migratory ones) act as reservoirs for the disease, thus changes in mammal or bird populations (as a result of nature conservation actions), or, more generally, an increase in land area dedicated to nature and forest (natural environments that can maintain a high degree of air humidity being favoured by the ticks themselves), can also play a role. Obviously, these evolutions can be influenced by climate change but depend to a large extent also on policy decisions.

As contact between humans and ticks occurs in the outdoors, e.g., when hiking or playing in forests, grassland, … the amount of time that people spend outdoors, as a result of climate related or other (e.g., cultural, recreational, …) factors, will also have an influence on the infection rate. It should be noted however that presence of ticks is not limited to “nature” in the strict sense, as they can also thrive in green areas within (semi-)urbanized environments, e.g., gardens or parks. Indeed, according to reporting by TekenNet of results for the year 2017 (Sciensano, 2018), most bites (65%) have been reported within 5 km of people’s homes, and the most reported environments where people said to have been bitten were gardens (44.8%) followed by forests (35.7%).

Climate scenarios in combination with species distribution models anticipate range expansions for ticks as a result of climate change, with a shift to higher altitudes and latitudes. In Sweden for instance, the northern distribution limit of I. ricinus, together with that of several other animal and plant species, has shifted northwards since the climate started to noticeably change in the late 1980s (Gray et al., 2008). Porretta et al (2013) estimated that the climatically suitable area of *Ixodida* could double by 2050 as a result of climate change (under different scenarios), with an expansion into northern Russia.

No projections seem however to be available regarding the climate effect on tick activity, let alone Lyme disease incidence, in regions (such as Belgium) where the disease is already endemic. As Gray et

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[1] https://tekennet.wiv-isp.be/

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al. (2008) point out, the magnitude of the effects of climate change in an endemic area is determined not only by ecological conditions but may be influenced by socioeconomic factors, human migration and settlement, ecosystems and biodiversity, migrating patterns of birds, land-use and land cover changes, human cultural and behavioural patterns, and immunity in the population.

The available data in Belgium have not been subjected to a rigorous statistical analysis but do as yet not point to a clear relation between bite frequency or Lyme disease incidence on the one hand and changing weather or climate conditions on the other hand.

Hence, there is no clear indication that climate change would result in a substantial increase of the incidence of Lyme disease in Belgium (although such an effect cannot be discounted altogether either) and no idea at all of the potential magnitude of such an increase. Estimating the cost of a possible increase of Lyme's disease in Belgium as a result of climate change is thus not possible at present. The economic (societal) impact of the disease *in the current situation* has been estimated in the Netherlands to be about 19.4 million euro, or 1.14 euro per capita for a population of 17 million inhabitants (van den Wijngaard et al., 2017). Extrapolated to Belgium, this would mean a total economic cost of about 12.5 million euro annually. A study to estimate the cost burden of Lyme borreliosis in Belgium is under way (see Geebelen et al., 2017) for the study protocol). No studies are presently available that assess the cost of a potentially increased incidence of Lyme disease in Belgium under conditions of climate change.

Combatting the disease in order to lower its (economic) burden is in any case not an easy task. Given the ecology of the disease, eliminating or adapting the (natural) environment in which it thrives is not an option, except in parks and other semi-natural environments (e.g., by maintaining lawns short). Massive population reduction of reservoir species is not feasible either. Vector control using pesticides is not recommended unless severe epidemic conditions are prevalent. Combatting the disease would involve changes to human behaviour (e.g., wear proper protective clothing, self-inspecting after outdoor activities) in combination with vaccination. There is however uncertainty whether a vaccine would be cost-effective, save for specific risk groups.

Mosquitos as a disease vector

Climate change was, and is projected to be, a factor in the recent expansion of the Asian tiger mosquito (*Aedes albopictus*) and a sand-fly species in Europe, which can disseminate several diseases (dengue[1] and chikungunya by the Asian tiger mosquito and leishmaniasis by the sand-fly species).

The Institute for Tropical Medicine (ITG) in Antwerp monitors the prevalence of the tiger mosquito via the project "Monitoring of Exotic Mosquitoes in Belgium" (MEMO). The MEMO-project focusses on 23 import locations spread over Belgium ((second hand) tyre shops, garden centres, ports and airports). In 2019, adult tiger mosquitos were spotted in a garden centre that imports "lucky bamboo", and eggs and larvae were detected in three motorway parking areas[2]. This confirms the introduction of this exotic mosquito via motorways from regions in France and/or Germany where the species is established. Introduction of mosquitos seems to be mainly caused by international transport, and not by "autonomous" migration of species as a result of climate change.

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[1] The primary vector for Dengue is *Aedes aegypti* rather than *Aedes albopictus*. The spread of *A. aegypti* into (northern) Europe is much more limited by climatological characteristics than is the case for *A. albopictus*.

[2] https://www.itg.be/N/Artikel/in-2019-opnieuw-tijgermuggen-gespot-in-belgie

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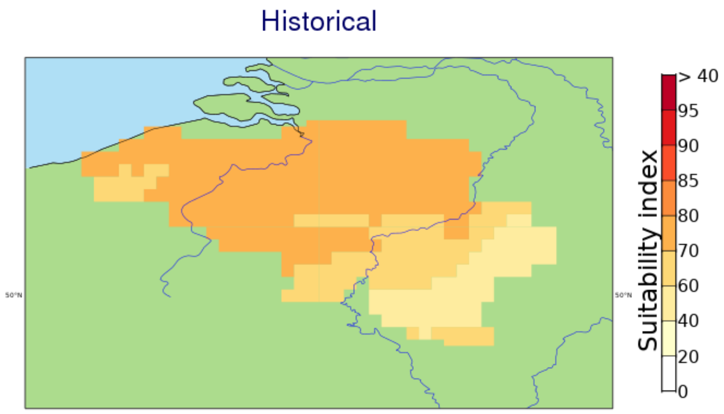

Figure 3-14. Suitability for the survival of Aedes albopictus (Tiger mosquito) for Belgium for the period 1976-2005. Source: Copernicus Climate Change Service & VITO, 'Climate projections of Asian tiger mosquito (Aedes albopictus) survival suitability for Europe[1].

The mosquito species has not yet survived winter in Belgium, although according to EEA (2017) the Belgian climate is suitable for establishment. Also, data contained in the Climate Data Store of the European Copernicus programme show a moderately high climatic suitability for the species (Figure 3-14). However, in urban environments, the urban heat island phenomenon strongly lifts the climate suitability for *Aedes albopictus*, as shown in Figure 3-15.

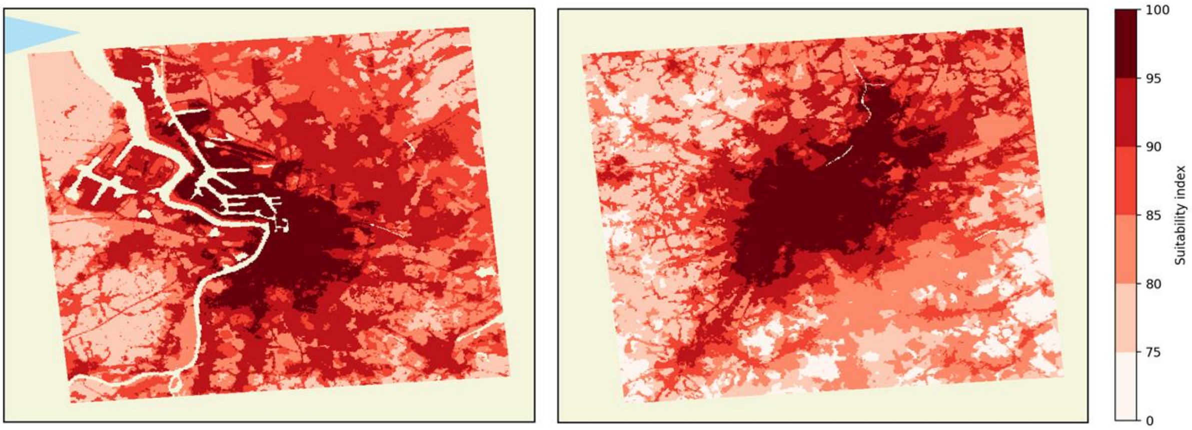

Figure 3-15. Suitability for the survival of Aedes albopictus (Tiger mosquito), as the average over the period 2008-2017, for Antwerp (left) and Brussels (right). Source: Copernicus Climate Change Service & VITO, 'Climatic suitability of the Aedes albopictus mosquito in European cities from 2008 to 2017[2].

As Medlock and Leach (2015) point out, not only climate change *per se*, but also the changes in land use brought about by climate change (e.g. adaptation measures such as provision of new wetlands or increased urban greenspace) can affect the risk of vector-borne disease, by increasing the available habitat for mosquitoes.

Disease cases that have been reported in Belgium can be attributed to infections abroad of travellers to Belgium, not by "autochthonous" infections starting from resident vector populations (which has occurred in France – where in 2018 the tiger mosquito was established in 51 départements[3]) with

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[1] https://cds.climate.copernicus.eu/cdsapp#!/software/app-health-aedes-albopictus-suitability-projections?tab=app

[2] https://cds.climate.copernicus.eu/cdsapp#!/software/app-health-urban-aedes-albopictus-suitability-climatology?tab=app

[3] https://solidarites-sante.gouv.fr/sante-et-environnement/risques-microbiologiques-physiques-et-chimiques/especes-nuisibles-et-parasites/article/cartes-de-presence-du-moustique-tigre-aedes-albopictus-en-france-metropolitaine

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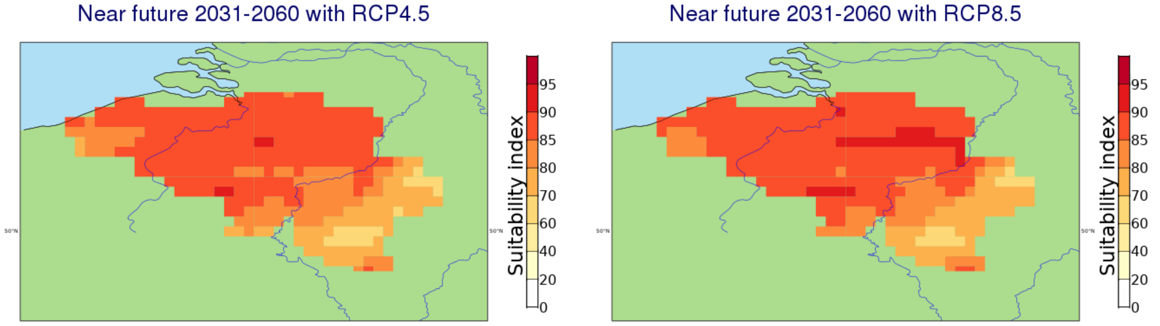
dengue and chikungunya, also see Dantec and Roux (2019) – so they are as yet not indicative of a climate change effect in Belgium. Where changes in reported cases do occur, this can for now be attributed to changes in travel frequency to certain regions and/or to changes in incidence in the regions where the disease is endemic. An example of the latter is the strong decrease in reported cases of chikungunya and zika in Belgium after the end of the epidemics of those diseases in Latin America and the Caribbean.

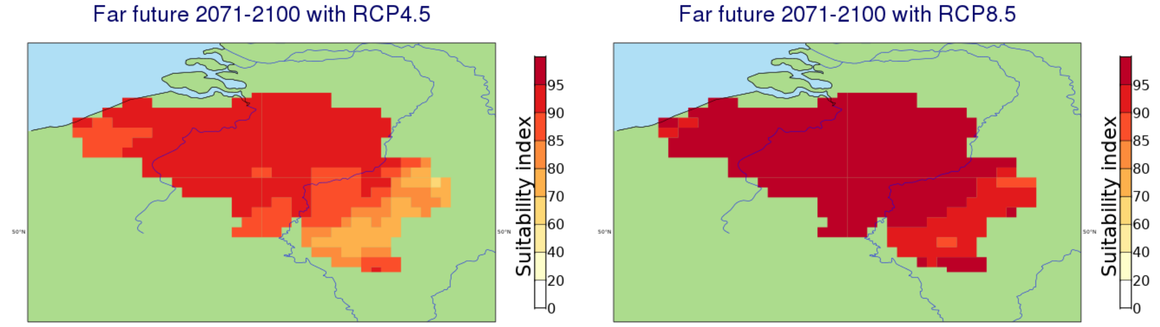
In 2018, the NRC (national reference centres) reported 3 cases of chikungunya and 101 cases of dengue. In all cases, it could be demonstrated that the patients were infected during travels abroad. The same goes for the reported cases of resp. leishmaniosis and malaria (note though that malaria is spread by the *Anopheles* mosquito, not the Asian tiger mosquito.)

Once carriers are present in Belgium, tropical diseases could theoretically be spread by "resident" populations of tropical mosquitos (if sufficiently abundant), and the establishment and survival of such populations could be facilitated by climate change.

While, as yet, the Asian tiger mosquito has not established itself in Belgium, permanent populations of other tropical mosquitos have already been reported. Scientists of the Institute of Tropical Medicine have found the Asian bush mosquito (*Aedes japonicus*) in Natoye (Hamois) and on the German border. In Natoye, mosquitoes have spread to a radius of 750 m around the local source population. Furthermore, *Aedes koreicus*, another exotic mosquito, still has an established population in Maasmechelen, but the control campaigns seem to be having an effect. Both *Aedes japonicus* and *Aedes koreicus* are less aggressive than *Aedes albopictus* and are not important transmitters of disease. As long as resident populations are small and contained, disease transmission within Belgium is unlikely in any case. The known populations are being actively targeted by pesticide treatment and elimination of breeding sites, and increase of the populations or dispersion outside the small area where they have been discovered has not occurred yet.


Near future 2031-2060 with RCP4.5

Near future 2031-2060 with RCP8.5


Far future 2071-2100 with RCP4.5

Far future 2071-2100 with RCP8.5

Figure 3-16. Projected suitability for the survival of Aedes albopictus in Belgium. Source: as in Figure 3-14.

It should be noted that some tropical diseases (notably the West-Nile virus) have acquired a foothold in Southern Europe. (A total of 1548 locally acquired cases were reported in the EU in 2018, about 90% from Italy, Romania, Greece and Hungary. This represents a sharp increase from the numbers reported in the period 2014-2017 (resp. 75, 122, 226 and 201 locally acquired cases). EFSA/ECDC, 2019). Since both the vectors and the animal hosts (poultry, wild birds) are present in Belgium, autochthonous

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infections cannot be excluded in the future. Symptoms range from a flu-like condition over the so-called West Nile Fever to more serious neurological conditions (encephalitis, meningitis, poliomyelitis). About 80% of infections do not result in any symptoms, 20% gets flu-like symptoms. About 1% of the latter can develop serious neurological conditions.

The two cases of West-Nile fever reported in 2018 in Belgium concerned persons infected in Serbia and Kosovo. Autochthonous cases of the disease in humans have not been reported so far. This may however change in the future. Different species of mosquito, mainly of the *Culex*-genus, can spread West Nile disease and are naturally present in North-Western Europe. Several studies confirmed that vector competence of European mosquitoes for West Nile virus increases with temperature. In the temperature range from 18 °C to 28 °C, transmission rates of northern European *Culex pipiens* increased from 0% to 33%. Thus, average northern European summer temperatures of 18°C appear to be an important limiting factor for West Nile virus transmission, and indeed temperature is likely the most important factor to explain why West Nile virus outbreaks have thus far been limited to southern and central Europe (Vogels et al., 2017). This situation may change as a result of higher temperatures due to climate change; in a situation of more frequent and prolonged temperature anomalies, there are no limiting factors for future West Nile virus circulation in northern Europe.

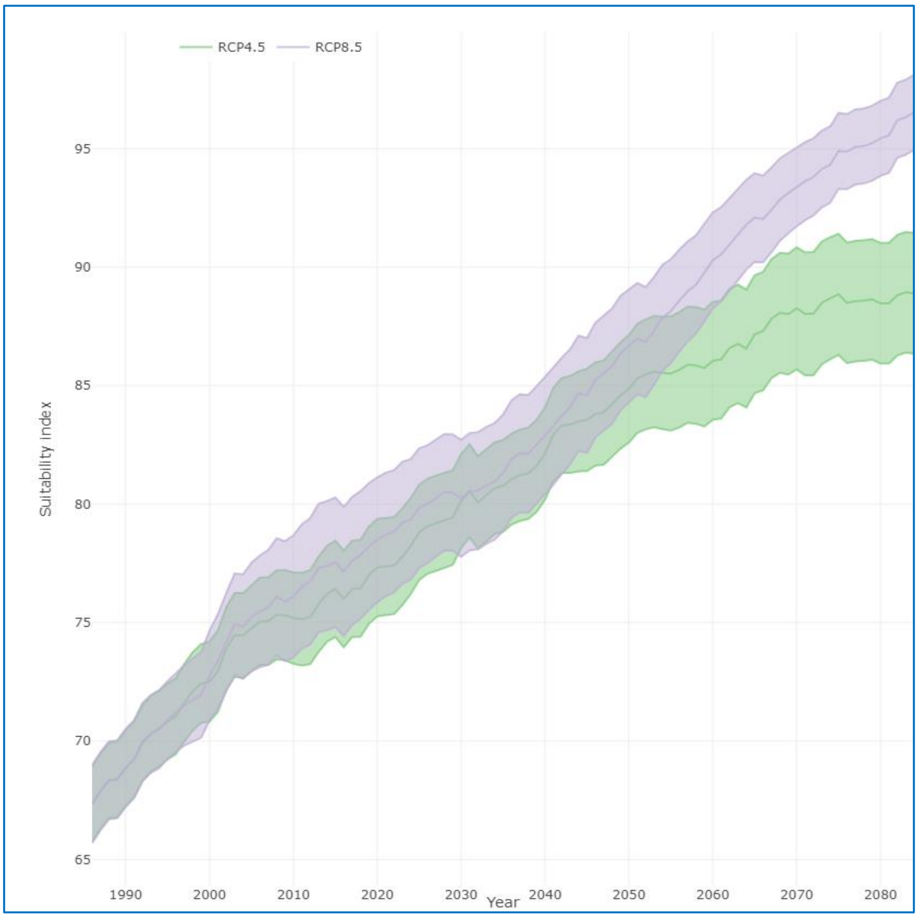

Figure 3-17. Evolution of the suitability for the survival of Aedes albopictus in Belgium for the present century. Source: as in Figure 3-14.

Concluding, so far, 100% of the observed cases in Belgium of the vector-related tropical diseases mentioned above have been attributed to infections caught abroad. Autochthonous infections have not occurred, as a result of a lack of vectors and/or the absence of the disease itself. In cases where (tropical) vectors are present, the populations have so far been contained and do not seem to present an immediate danger. The potentially most worrying disease appears to be West-Nile fever, as it is already present in southern Europe and as both vector and host populations have established in Belgium. Distribution models based on projected July temperatures under a medium emissions

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scenario (SRES A1B) do however not show an increase in the probability of West Nile virus infections in Belgium (EEA, 2017).

Generally speaking, climate change could worsen the situation, by facilitating both the spread of the diseases and the establishment of the (tropical) vectors needed to spread it. The climatic suitability for *Aedes albopictus* is projected to increase (Figure 3-16, Figure 3-17) as climate models project warmer and wetter climates.

Models of chikungunya transmission in Europe under climate change scenarios have suggested increases in the level of risk in much of western Europe, including the Benelux countries. A climate-related increase in the density or active season of *Aedes albopictus* could also lead to a small increase in the risk of dengue in Europe. Some malaria models suggest that there will be increased suitability for malaria transmission in continental Europe under future climate change, but land-use and public health control measures would most likely be sufficient to mitigate the risk of malaria at the fringes of its distribution (EEA, 2017).

One would expect that as a result of the available scientific expertise on tropical diseases in Belgium and of the well-functioning health care system, epidemical situations in the near future are not very likely to occur. However, rigorous monitoring of the diseases and monitoring of and combatting the vectors is a prerequisite for this outcome, and continued support for those activities is thus of prime importance.

3.1.4. Temperature effect on allergies

There is considerable evidence to suggest that climate change will have, and already has, impacts on aeroallergens, i.e., airborne allergens such as pollen or spores, which trigger an allergic reaction. There is also some evidence of impacts on other aeroallergens than pollen, such as mould spores. Health effects that may increase are allergic rhinitis and asthmatic symptoms (Brits, 2010).

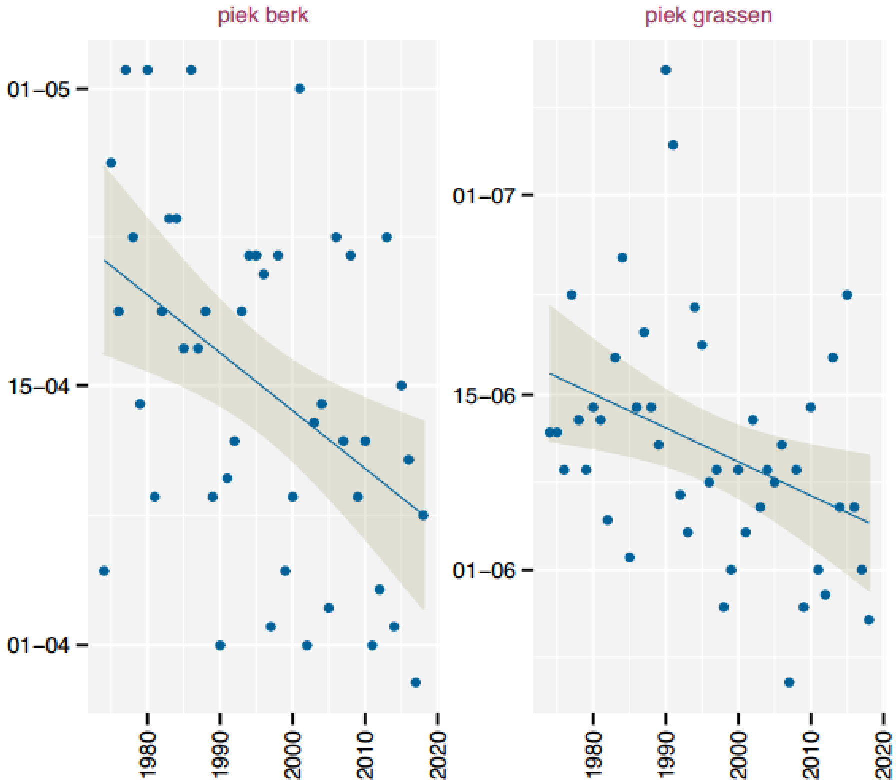

Figure 3-18. Evolution of the annual pollen peak of birch (left) and grass (right). The vertical axis shows the date within a given year, and the blue line shows the trend and the grey areas represent uncertainty. Source: Vriens et al. (2019).

It is expected that climate change may induce an increase in airborne pollen, an increase of the allergen potency of pollen grains, and variations in the pollen season timing, with an earlier onset and a longer duration (Buffaerts et al., 2018). For instance, in 2020 the pollen season for alder and hazel trees started around mid-January, i.e., two weeks earlier than usual, which can be attributed to mild temperatures in the preceding months[1].

Available data do indicate that recent changes in maximum or minimum temperatures, or both, in association with anthropogenic climate change, are significantly correlated with both increasing airborne pollen loads and longer pollen seasonality across the northern hemisphere. This highlights the importance of future temperature increases on health impacts related to pollinosis, such as rhinitis and allergic asthma (Ziska et al., 2019). The analysis by Ziska et al. (2019), based on data from 17 pollen collection stations in the northern hemisphere, illustrates a clear positive correlation between recent global warming and an increase in the seasonal duration and amount of pollen for multiple allergenic plant species on a decadal basis. The lengthening of pollen seasons is related both to earlier springs (i.e, last spring frost occurring earlier) as well as later autumns (delay in the occurrence of the first autumn frost). Data indicate that recent climatic changes, through temperature, are in fact already affecting pollen amounts as well as season duration and timing in the northern hemisphere. These observed changes have immediate and future health implications, particularly for allergic diseases. Future climate projections also suggest changes in the duration of the pollen season (e.g., start date, maximum season duration, and end date) and an estimated doubling in sensitization to allergenic plants such as ragweed (*Ambrosia*). For the Brussels data, the analysis by Ziska et al. (2019) suggests a statistically significant average change of the seasonal cumulative pollen load of 2.8% per year as well as a statistically significant change in the duration of the pollen season of 0.78 days/year, on average. Figure 3-18 clearly shows this trend for birch and grasses and Figure 3-19 independently shows a similar trend for birch.

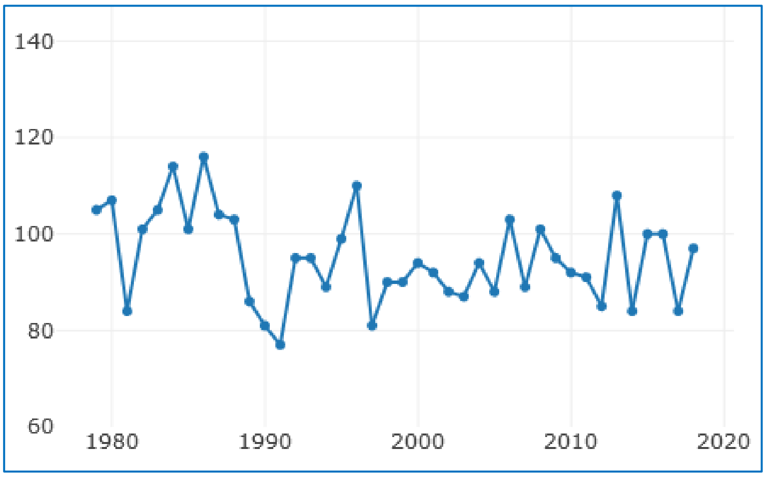

Figure 3-19. Annual fluctuation for recent decades of the day within the year (vertical axis) when the pollen season for birch starts in Belgium. Source: data from the Copernicus Climate Data Store ('European Health'), start of season calculated according to the method of solomon et al. (2013).

The date on which peak concentration for birch and grass pollen occurs shows important fluctuations from year to year, but over a longer period the trend is unmistakable. In the period 1975-1985 the peak for birch was around April 21, whereas in the period 1995-2018 it was on average a week earlier. The same phenomenon can be observed for grasses, with a peak around June 7 for the period 1997-2018, i.e. more than a week earlier than in the period 1975-1995. At the same time, an increase in the daily concentration of different species of trees and grasses has been observed. In the Netherlands, RIVM (2014) has calculated that by 2050 the season for birch resp. grass pollen could start on average 9 resp. 10 days earlier than in the reference period 1981-2010.

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[1] https://airallergy.sciensano.be/nl/content/brussel

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In the earlier mentioned study by Bruffaerts et al. (2018), based on data from Brussels (1982-2015), an overall trend of increase in daily airborne tree pollen (except for the European beech tree) was revealed as well as an overall trend of decrease in daily airborne pollen from herbaceous plants (except for Urticaceae) and an earlier onset of the flowering period for birch, oak, ash, plane, grasses, and Urticaceae. The rates of change in pollen annual cycles were shown to be associated with the rates of change in the annual cycles of several meteorological parameters such as temperature, radiation, humidity, and rainfall (although factors as plant physiology and phenology, land cover, among other, also play an important role). Moreover, pollen concentrations of several taxa were shown to have increased during the start of each specific season. Note that in Bruffaerts et al. (2018) pollen concentration trends were associated with the overall increasing trend of temperature and radiation, but inversely associated with the fluctuating trends of relative humidity and rainfall.

Moreover, higher temperatures as well as higher concentrations in carbon dioxide seem to have an impact, at least for some species, not only on the amount of pollen produced, but also on the allergy inducing properties of the pollen.

Climate change may also have an impact on allergies by its effect on the spread of invasive exotic plant species, such as ragweed (*Ambrosia* spp., and specifically *Ambrosia artemisiifolia*), and this effect may be more important than changes in the pollen season of endemic vegetation. (Ragweed is spread by human activities (transport), but climate change can be a facilitating factor for establishment in new environments. ICEDD (2014) cites a northward expansion of 200 km for each degree increase in the average annual temperature for plants.)

Ambrosia causes severe allergic reactions in sensitive persons, and the fact that it blooms in September and October lengthens the overall allergy season with two months[1] . The pollen load map of Europe[2], based on measurements of the last 10-15 years, shows the presence of *Ambrosia* pollen in the southern half of France and in south-eastern Europe, but not yet in Belgium, although the species is sporadically present. The Atopica[3] research project estimated that by 2050 airborne ragweed pollen concentrations could be about four times higher than they are now. Roughly two-thirds of this increase would be related to climate and land-use changes that will extend ragweed habitat suitability in northern and eastern Europe and increase pollen production in established ragweed areas (Hamaoui-Laguel et al., 2015).

The effect of an increase in length or severity of the pollen season on the incidence of allergic rhinitis or asthma has not yet been studied for Belgium or for comparable countries. Estimates of the proportion of the population that is allergic to pollen are available, but time series of this proportion are not. This is understandable as allergic rhinitis is often self-treated, so data from general practitioners and hospitals are incomplete.

A link between climate change and the prevalence of pollen-related ailments is likely, but other factors such as air pollution, moderating factors and adaptation measure may also play a role. Increase in the average age of the population may to a certain extent counterbalance other factors, as susceptibility to allergic reactions tends to diminish with age.

RIVM (2016) cites data from an unpublished study that suggests that the cost for treatment of allergic rhinitis in the Netherlands could by 2050 increase to 13,400 €/1000 patients compared to 6,200 € in 2008. A large proportion of this difference would be due to the spread of *Ambrosia* and other new allergenic plant species. Indirect costs such as loss in labour productivity could however be several times as high as the treatment costs.

RIVM assesses both the impact and the potential frequency of occurrence of climate change on health effects by allergens as ‘high’, given the proportion of the population that is affected by allergies and the probable increase in duration and intensity in the pollen season – but assesses the knowledge base

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[1] https://nl.wikipedia.org/wiki/Alsemambrosia

[2] available at https://www.polleninfo.org/country-choose.html

[3] https://www.atopica.eu/

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underpinning those statements as ‘low’.

3.1.5. *Temperature effect on food spoilage*

There is a direct causal link between climate change (notably higher temperatures), and the potential increase in food-related infections. The development of *Salmonella*, notably, is clearly influenced by temperature. ICEDD (2014) cites an increase in reported salmonellosis frequency of 4 to 10% for each increase of the mean monthly temperature with one degree above a threshold of 5°C (D’Sousa et al. 2004). However, the latter is based on data for Australian cities, thus conclusions should be handled with caution. Moreover, the authors acknowledge that ‘is not clear that a relationship between short-term fluctuations in temperature and disease rates implies an increase in disease rate when average temperature increases gradually over a long time period’. Interestingly, in D’Sousa et al. (2004) closest fits were found with the temperature of the month preceding the case reporting. To the authors, this suggests that temperature might be more influential earlier in the production process rather than at the food preparation stage.

Seasonal temperatures have been linked to salmonellosis cases, but public health interventions can attenuate the effect of warmer temperature. The development of *Listeria*, on the other hand, does not seem to be influenced by higher temperatures.

The *Salmonella* bacteria is transmitted to humans orally: mainly by ingesting foodstuffs that come from contaminated animals which are consumed raw or undercooked (meat, eggs, raw egg products). Salmonellosis arises more frequently in summer, during the party and barbecue season when foods are kept at ambient temperature for a long time, which promotes the development of bacteria. Foods typically at risk are poultry, preparations made from raw eggs, pork meat and dairy products. Contrary to most other member states, the notification of non-typhoidal salmonellosis in humans is not mandatory in Belgium (EFSA/ECDC, 2019).

RIVM (2016) states that, due to the relatively good level of food hygiene, risks for the Netherlands are probably limited. It can be assumed that the same goes for Belgium; as long as proper precautions (such as cooling, high turnover etc.) are taken both at consumer level and at the level of the production and procession facilities risks will be limited. Higher temperatures and longer warm periods will of course increase the pressure on systems that have to ensure food safety. Still, the ‘weak link’ in the chain is probably the household rather than the producers or processors of the food, who have to adhere to strict quality norms and are subjected to controls. If climate change were to result in an extreme decline in the reliability of energy provision, cooling installations (at all levels) might however be compromised.

In Belgium, 2,958 cases of salmonellosis, or about 26 cases per 100,0000 inhabitants, were reported in 2018 (EFSA/ECDC, 2019); 554 of those cases could be attributed to 3 separate food-borne outbreaks, the remainder being ‘sporadic’ cases. Figures on case rates (i.e. number of cases per 100,000 inhabitants, per year) for 2014-2017 are of the same order of magnitude as for 2018 (between 20.2 and 27.1). Those figures represent an important decline compared to the period before 2004; e.g., in the 1991-2000 period, on average between 10,000 and 15,000 cases were reported each year (ICEDD, 2014). The decline can, among other, be attributed to obligatory vaccination of egg-laying hens beginning in 2005. On a European level, the previous decreasing trend has stabilized in the last 5 years.

Figure 3-20 shows salmonellosis data (counts per week) from 2011 to 2018; no trend emerges. The case rate is higher in the provinces of West and East Flanders, which may have to do with culinary habits (consumption of raw eggs and raw meat).

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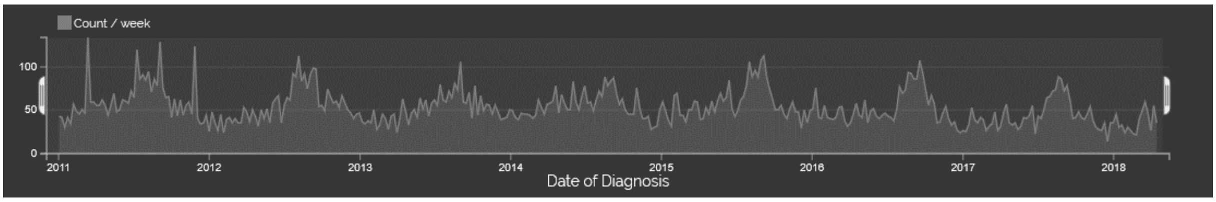

Figure 3-20. Number of salmonellosis cases diagnosed per week in the period 2011-2018. Source: National Reference Centres, see https://epistat.wiv-isp.be/dashboard/.

At the European level, there have been a number of studies on climate and food-borne disease, notably salmonellosis. Kovats et al. (2011) estimated welfare costs of €68 to €89 million/year (in the 2050s and 2080s respectively) falling to €46 to €49 million/year if a decline in incidence (due to better regulation) was included. The IMPACT2C study (COACCH, 2018) estimated resource costs for additional hospital admissions and additional cases of salmonellosis and campylobacteriosis at around €700 million in 2041–2070 period for the A1B scenario and around €650 million in the E1 scenario.

The cost figures cited above were based on an estimate of (max.) 13,030 resp. 16,915 additional cases in 2050 resp. 2080 at EU-level. Other studies state that under a high emissions scenario, climate change could result in up to 50% more temperature-related cases by the end of the 21st century than would be expected on the basis of population change alone. However, these estimates are associated with high uncertainty (Watkiss and Hunt, 2012). Moreover, health promotion and food safety policies can mitigate adverse impacts on public health.

ICEDD (2014) uses the proportion of *Salmonella* cases in Wallonia to the European figures as a means to estimate the additional number for Wallonia. Using the same principle and based on 2018 figures (with Belgium representing about 3% of all *Salmonella* cases in the EU), extra cases in Belgium in 2050 resp. 2080 can be estimated to be of the order of 409 resp. 531 additional cases, which represents an increase of about 14% resp. 18% compared to 2018. ICEDD (2014) cites a treatment cost for salmonellosis of on average 5250 € per case.

3.1.6. Water-borne diseases

Water-borne illnesses are caused by agents entering the body through ingestion of water (drinking, recreational or coastal water). Pathogens that are transmitted via water may be susceptible to changes in persistence, survival, replication and transmission due to climate change phenomena such as temperature increase, precipitation, extreme weather events and season's length. Brits et al. (2010) mention *E. coli* infection, Campylobacteriosis, Cryptosporidiosis, Shugellosis, Giardiases, Yersiniosis, Amoebiasis, Cholera and Legionellosis as water-borne diseases that may be influenced by climate factors. Not all of those are relevant to the Belgian situation. It should also be noted that a temperature dependence (such as is the case with Legionellosis) does not necessary mean that climate change would influence the prevalence of the disease (EEA, 2017).

Broadly speaking, climate change can have an impact on the prevalence of water-borne diseases in several ways:

1. Higher water temperatures in surface water bodies can lead to an increased development of some organisms linked to disease (e.g. Vibrio) or the appearance of new disease-causing organisms. Intense precipitation events can also lead to the contamination of surface water bodies with disease-causing agents that are present in sewage (e.g. Norovirus). People coming into contact with contaminated water during recreational of professional activities might run a higher risk of being infected. The infection of seafood (bivalves) living in the infected water and contamination of food via polluted irrigation water from other potential pathways for diseases with a relation to climate change.
2. People may come into contact with surface water when inundations of their living or working environment occur. If this inundation water is polluted, increased disease prevalence can be the result.

3. People may come into contact with polluted water as a result of sewer overflows into the streets during episodes of high-intensity rainfall, or overflow of small waterways in which the sewers discharge, in normal and/or peak discharge conditions.

If higher temperatures and lower water levels in surface water bodies that are being used as a source for domestic water production would lead to an increased disease risk in the ‘raw’ water, the distributed water might also be a carrier of disease-causing organism. In Belgium, this appears however to be unlikely given the stringent water quality criteria and the state-of-the-art techniques being used by the public drinking water companies.

The main organisms and corresponding diseases that may be spread by one or more of the pathways described above are discussed below (based on EEA, 2017; EFSA/ECDC , 2019; and Epistat data, 2020), with a focus on the probability that climate change may result in an increase in disease incidence.

Brackish water and elevated ambient temperature are ideal environmental growth conditions for certain ***Vibrio* species**, that can cause food-borne outbreaks (seafood) as well as wound infections, septicaemia and cholera, in susceptible individuals exposed during bathing in contaminated marine environments. Suitable conditions can be found during the summer months in estuaries and enclosed water bodies with moderate salinity, such as the Baltic Sea. Elevated levels of non-cholera *Vibrio* species infections have been observed during extended hot summer seasons with water temperatures above 20°C in the Baltic Sea and the North Sea (Hemmer et al., 2007; Baker-Austin et al., 2012; Sterk et al., 2015). The number of suitable days per year in the Baltic for pathogenic *Vibrio* transmission reached 107 in 2018, the highest since records began, and two times higher than the early 1980s baseline. The percentage of coastal area suitable for *Vibrio* infections from 2010 has increased at northern latitudes (40–70° N) by 3.8%, compared with the 1980s baseline, with 2018 the second most suitable year on record (5% above the baseline). The area of coastline suitable for Vibrio has increased by 31% in the Baltic. Environmentally acquired *Vibrio*-infections in humans associated with particularly high sea surface temperatures have also been reported along the North Sea coast of Europe in recent years (Vezzulli et al., 2016). Increased numbers of infections can be expected based on the effects of increased temperatures under climate change scenarios. It should be noted however that most of the figures given above are not based on case data. Control efforts, such as water, sanitation and hygiene programs, and vector control efforts, may help to mitigate these effects.

Cryptosporidiosis is an acute diarrheal disease caused by intracellular protozoan parasites. The most commonly identified vehicles are contaminated drinking water and contaminated recreational water. For example, several days of heavy rain in June 2013 resulted in river flooding in eastern Germany, and activities in the dried-out floodplain led to infection among children (Gertler et al., 2015). Heavy rainfall has also been associated with the contamination of water supplies and outbreaks of cryptosporidiosis (Aksoy et al., 2007; Hoek et al., 2008), as the concentration of *Cryptosporidium*-oocysts in river water increases significantly during rainfall events. Dry weather conditions preceding a heavy rain event have also been associated with drinking water outbreaks (Nichols et al., 2009). Observed *Cryptosporidium* cases in Belgium (Figure 3-21) show high values in the summer and early spring of 2016 and 2017, but it is not clear whether those peaks were weather-related.

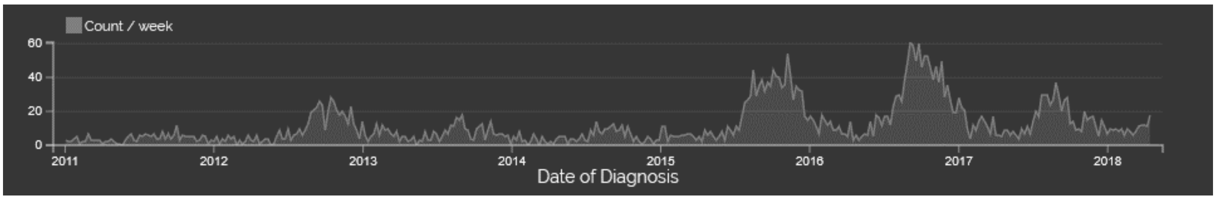

Figure 3-21. Number of Cryptosporidium cases per week in Belgium. Source: sentinel laboratory network (Epilabo), see https://epistat.wiv-isp.be/dashboard/.

In Europe, **campylobacteriosis** is the most common bacterial cause of diarrheal disease. The association of campylobacteriosis with a number of weather-related factors, such as temperature, rainfall, humidity and sunshine, is inconsistent and lacks a clear explanatory mechanism, as

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Campylobacter does not replicate outside its animal host. There is a clear seasonality to the data in a number of European countries, with more cases during the summer months. Rain in early spring can trigger campylobacteriosis outbreaks (Louis et al., 2005). With the projected increase in heavy rainfall events in northern Europe, the risk of surface and groundwater contamination is expected to rise. Observed *Campylobacter* cases in Belgium do not seem to exhibit a trend over the period 2011-2018 (Figure 3-22).

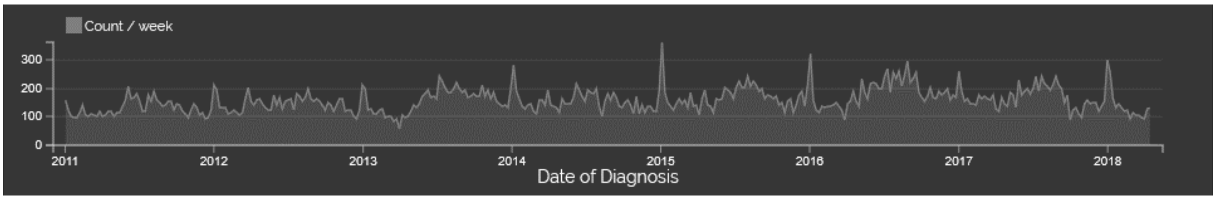

Figure 3-22. Number of Campylobacter cases per week in Belgium. Source: sentinel laboratory network (Epilabo), see https://epistat.wiv-isp.be/dashboard/.

Norovirus is the most common cause of viral diarrhoea in humans with a pronounced winter seasonality. Heavy rainfall and floods may lead to wastewater overflow which can contaminate shellfish farming sites. Flood water has been associated with a norovirus outbreak in Austria (Schmid et al., 2005). In Europe, norovirus season strength was positively associated with average rainfall in the wettest month (Ahmed et al., 2013). Water-borne transmission of the virus is probably influenced by rainfall, causing norovirus seasonality (Marshall and Bruggink, 2011). The magnitude of rainfall has also been related to viral contamination of the marine environment and with peaks in diarrhoea incidence (Miossec et al., 2000). The predicted increase of heavy rainfall events under climate change scenarios could lead to an increase in norovirus infections because floods are known to be linked to norovirus outbreaks.

3.1.7. Health impact of inundations and extreme weather

Flooding

Flooding can affect human health through drowning, heart attacks, injuries, infections, exposure to chemical hazards and mental health consequences. Disruption of services, including of health services, safe water, sanitation and transportation infrastructure can play a major role in vulnerability. The vulnerability to flooding of institutions such as day care centres, homes for the elderly and hospitals is of particular concern.

Health impacts caused by infections during or after flood events have been discussed under the heading 'Water borne diseases' (see Section 3.1.5) and thus will not be treated here. The risk from infectious diseases due to flooding is in any case relatively small in Europe and certainly in Belgium, due to a functioning public health infrastructure, including water treatment and sanitation.

For a medium emissions scenario (SRES A1B) and in the absence of adaptation, *river flooding* has been estimated to affect about 300,000 people per year in the EU by the 2050's, and 390,000 people by the 2080's; the latter figure corresponds to more than a doubling with respect to the baseline period (1961–1990). The British Isles, western Europe and northern Italy show a robust increase in future flood hazards; these regions also show the greatest increase in the population affected by river floods (EEA, 2017). Forzieri et al. (2017) estimate an additional number of deaths of about 106 per year in the period 2071-2100, which represent an increase of about 54% compared to the reference period (1981-2010). In terms of people exposed, they expect an increase of about 105% over the same time span, which is comparable to the relative increase reported in EEA (2017).

If no additional adaptation measures were taken, the number of people affected by *coastal flooding* in the EU at the end of the 21st century would range, according to EEA (2017), from 775,000 to 5.5 million people annually, depending on the emissions scenario. The number of deaths in the EU due to coastal flooding in the 2080's would increase by 3000, 620 and 150 per year under a high emissions

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scenario (assuming 88 cm sea level rise), the SRES A1B 'business as usual' scenario and the E1 mitigation scenario, respectively (EEA, 2017). Two-thirds of these deaths would occur in western Europe. Forzieri et al. (2017) estimate a total of 233 deaths per year (for Europe as a whole) associated with coastal flooding (period 2071–100) compared to only six fatalities per year during the reference period (1981-2010). Coastal adaptation measures (dikes and beach nourishment) could significantly reduce risks to less than 10 deaths per year in 2080 (Ciscar et al., 2011; Kovats et al., 2011).

According to the European Flood directive[1], member states have to report on flood hazard and flood risk and must publish corresponding and publicly available maps. These maps identify areas with a high, medium and low likelihood of flooding and indicate expected water depths. ('Medium' being defined as an event with a probability of occurrence of 1/100. The low and high likelihoods have no corresponding probability in the Directive.) In the areas identified as being at risk the number of inhabitants potentially at risk, the economic activity and the environmental damage potential have to be indicated.

It should be noted that the hazard and risk maps discussed here give probabilities based on the present climate conditions. Equivalent maps that take into account climate change are not available in all cases. Maps with low probability (i.e., events that are rare presently) can be interpreted as representing conditions that under more or less severe conditions of climate change would occur more often, under the assumption that climate change will enhance the inundation probabilities and risks. For instance, in the Walloon Region, the so-called "extreme" (low probability) scenario is explicitly considered as representing the potential 100-year return period scenario at a 2050 horizon, including the effects of climate change[2].

In Belgium, each of the three regions has developed its own web-based portal where the maps prepared according to the Floods Directive can be consulted[3]. All portals show the information required by the directive. In Flanders, data layers with estimates of the expected maximum damage (in €/m²), the expected economic damage (€/m²) for high, medium and low probability as well as the aggregated economic risk (€/m²/year) are also available, although they cannot be directly visualized in the mapping tool of the portal. The Flemish region has also developed a 'Climate Portal[4]' that, among other climate change-related data, contains information on the extent (hazard) and impact (risk), explicitly accounting for climate change.

Integrated information on flood hazard and flood risks is not available at the level of Belgium; instead, it has to be collected by consulting information for the different regions and for the different river basins within those regions. The calculation of the total floodable area in Belgium based on the different sources is shown in Table 3-2.

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[1] https://ec.europa.eu/environment/water/flood_risk/implem.htm

[2] https://ec.europa.eu/environment/water/flood_risk/pdf/fhrm_reports/BE%20FHRM%20Report.pdf

[3] www.waterinfo.be (Flemish region), geoapps.wallonie.be/inondations (Walloon region) and https://environnement.brussels/thematiques/eau/leau-bruxelles/eau-de-pluie-et-inondation/cartes-relatives-aux-inondations-pour-la (Brussels region).

[4] https://klimaat.vmm.be/

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Table 3-2. Estimated total floodable area and number of potentially affected people in the occurrence of an inundation with a 100-year return period (T100) for the different river basins in Belgium. Even though the Rhine and Seine rivers are not located in Belgium, they do have portions of their basins within the country as certain rivers in the Walloon region flow towards both.

Hydrographic unit (sub basin)	Floodable area (ha)	Potentially affected population at T100
Scheldt (Flanders)	98,551	70,000
Meuse (Flanders)	4,060	942
Pluvial flooding (Flanders)	66,000	N/A
Scheldt (Wallonia)	49,410	79,581
Meuse (Wallonia)	103,840	124,622
Rhine (Wallonia)	6,720	2,626
Seine (Wallonia)	710	68
Scheldt (Brussels)	3,373	72,540
TOTAL (Belgium)	332,664	350,379

According to this information, the total floodable area in Belgium is of the order of 333,000 ha, or about 11% of the total area. Note that the area affected by pluvial inundations in Flanders is not available in the basin management plans, but has been calculated separately. A figure for the population potentially affected by pluvial flooding is as yet not available.

It should also be noted that there are notable differences in the methods and definitions used in the different regions. For instance, the definition of a flood with low probability is not the same in the Flemish and Walloon Regions: in Flanders, it is defined as an inundation with a probability of 1/1000; in Wallonia as the flood caused by a river discharge equivalent to a discharge with a probability of 1/100, augmented by 30%.

As such, the figures for the different regions are not readily comparable, and the summation of the different figures yields an order of magnitude rather than an exact figure.

Figures for the potentially affected population are given in Table 3-2. As the definitions of low, high and extreme probability differ between the regions, the figures given are only for a 1/100-year probability (which is the only one calculated for each region). The resolution used in reporting population data is not the same in the different regions. In Flanders, population affected is reported at municipal level, or, for larger municipalities, at sub-municipal level. In Wallonia, more than 6000 water course segments are used as a reporting basis. For the total figures, this does of course not make a difference. Overall, some 350,000 persons can be potentially affected by a flood with a 1/100 chance of occurrence; this is about 3% of the Belgian population.

It should also be noted that information about the potentially affected population is based on the number of inhabitants within the zones that are prone to be flooded at a given probability; as such it does not provide information on the nature of the consequences (injuries, disease, death, mental health problems, …) nor does it take into account coping mechanisms and adaptation measures that might lower the number of people that are affected in practice by the flooding. The same goes for information about potentially affected vulnerable objects such as day care centres, hospitals, homes for the elderly, … (see Flemish Climate Portal data below). Forzieri et al. (2017) give figures for both people exposed and corresponding deaths, for different hazards. For Belgium, they estimated (for a business-as-usual scenario of greenhouse gas emissions (SRES A1B)) between 0 and 2 deaths per year associated with river flooding in the period 2071-2100. In the same period, between 6,000 and 35,000 persons would be exposed to river flooding every year.

There is little information available on the nature of the impacts that persons at risk must undergo in case of inundations. Deaths as a result of floods are rare in Belgium, but this could become more important for floods with lower probabilities and/or as the climate changes. Fatalities are likely to be more important in the case of inundations caused by the sea than those caused by river flooding, as both inundation depth and duration are likely to be higher in the former case. Injuries and diseases caused by floods can be very diverse, and no information is available as to the relative importance of each. Flooding is also associated with mental health impacts, and coastal flooding in the EU could potentially cause five million additional cases of mild depression annually by the end of the 21st century, under a high sea level rise scenario, and in the absence of adaptation (EEA, 2017).

As mentioned before, the figures regarding the floodable area and the potentially affected population given in Table 3-2 do not explicitly account for climate change. The Climate Portal developed by the Flemish region (see above) does however take climate change into account in its assessment of the impacts of flooding. It does so for a so-called high-impact scenario[1] in the year 2100. The real impacts in the year 2100 are expected to be situated somewhere between the present situation and the situation represented by the high impact-scenario, depending on the future evolution of greenhouse gas emissions and of adaptation measures taken[2].

According to the data presented in the Climate Portal, the floodable area in Flanders (under a high impact scenario in 2100) would increase with 77%, resulting in an additional 130,000 ha that would become floodable (not including coastal flooding as result of sea level rise). Note that the ‘floodable area’ does not only include fluvial but also pluvial floods. Despite the more limited area, inundations of pluvial origin affect 5 to 10 more buildings than inundations of fluvial origin, as the former are the predominant cause of inundations in urbanised areas).

According to the data in the Flemish Climate Portal, the average inundation probability in Flanders would increase 5 to 10-fold, an inundation with an annual probability of 1/100 under present conditions having a probability of 1/10 in 2100, and a 1/10 inundation today happening on average every two years in 2100. Average water levels during inundations with a 1/1000 annual probability would increase by 22 cm on average, but the increase could be as high as 120 cm in certain areas. The proportion of vulnerable institutions (day care centres, hospitals, homes for the elderly, schools, ...) affected by ‘dangerous’ flooding (i.e., flooding depth exceeding 70 cm, which is expected to result in acute health impacts and possibly deaths) would more than double, from 7.3% under present conditions to 15.7% in 2100 (Table 3-3). In certain urban areas, the proportion could be as high as 40%. It should be noted that those figures are based on the actual position of the institutions transposed to 2100, and thus do not account for any form of adaptation.

For flooding as the result of sea level rise, the proportion of vulnerable institutions affected by dangerous flooding would increase from 9% under present conditions to 24% under a high impact scenario in 2115 (corresponding to a sea level rise of 100 cm), see (Table 3-3). In Ostend, this would mean an increase from 20 to more than 80 vulnerable institutions that would be affected by floods of 70 cm or higher. Note that of the 2760 vulnerable institutions affected in 2100 by fluvial and pluvial

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[1] This scenario corresponds to the upper limit of the 95% confidence interval of the available climate model results relevant for Flanders (except for sea level rise, where a rise of 80 cm by the year 2100 has been taken into account, in accordance with the Flemish Coast safety Plan). The explanatory text of the Climate Portal states that this high-impact scenario ‘corresponds to the internationally used RCP 8.5 scenario’, that results in an average global temperature change of between 3.2°C and 5.4°C in the year 2100. The results can thus be considered as worst case.

[2] According to the explanatory text to the portal, impacts for other levels of temperature change than those corresponding to the high impact scenario can be estimated by considering the impacts in a given year prior to 2100 as a proxy for the impacts in 2100 at lower levels of temperature change. For instance, the impacts for the high-impact scenario in 2030 can be considered as being equivalent to the impact of a 1.5°C temperature increase in 2100. For inundations, however, only figures for 2100 are at present available in the portal.

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inundations, 377 would be in Antwerp alone, and another 151 in Ghent. Forzieri et al. (2017) give an estimate of one fatality/year associated with coastal flooding in the period 2071-2100 (for the SRES A1B-scenario).

Table 3-3. Number of vulnerable institutions in Flanders affected by inundations exceeding 70 cm depth. Source: based on data contained in the Flemish Climate Portal.

Nature of inundations	Climate scenario	# vulnerable institutions affected by inundations of 70 cm or more
Fluvial and pluvial	Present conditions	1320
	High impact 2100	2760
Caused by the sea	Present conditions	80
	1/1000 storm in 2115	207

Estimates comparable to the ones described above have not been made for the Walloon or Brussels regions. However, as indicated in the primary risk evaluation of the Walloon region, climate change has been taken into account by the choice of the ‘extreme’ (low probability) scenario (SPW, 2018). This scenario works with river discharges in 2100 that are 30% higher than the 100-year floods without climate change; the difference being considered as the additional impact of climate change on the 100-year flood. This is based on the results of the project ‘Adaptation de la Meuse aux Impacts des Evolutions du Climat’ (AMICE) that found that 100-year floods in the Meuse river basin in the period 2071-2100 would, as a result of climate change, be 30% higher than in the reference period 1961-1990. Yet, those results are not universally applicable in reality. A similar study from 2017 for (sub)tributaries of the Scheldt river (Zenne and Dender) found that the increase in centennial discharge in those rivers under the influence of climate change would be of the order of 100% instead of 30% (SPW, 2018).

The calculations performed in the framework of the reporting of the Floods Directive indicate that, compared to the 1/100 year-scenario without climate change, the Walloon ‘extreme’ scenario (being representative for the effect of climate change) would result in 50,000 additional hectares being inundated under a 1/100 scenario. This would represent an increase of 50% of the total area inundated by a ‘normal’ 100-year flood compared to a 100-year flood under conditions of climate change. Those figures (both in absolute and relative terms) are somewhat lower than the corresponding figures for Flanders given above. This could at least partly be explained by the different topography in both regions, but the figures are hard to compare in any case, as the increase in Flanders is expressed compared to a 1000-year storm and the increase in Wallonia compares to a 100-year storm.

On the basis of the different flood risk management plans for the Walloon region an estimate can also be obtained of the additional number of people affected due to climate change, by calculating the difference between the T100 scenario and the ‘extreme’ scenario. The data are summarized in Table 3-4. According to those figures, climate change would cause almost 380,000 additional people to be affected by inundations in case of a 1/100 flood, which would mean and increase of 183%. This appears a lot, especially when compared to the increase in flooded area, that is only 50%. However, the fact that more severe floods would probably affect relatively more urban areas could at least partially account for this fact.

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Table 3-4. Potentially affected population at the 100-year inundation (T100) in the Walloon Region.

Hydrographic unit (sub basin)	**Potentially affected population at T100**		
	without climate change	with climate change (extreme scenario)	extra due to climate change
Scheldt (Wallonia)	79,581	184,238	104,657
Meuse (Wallonia)	124,622	396,426	271,804
Rhine (Wallonia)	2,626	5,188	2,562
Seine (Wallonia)	68	136	68
TOTAL (Wallonia)	206,897	585,988	379,091

The flood-related information (in terms of e.g. number of people affected) in the Water Management Plan 2016-2021 of the Brussels Capital Region (Bruxelles Environnement, 2017) does not specifically take into account climate change but, according to the Plan, the measures proposed would account for the future effects of climate change.

Extreme weather

Floods are caused by extreme weather, but extreme weather, induced or becoming more probable as a result of climate change, can have other impacts with potential health consequences. Examples of such phenomena are heatwaves, extreme precipitation, hail, windstorms, landslides and forest fires. Those phenomena, which are not all equally relevant to the Belgian situation, can result in injuries or death, either directly (e.g., injuries due to falling branches during storm conditions), or through their impact on, for instance, traffic related fatalities. By their very nature, extreme weather events are rare, and as such no clear picture is available of their health impact, but might become more frequent and/or more severe in the future. However, scientific literature for Belgium on the future health impact in terms of injuries and death, among other, is rare.

Natural hazards always have and will continue to have significant consequences for society, such as premature mortality, several communicable and non-communicable diseases, mental health issues, and effects on occupational health, nutrition and social function (IPCC, 2014a; Wolf et al., 2015; UNISDR, 2015). Extreme weather- and climate-related events such as heatwaves, heavy precipitation, droughts, …, can also disrupt health and social care service delivery, and can damage healthcare infrastructure.

Modelled projections of *extreme precipitation* events indicate an increase in the frequency, intensity and/or amount under future climate in Europe, and events currently considered extreme are expected to occur more frequently in the future. Globally, a 1-in-20-year annual maximum daily precipitation amount is likely to become a 1-in-5- to 1-in-15-year event by the end of the 21st century (IPCC, 2013).

Windstorms can lead to structural damage, flooding and storm surges, which may be caused either by the wind itself, in particular short gusts, or by accompanying heavy precipitation. These events can have large impacts on human health and on vulnerable systems, such as forests, as well as transport and energy infrastructures. According to Munich RE's natural catastrophe loss database (NatCatSERVICE), storms were the costliest natural hazard (in terms of insured losses) in Europe between 1980 and 2015; they ranked second for overall losses and fourth in terms of the number of human casualties. A comprehensive review study covering the North Atlantic as well as northern, north-western and central Europe shows large agreement among models that the intensity of winter storms will increase in all these regions over the 21st century (Feser et al., 2014).

Heavy precipitation events can introduce faecal contamination into rivers and lakes and in turn decrease the quality of drinking water. They can also overload the capacity of sewage systems, causing

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discharge of untreated water. Pathogens can then infiltrate the drinking water supply and lead to waterborne outbreaks (see also the chapter on waterborne diseases). In Belgium, those impacts are probably of limited importance, given the quality of both water treatment infrastructure and of the health system.

Landslides occur as a combination of meteorological, geological, morphological, physical and human factors. Extreme weather- and climate-related events are the most common trigger of landslides in Europe. Shallow landslides are mostly triggered by heavy and/or persistent precipitation events; surface water run-off caused by heavy precipitation can induce some types of landslide, such as hyper-concentrated, debris flows or mudslides.

Hail can be responsible for significant damage. There is however little knowledge of hail risk across Europe beyond local historical damage reports, because of the relative rarity of severe hail events and the lack of uniform detection methods (Punge et al., 2014). The limited number of studies that have investigated projections of hailstorms appear to be inconsistent and demonstrate changes that are not very large and often lacking statistical significance. As mentioned in Section 2.7, climate projections conducted within CORDEX.be (Termonia et al., 2018) for the end of the century under IPCC scenario RCP8.5 point towards a reduced number of hail events but an increase of the main hailstone size. Yet, future projections of hailstorms feature a high level of uncertainty.

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3.2. INDUSTRY AND SERVICES

3.2.1. General considerations

Industry and services are facing two types of climate related risks: transition risks, related to the conversion towards low CO_2 production and operations, and the exposure to physical climate risk. With respect to the latter, extreme weather, as well as slower evolving phenomena, are expected to increasingly pose a threat to business continuity. In particular, companies that depend on global chains of production, storage, supply, processing, retail and consumption will be exposed to an enhanced risk from climate change, not in the least because they often rely on suppliers, production and transportation in regions across the globe with a high climate vulnerability.

Companies realise that they are exposed to price risks because of the price volatility of raw materials and commodities, e.g., prices of crops, energy and water, in the case of extreme events such as a drought. CDP (2019) has estimated that globally, companies have a value at risk (both transition and physical) approaching one trillion USD. As to the physical risks, companies cite the following drivers, in order of importance:

- reduced revenue from decreased production (linked to transport or supply chain difficulties);
- increased operation costs (e.g. inadequate water supply);
- increased capital costs (damage to facilities);
- reduced revenues from lower sales.

While the awareness of companies regarding physical climate risk is lagging behind the awareness of the transition issue, slowly but surely it is transpiring that an assessment of physical climate risk as a basis for action is urgently required. Marsh & McLennan Companies (2017) refers to the exposure and vulnerability of companies to physical climate change impacts, stating:

> “An effective resilience strategy should address how climate and market changes can impact corporate and financial performance. To better understand how climate resilient your company is, we recommend the following steps: (1) assess climate vulnerability of operations and facilities, (2) embed climate risks into enterprise risk management programs, and (3) undertake scenario analysis to enhance decision making around risks and opportunities.”

Industrial companies recognize that extreme weather events are already causing severe disruption to their operations, and associated losses are increasingly affecting corporate balance sheets; they increasingly realize that they will have to consider their exposure to physical climate risk in order to safeguard business continuity (Biagini and Miller, 2013).

One could of course argue that, since ancient times, weather variability always has constituted an important challenge for business planning, and business should know how to deal with it. Yet, challenges in anticipating climate change impacts are different, because this variability itself is now changing, i.e., climate risks and associated economic losses are expected to considerably deteriorate beyond what we would consider as a ‘regular’ variability. As a result, companies are increasingly concerned about potentially disruptive climate impacts that might bring them near the limits of their current resilience (Adaptation Scotland, 2017).

Moreover, it is to be expected that, increasingly, financial institutions, investors, and customers, will require that companies report on their climate risk exposure, and implement strategies to enhance resilience and ensure business continuity. Already, a survey recently conducted by Ernst & Young (2017) finds that investors expect that companies articulate the potential physical impacts of climate change on their assets and supply chain. In this respect, the Climate-related Financial Disclosures mechanism (TCFD, 2017) may become an important game changer as businesses will be increasingly expected (or forced) to disclose their climate vulnerability, transition- as well as physical climate risk-related.

The industry and services sector exhibit the particular property of being vulnerable to a multitude of risks, see Table 3-5 for a (non-exhaustive) overview. Indeed, the global value chain (Gereffi and

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Fernandez-Stark, 2016) of companies is often very extensive, and may involve a multitude of sectors, ranging from agriculture, over transport (road, sea, air), energy, infrastructure and to water, among other. Much of this vulnerability stems from climate change impacts outside Europe, climate having impacts on all stages of a company's value chains EEA (2017).

Table 3-5. Non-exhaustive overview of physical climate risks faced by the industry and services sector.

	impacts
extreme heat	– labour productivity loss – overheating of servers and other IT equipment – altered consumption patterns – reduced airfreight cargo (weight limit at take-off)
drought	– crop yield losses and shift of plant types – enhanced irrigation costs – increased competition for water – reduced hydroelectrical power availability
flooding	– storage facilities & materials source sites inundated – damage to IT equipment and infrastructure – labour productivity loss (staff unable to reach work) – consumers unable to access shops
storms	– risks to transport over land, by air and sea – compromised integrity of manufacturing plants – delays and loss of goods
sea level rise	– accessibility of harbour areas compromised – inundation of coastal industrial facilities

While climate impacts to some economic sectors (e.g., energy) have been well investigated, the industry and services sector has been largely under-researched with respect to climate change impacts (IPCC, 2014b). As a result, reliable information regarding the impact of climate change on industry is rather scarce. For instance, the EEA (2017) states: "Some climate-sensitive sectors, systems and issues are not covered in this *[i.e., their]* report owing to a lack of reliable information across Europe, including on industry and manufacturing."

Forzieri et al. (2018) investigated the impact of climate change on critical infrastructure in Europe, and found that, with a changing climate, the industry sector faces the highest damage. While current damage losses are dominated by floods (river and coastal) and windstorms, which cause structural damage to infrastructure and machinery, it is expected that in the coming decades droughts and heatwaves will have an increasingly dominant impact. However, it should be added that this conclusion is biased towards the sub-sector of the water/waste treatment systems, while the remaining industrial sub-sectors considered – i.e., the metal industry, mineral industry, chemical industry and refineries – would still predominantly be affected by floods and wind storms. For Belgium this matters, given the strong presence of the metal (southern part of Belgium) and chemical/refinery industries (northern Belgium) in the country.

Adaptation research and actions – including the assessment of physical climate risk – have, to date, almost exclusively focused on the public sector, and much less on the private sector. In addition, while 75% of companies acknowledge climate risk, only 30% conduct risk assessments, and of these, most consider risks from current climate variability and extremes only; a mere 5% really take action to manage climate risk (Agrawala et al., 2011).

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ISO – the International Organization for Standardization[1] also increasingly recognizes the importance of climate as an integral aspect of good business management: in June 2019 they published ISO 14090 and 14091, which focus on adaptation to climate change including vulnerability, impacts, and risk assessment (ISO, 2018). In the future, a business certified with one of these ISO labels would show customers and shareholders alike that they are well prepared to continue the provision of their products and services, even in case of disruptive climate events.

Finally, the UN Sustainable Development Goals (SDGs) – in particular SDG 13 'Climate Action' – urge businesses to 'prepare to adapt to climate change and build resilience in their operations, supply chains and the communities in which they operate'[2].

3.2.2. Labour productivity loss related to extreme heat

Extreme heat, apart from leading to higher morbidity and mortality, will also affect labour productivity losses in the future (Forzieri et al., 2017; Gasparrini et al., 2017; Mora et al., 2017; Estrada et al., 2017; Orlov et al., 2019; Pal and Eltahir, 2015).

A few studies been conducted in this domain of extreme heat versus labour productivity loss for a few cases in Belgium, and a brief account of the main outcomes will be provided in the remainder of this section. The studies mentioned below make use of the wet bulb globe temperature (WBGT):

$$WBGT = 0.7T_w + 0.2T_g + 0.2T_d,$$

with T_w the wet-bulb temperature, T_g the black globe temperature and T_d the dry bulb temperature (i.e., the actual air temperature). Details regarding this calculation method are presented in Lauwaet et al. (2020); suffice to know that the WBGT incorporates effects of air temperature, humidity, ventilation (wind) and short- and longwave radiation exposure. As such, this indicator attempts to represent the actual heat stress that is experienced by the human body, well beyond the sole impact of air temperature. The WBGT is also an ISO standard to quantify human heat stress (ISO, 1989), and is included in Belgian labour law as a Royal Decree (FOD WASO, 2011) to determine the rest periods labourers are entitled to in case of extreme heat, as shown in Table 3-6.

Table 3-6. Work-versus-rest regime for different intensities of labour, in case of exposure to heat stress as expressed by the WBGT.

	work regime			
	light	semi-heavy	heavy	very heavy
	WBGT values (°C)			
45' work / 15' rest	29.5	27	23	19
30' work / 30' rest	30	28	24.5	21

Figure 3-23 shows an example of the spatial variability of the WBGT within an urban neighbourhood of Antwerp. Note the strong WBGT gradients – highlighting the cooling role of urban green vegetation.

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[1] https://www.iso.org/home.html

[2] https://www.uncclearn.org/sites/default/files/inventory/16-00055_why_it_matters_climate_action_business_letter_size_1p.pdf

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Figure 3-23. Simulated spatial variability of the WBGT on a typical warm summer afternoon (here the maximum value of the WBGT on 24 July 2012) for the 'Oud-Berchem' neighbourhood located slightly to the west of the Antwerpen-Berchem train station. Blue areas (cool) generally correspond to the presence of green vegetation. Source: Lauwaet et al. (2018b).

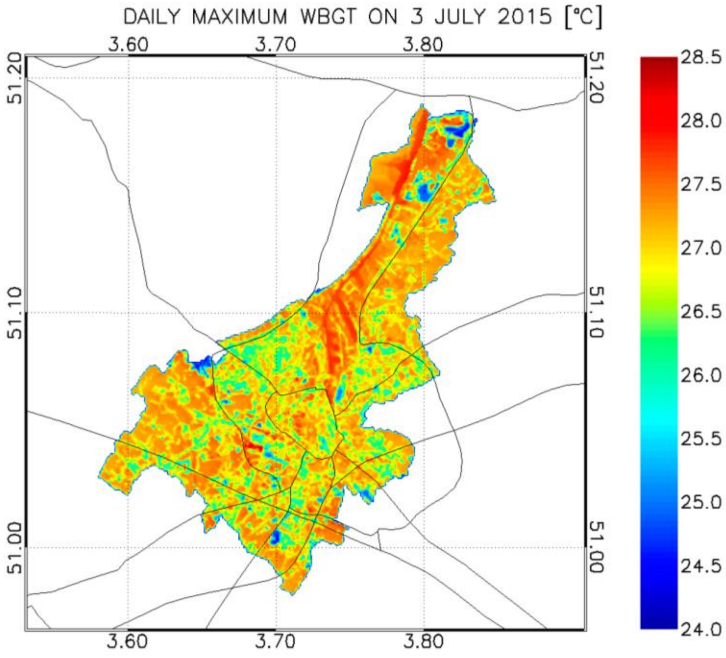

Figure 3-24. Spatial distribution of the highest WBGT value occurring on 3 July 2015 in Ghent. Source: Lauwaet et al. (2020).

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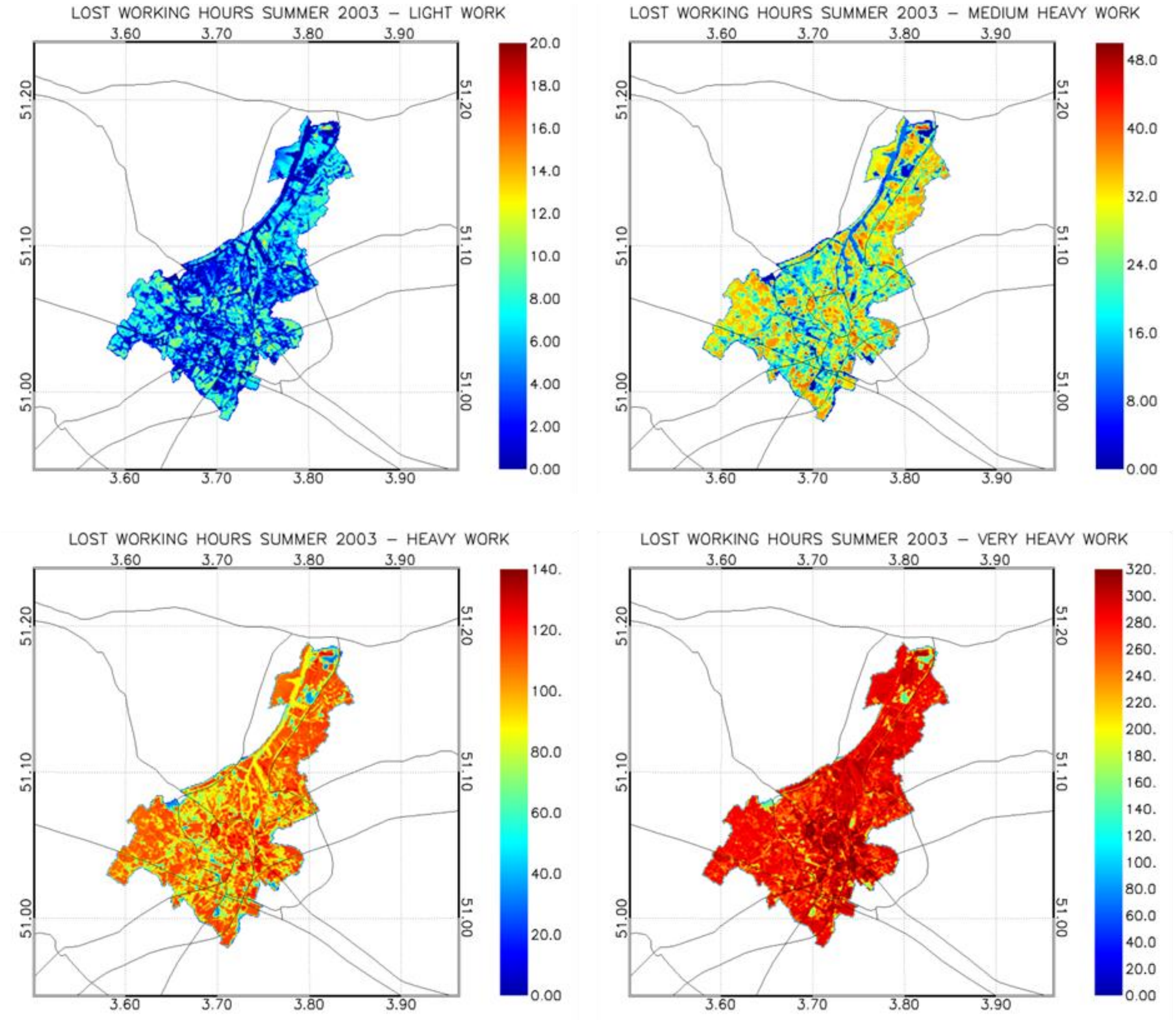

LOST WORKING HOURS SUMMER 2003 – LIGHT WORK

LOST WORKING HOURS SUMMER 2003 – MEDIUM HEAVY WORK

LOST WORKING HOURS SUMMER 2003 – HEAVY WORK

LOST WORKING HOURS SUMMER 2003 – VERY HEAVY WORK

Figure 3-25. Number of lost labour hours (per person) following the work/rest regime regulations referred to in Table 3-6, for the hot summer of 2003 in the Gent area, discriminating between different levels of outdoor work (light to very heavy work). Source: Lauwaet et al. (2017a).

At a somewhat larger scale, Figure 3-24 shows the spatial distribution of the WBGT in the city of Gent on a warm summer day, again clearly showing the cooling effect of green areas, but also cooling derived from water areas.

Lauwaet et al. (2020) simulated WBGT patterns for the Gent area for the hot summer of 2003, and based on that they estimated the potentially lost working hours when applying the work/rest regime of Table 3-6. These lost working hours, by category of labour intensity, are shown in Figure 3-25, with values up to several hundreds of hours of productivity loss for very heavy outdoor work. Considering that, with climate change, summer heat as that experienced in 2003 may become fairly common (Schär et al., 2004), this may become a burden on sectors that rely on heavy outdoor work, such as the construction sector.

Figure 3-26 shows the result of a comparable exercise, from Lauwaet et al. (2017b), but conducted for the Brussels Capital Region. Again, spatial patterns of the WBGT were used together with the work/rest regimes of Table 3-6 to estimate the amount of lost working hours during the summer of 2003, amounting to more than 10% in some areas for the ‘heavy work’ category, and once more showing the impact of the urban heat island.

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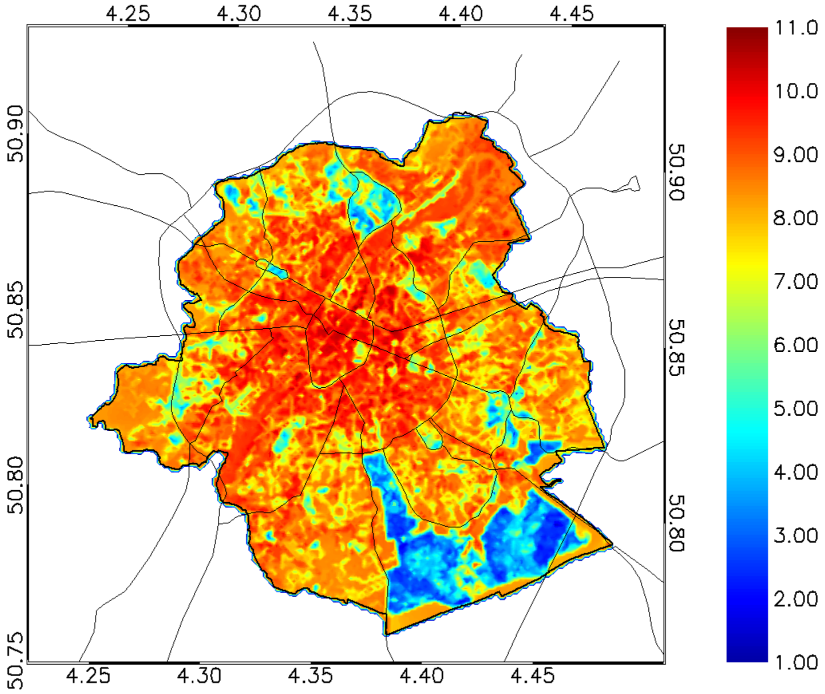

Figure 3-26. Potentially lost work hours based on the simulated WBGT regime in combination with data featuring in Table 3-6 (work/rest regime) for Brussels, summer of 2003. Source: Lauwaet et al. (2017b).

Finally, Hooybergs et al. (2015) conducted simulations of indoor thermal comfort (again using the WBGT) for a typical office building located in the south of Antwerp (actually, in this case VITO's Berchem satellite office), using urban climate simulations together with detailed building energy balance calculations, accounting for building characteristics such as thermal inertia, wall isolation, exposure of windows with respect to solar position throughout the day, and the dimensioning of the ventilation system, among other. Figure 3-27 shows the estimated lost working hours (blue) for desk workers ('light work'). The green and red bars show what can be achieved (in terms of reducing this number of lost hours) by rather simple 'common-sense' (and not very costly) adaptation measures such as increased ventilation (night-time 'flush') or keeping the solar blinds down.

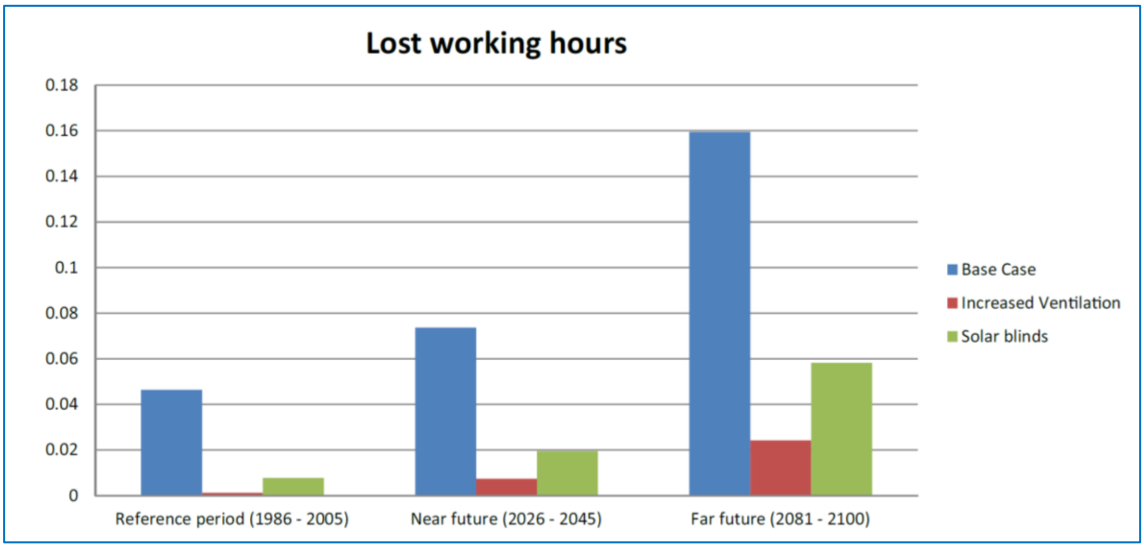

Figure 3-27. Estimated fraction of lost working hours in the south-facing room during an average summer (May-September), considering scenario RCP8.5 and different time horizons (horizontal axis). The blue bars refer to the situation without tempering measures, red bars denote increased night-time ventilation ('flush') to cool the building, and the green bars correspond to the situation where solar blinds are operated in such a way as to reduce incoming solar radiation, but disregarding ventilation. Source: Hooybergs et al. (2017).

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3.2.3. *Impact of climate change to the insurance sector*

In a recent report, the Belgian federation of insurance companies Assuralia (2019) states that 'the unsteadiness of natural phenomena is exerting its influence, against the background of climate change that promises more extreme weather conditions'. Climate-related risks are increasingly cited by the insurance sector as a potential threat to their financial stability (NBB, 2019). Apart from the risk related to the transition towards a low-carbon economy, insurance companies are exposed to the impact of climate change itself, i.e., the physical risk, both in terms of their assets (through depreciation of investments) and liabilities (through increasing claim levels).

As yet, the impact of climate change on losses and damage claims is difficult to determine (EC, 2017; Van den Broeck et al., 2019). On the one hand this is related to the variability of extreme weather, which may be masking long-term trends. Moreover, the number of damage cases and monetary claims is not only due to changes in weather extremes, but also to changes in vulnerability (e.g., more houses in flood-prone areas); disentangling both effects is not straightforward. However, it is expected that the frequency and intensity of extreme weather will increase with climate change, resulting in increased damage costs. Consequently, higher insurance premiums are expected in future years due to climate change, and insurers consider that some risks may become uninsurable over the medium and long term. Yet, such increases might be mitigated by prevention, both at a macro (regional) and micro (local authority, owners of buildings) level.

Although financial institutions seem to be aware of potential climate related risks, they have so far made relatively little progress in quantifying and integrating them into their risk management (NBB, 2019). This may be related to the fact that, traditionally, insurance companies consider time horizons of months to years, rather than decades, which in turn is related to the fact that insurers can fairly easily adapt their tariffs according to new insights with respect to weather extremes.

With respect to liabilities and claims, climate affects, among others:

- car insurance, in particular the so-called casco ('casualty and collision') insurance which nowadays generally includes damage by storms, hail and flooding;
- conversely, the third-party liability car insurance has seen decreasing damage costs (over the period 2010-2014), which has been attributed to less harsh winter road conditions, although other factors also contribute to this evolution, such as better-equipped cars (technology), better infrastructure and law enforcement (speed cameras);
- fire and property insurance policies, which include damage by flooding, storms, hail, sewer overflows and landslides;
- hospitalisation insurance could be affected increasingly by heat-related hospital admissions;
- since 2020 an agricultural insurance against drought and related yield loss has been introduced, replacing damage compensation from the Flemish Disaster Fund.

Floods, windstorms, hail and drought are identified as the most impactful climate events for Belgian insurers (NBB, 2019). In a survey conducted among insurance companies on the key physical climate risk factors they considered most impactful, the following climate related hazards were identified (with a numerical relevance indication given between brackets): floods (100), windstorms (75), hail (75), drought (75), freeze/snowfall (38), heatwaves (25) and wildfire (13). Verification of the main claims cost in recent years confirms storms and flooding as the main calamities.

As mentioned in Section 2.7, climate projections conducted within CORDEX.be (Termonia et al., 2018) for the end of the century under IPCC scenario RCP8.5 point towards a reduced number of hail events but an increase of the main hailstone size.

Considering floods, Hosseinzadetalaei et al. (2020) performed a risk assessment for 20-, 30-, 50- and 100-year flood return periods over Europe from the continental down to the national level for the late 21st century. Integrating hazard and socio-economic indicators, their results show a drastic increase (up to 87%) in future flood risks of different return periods over Europe. For Belgium, in particular, the enhanced hazard goes together with an enhanced exposure because of the expected increasing

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population density.

VMM, in a study on flood risk in the Heulebeek catchment[1], attributed flooding damage changes to climate change, the increasing share of impermeable surfaces and the increasing share of built-up zones in flood-prone areas. Focusing on the centre of the municipality of Moorsele, and using hydrologic modelling accounting for climate change hazard, they found that a significant number of buildings was at risk for flooding under climate change (Figure 3-28). In the wider Heulebeek catchment, they found that with climate change the number of houses exposed to an annual 1-in-10 probability of flooding mays rise from 1450 currently to 2750 in the future.

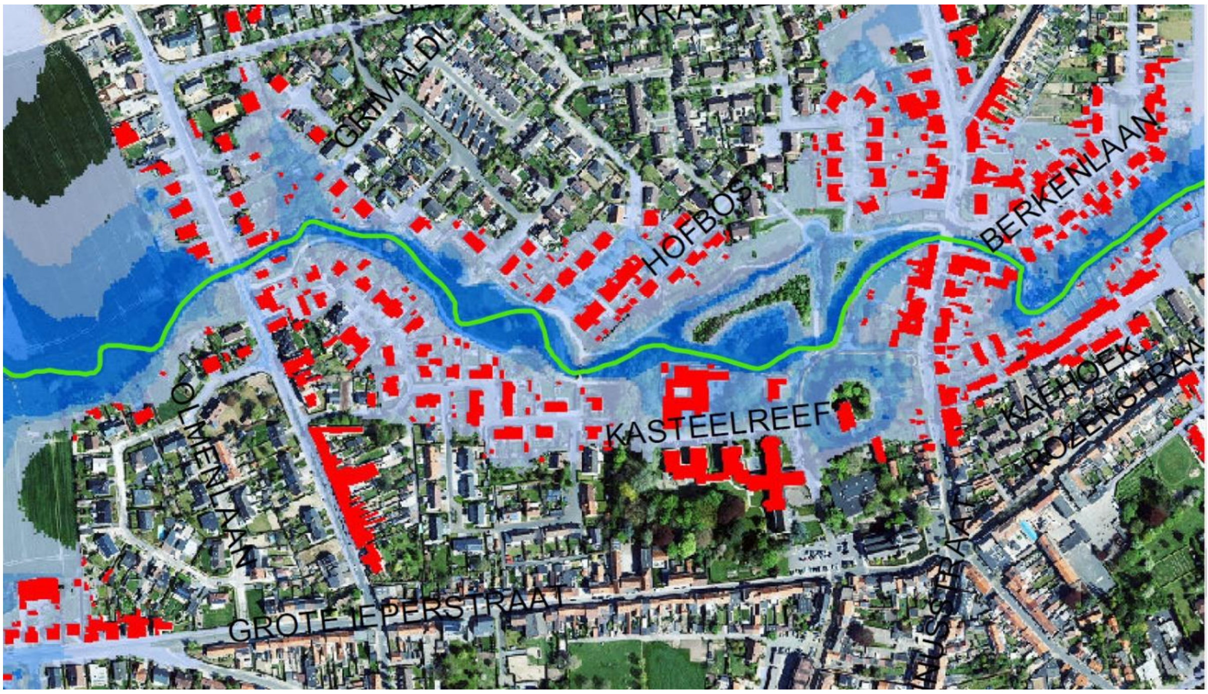

Figure 3-28. The buildings shown in red are at medium risk of flooding under climate change. Dark and medium blue contours show a high resp. medium risk for flooding under current climate conditions, the clear blue contours represent a medium probability for flooding under climate change. Source: Afdeling Operationeel Waterbeheer van de Vlaamse Milieumaatschappij (VMM).

Beckers et al. (2013), also accounting for both changes in climate hazard and socio-economic vulnerability (through land use changes affecting the share and value of built zones in flood prone areas) found that, for the built zones near the Meuse river, between 2009 and 2100 flood damage could be multiplied by 1.01–1.4 in a moderate (labelled 'dry') climate scenario and by 5.4–6.3 in a high ('wet') scenario. In the wet scenario, the effect of climate change was found to be 3–8 times more influential than the effect of urbanization.

According to the Flemish Climate Portal[2], under a high impact scenario, by 2100 the percentage of buildings exposed to dangerous flooding levels (flooding depth > 70 cm) will increase from a current average value of 2.6% to 6.9%; locally, the figure may reach as high as 15-20% of buildings exposed to dangerous flooding levels. More information on flooding and its impact on infrastructure is provided in Section 3.1.7.

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[1] https://www.west-vlaanderen.be/sites/default/files/2020-03/03_heulebeek-Maarten%20Goegebeur.pdf

[2] klimaat.vmm.be

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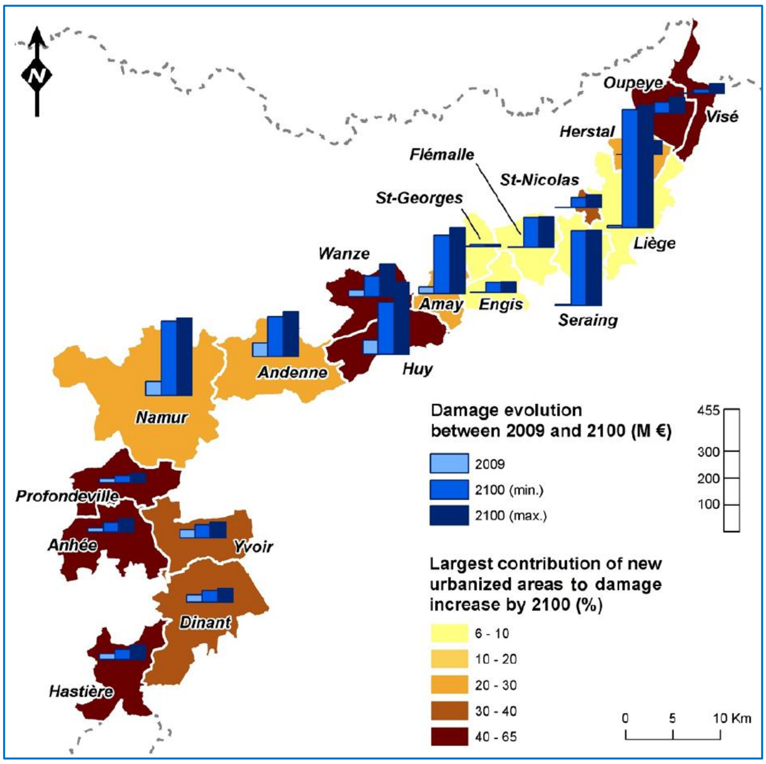

Figure 3-29. Simulated flood damage (blue bars) for the current situation and the end of the century under a high ('wet') climate scenario. The share of the land use changes (new urban areas) is shown as the municipalities' yellow-to-red colour range. Source: Beckers et al. (2013).

In a study for the UK, according to CISL (2019) the present-day risk to UK mortgaged properties from wind storms is considerably lower than that of flood risk. (Also, a large uncertainty persists with respect to the frequency and severity of future wind storms.) Projections indicate that, under a 2°C warming scenario, the number of properties located in the UK that are at considerable risk of flood (coastal, fluvial, pluvial) could increase by 25%, this figure rising to 40% under a 4°C warming scenario. For assets abroad, such as commercial property (office buildings and shopping centres, among others), average loss under a 4°C warming scenario may reach 70-80% for those assets that are located in tropical cyclone areas.

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3.3. BIODIVERSITY

Land (or sea) use change and direct exploitation together account for more than half of the biodiversity loss imputable to human activities. Climate change is currently responsible of about 15% of the decline (IPBES, 2019). It does represent, however, an increasing threat for biodiversity and ecosystem services (ESS). Climate change and biodiversity loss are intrinsically linked as they share common drivers, and observations show that ongoing climatic changes already affect biodiversity. Future climate change is expected to intensify and become one of the main drivers of biodiversity decline and a collapse of Natural Capital. It will likely reduce ecosystems' resilience towards other stressors, including pollution, habitat fragmentation, biological invasion and (over)exploitation of natural resources, and further reinforce these drivers of biodiversity loss (EEA, 2019a; IPBES, 2019; Kovats et al., 2014).

Nature's contributions to people, i.e., ESS, include regulating, material and non-material services (IPBES, 2018). Due to the complexity of biodiversity assessments and existing interactions between different stressors, it is very difficult to attribute observed and expected decline in biodiversity and nature's capacity to provide ESS to climate change. Monetizing biodiversity loss is even more complex (EEA, 2017). Even so, Belgium's National Climate Commission appraises the climate-related costs for maintaining biodiversity among the highest of different sectors (NCC, 2017). Conservation of biodiversity and ESS will increasingly require resources and efforts, both in- and outside protected areas. Projected regional climatic change will put pressure on local species, and considerably impede survival of endangered species. Progress that has been booked in the protection of these species may recede due to new challenges posed by climate change (Grootaert, 2014). This means that biodiversity conservation, including the management of specific Natura-2000 sites irrespective of their status (which constitutes 15.9% of Belgium's territory; Grootaert, 2014), will also become more demanding (EEA, 2017). While in our report we assess the specific impacts of climatic changes on biodiversity and ESS within Belgium, it is likely that climatic impacts outside our country also have large effects on ESS delivered to Belgium due to migration or reduction in supply of goods or services (EEA, 2019a).

The clearest universal challenge is the observed and further expected shift northward, and toward higher altitudes, and phenological changes (i.e., change in periodic life cycle events of flora and fauna) as a consequence of rising temperatures for flora and fauna species in all types of ecosystems, endangered or not. While species may move northward or alter their behaviour as an adaptation strategy, it is commonly recognized that often their adaptation rate – or that of species on which they depend in the food web – cannot keep track with the shifts in climate conditions, which leads to a progressive decline in biodiversity on the European continent (EEA, 2017, 2019a; IPBES, 2018; Menzel et al., 2006; NCC, 2017). Other stressors for biodiversity, specifically barriers in fragmented landscapes and alien species that benefit from rising temperatures to invade territories, further challenge endemic species and impede migration (IPBES, 2018; Kovats et al., 2014; NCC, 2017). Species migration and altered fitness will drive local shifts in species distribution, interactions and ecosystem functioning, and include an increased risk of extinction for some species (EEA, 2017; Kovats et al., 2014). The fraction of species at risk of climate-related extinction is 5% at 2°C global warming up to 16% at 4.3°C global warming (IPBES, 2018). Another major challenge, in addition to the relatively gradual change in temperature, is the more frequent occurrence of extreme weather events, which has an adverse impact on the survival of diverse species by direct mortal impacts (Bahn et al., 2014). The compounding risks and negative impacts of different drivers are expected to intensify with climate change in the future (EEA, 2019a). In Belgium, in the context of the reporting duty for habitat directive 92/43/CEE on the conservation of natural habitats and wild fauna and flora, an assessment made in 2019 indicates that 20% of the Directive's species in the Continental Bioregion (South of Sambre and Meuse Rivers) are threatened by global warming (Motte G., personal communication 11 March 2020).

In the next paragraphs, impacts of climate change on biodiversity and ESS in aquatic and terrestrial ecosystems in Belgium are described. We start with two overview tables (Table 3-7 and Table 3-8) summarizing climate related vulnerabilities. Thereafter, specific impacts are elaborated and illustrated by recent observations or model projections for the future.

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Table 3-7. Ecosystem, biodiversity and ESS vulnerabilities to projected climatic changes in Belgium

		Vulnerabilities				
		Climatic change				
		Temperature rise	**Change in precipitation pattern**	**Extreme weather**	**Sea-level rise**	**Atmospheric $[CO_2]$ rise**
Aquatic ecosystems	**Marine**	- Northward migration of species - Invasion of algae → anaerobic conditions		- Sudden destruction of habitats and species populations		- Acidification of sea water
	Fresh water	- Increased evaporation and low-flows in summer - Invasion of algae → anaerobic conditions	- Low-flows in summer - High intra-annual variation in flow rates	- Inundations & sudden destruction of habitats and species populations - Increased mortality due to lethal temperatures and low oxygen saturation	- Intrusion of salty water & habitat disappearance	- Acidification of surface water
Terrestrial ecosystems		- Invasion of alien species and pests - Phenological changes - Northward migration of species and habitats - Increased evapotranspiration and susceptibility to drought - Longer growing season	- Lower water availability in summer - Reduced biomass production (flora) - Higher fire risk	- Inundations & sudden destruction of habitats and species populations - Increased mortality due to lethal temperatures or prolonged droughts - Higher fire risk	- Intrusion of salty water & habitat disappearance	- Increased biomass production (flora) in optimal conditions
Overall		Change in species distribution and composition, species inter- and intra-specific interactions, tropic web, community structure, ecosystem functioning & productivity; increased risk of extinction				

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Table 3-8. Affected ESS in Belgium by projected climatic changes according to ecosystem type

<table>
<tr><th colspan="8">Affected ESS</th></tr>
<tr><th></th><th></th><th colspan="5">Climatic changes</th><th rowspan="2">Expected pressure from climate change</th></tr>
<tr><th></th><th></th><th>Temperature rise</th><th>Change in precipitation pattern</th><th>Extreme weather</th><th>Sea-level rise</th><th>Atmospheric [CO_2] rise</th></tr>
<tr><td>Aquatic ecosystems</td><td>Marine</td><td colspan="5">- Food provision</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Climate regulation</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Ocean acidity regulation</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Regulation of hazardous or dead organisms</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Quality of life contribution (education, health, heritage, recreation, security, livelihood,…)</td><td>↑</td></tr>
<tr><td></td><td>Fresh water</td><td colspan="5">- Regulation water quality</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Regulation of hazardous or dead organisms</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Flood, erosion and hazard regulation</td><td>↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Quality of life contribution (education, health, heritage, recreation, security, livelihood,…)</td><td>↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Water production</td><td>↑↑↑</td></tr>
<tr><td>Terrestrial ecosystems</td><td></td><td colspan="5">- Food provision</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Climate regulation</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Coastal protection</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Regulation of hazardous or dead organisms</td><td>↑↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Bio-based fuel & material provision</td><td>↑ for wood;
↑↑ for bio-fuels</td></tr>
<tr><td></td><td></td><td colspan="5">- Air quality regulation</td><td>↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Flood, erosion and hazard regulation</td><td>↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Quality of life contribution (education, health, heritage, recreation, security, livelihood,…)</td><td>↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Soil (fertility) formation & protection</td><td>↑</td></tr>
<tr><td></td><td></td><td colspan="5">- Pollination</td><td>↑↑</td></tr>
</table>

Shading indicates the current balance between ESS demand and availability: 🟥 for imbalance between demand and availability; 🟧 for vulnerable balance between demand and availability; 🟩 for stable balance between demand and availability. Arrows indicate expected impacts of climate change on the availability of ESS: ↑ for low increasing impact; ↑↑ for medium increasing impact; ↑↑↑ for high increasing impact. Adopted from Stevens et al. (2014) who made assumptions for the Flemish Region

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3.3.1. Aquatic ecosystems

Observed and projected climatic changes in Belgium already affected and will continue to affect marine and fresh water resources.

Marine

Rising temperatures and acidification due to elevated atmospheric CO_2 concentration affect the North Sea and poses a threat to sea life in marine habitats (IPBES, 2018). Recent temperature rise in the North Sea is generally more pronounced than in more southern and less enclosed seas. Although eutrophication and overfishing also affect North Sea species, changes in species abundance and marine ecosystems are at least partly due to temperature-driven northward species shift. These changes have already induced a decline in specific species populations, including those of sardines, red mullet, bass and cod. Barnacles, snails, decapods, jellyfish and other warm water loving (invasive) species on the other hand profit from the higher temperatures and thrive now better in the North Sea (van Ypersele and Marbaix, 2004; Philippart et al., 2011). Although warming may locally lead to an increase in fish biodiversity, this is often accompanied by a change in the fish community structure, with growing populations of relatively small species (like sprat, anchovy and horse mackerel) but declining populations of larger species (like bass, red mullet and cod) in the North Sea (Perry et al., 2005). In the past 40 years, fish species populations have shifted by about 10° latitude northward (or 250 km per decade), and this evolution has accelerated in the last 20 years (EEA, 2017). The observed northward shift of a number of North Sea species is shown in Figure 3-30. Next to warming, acidification also threatens many marine organisms, particularly those relying on calcium carbonate for shells and skeletons, whole marine ecosystems and fisheries (NCC, 2013).

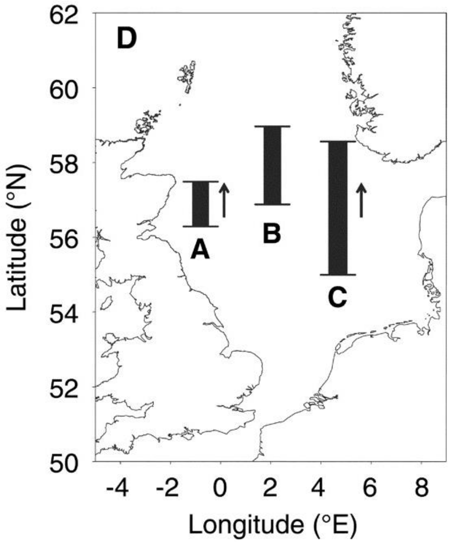

Figure 3-30. Northward shift of North Sea fish distributions (shifts in mean latitude of centres of abundance) between 1977 and 2001 for (A) Atlantic cod (Gadus morhua), (B) anglerfish (Lophius piscatorius), and (C) snake blenny (Lumpenus lampretaeformis). Arrows indicate where shifts have been significant over time. Source: Perry et al. (2005)

Future changes in temperature and acidity will continue to disrupt marine habitats and community structures and possibly lead to the local extinction of marine plant and animal species, including commercially caught ones. The changes compromise the North sea's regulation of its own acidity, its rich biodiverse ecosystem and the whole marine trophic web, which provide crucial ecosystem services including food provision and the fishery sector (Philippart et al., 2011). Changes in the physical properties of the seas can induce abrupt changes of whole ecosystems, so-called regime shifts, which reduce its resilience and affect the provision of ESS (EEA, 2017). Given the global extent of climate change and the connection between oceans and seas, pronounced local changes in near-by seas (e.g. the Mediterranean Sea) can cause ecological shifts in the North Sea as well (Conversi et al., 2010).

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Currently, warm water fish species are less economically valuable than cold water species (van Ypersele and Marbaix, 2004). Still, Johnson et al. (2020) estimated an increase in fish production ESS by 2050 (compared to 2011) that can be delivered by Belgium's seas, with a higher increase in a scenario where energy-sober behaviour and high availability of low-carbon technologies (~RCP 2.6; described by Rozenberg et al. (2014)) is combined with avoidance of agricultural or urban development in areas that are currently valuable for delivering ESS.

Connected to the sea are coastal and estuarine land zones that are also home to diverse ecosystems. Those ecosystems, including marsh areas, are dependent on salt level, sedimentation and inundation regimes. The projected changes in temperature, precipitation and frequency of extreme events and the concurrent sea level rise challenges these biodiverse ecosystems and habitats for local fauna and flora, and the ESS it provisions. Sea level rise will lead to changes in ecosystems and habitat for local species, with challenges and opportunities depending on possibilities to follow (EEA, 2017; Van der Aa et al., 2015). Shift of marsh areas of the Sea Scheldt following future sea level rise is expected to be feasible (Temmerman et al., 2004), while for the Western Scheldt ecosystem, changes in sediment loads are expected to hinder movement of marsh areas (Van Braeckel et al., 2012).

Increased surface temperatures of the North Sea have already benefitted warm water swimming crabs in recent years, which in turn triggered establishment of lesser black-backed gulls at the Belgian coast (Luczak et al., 2012). Future sea level rise will cause intrusion of salty water in aquatic and terrestrial ecosystems near Belgium's 65 km long coastline and erosion of coastal land. This will destroy existing ecosystems, put pressure on the fresh water reserves and habitats in dunes and polders, and affect the recreational and touristic value of the coastal region. A number of valuable nature reserves nearby the coast, including the Westhoek, Ijzermonding, Fonteintjes and Zwin, are specifically under threat (van Ypersele and Marbaix, 2004; NCC, 2013). With regard to extreme events, one third of our coastline and its ecosystems is insufficiently protected against super storms (combining high tide and strong wind; NCC, 2013), that will become more probable in the future.

Large parts of our coastal area are extremely vulnerable since many lay below sea level during annually recurring average storms (Stevens et al., 2014). Weakened coastal ecosystems will eventually lead to a decrease in coastal protection ESS that coastal ecosystems can serve in Belgium, independently of the type of socio-economic pathways that are assumed (Johnson et al., 2020).

Freshwater

Freshwater ecosystems in Belgium, as across the whole of Europe, suffer from climatic changes, in addition to the adverse effects of other stressors like agricultural intensification and urban development. Seasonality of river flows across Europe is expected to further intensify in accordance with recent observed trends, including declined summer (precipitation and) river flows and increased winter (precipitation and) river flows (EEA, 2019a; IPBES, 2018). Besides changes in precipitation patterns, also temperature rise affects aquatic ecosystems because of a lower oxygen saturation at higher temperatures (NCC, 2013). The sudden impact of extreme high or low flows can destroy ecosystems and compromise flood protection and water quantity and quality regulating ESS, and in general involve high costs (van Ypersele and Marbaix, 2004).

But also gradual changes complicate the maintenance of water habitats for several species, which in turn affects the regulation of the quality and quantity of our freshwater resources by local aquatic ecosystems. Deteriorated ecosystems near rivers and lakes have diminished capability to regulate fluvial floods and prevent inundations in these vulnerable areas, affecting the execution of existing flood plans (NCC, 2013; Van der Aa et al., 2015). About 4% of the Flemish Region floods once every 100 years, affecting about 1% of the Flemish population, and 30% of the Flemish Region is currently sensitive to inundations – shares that may increase in the future. This land is very vulnerable to increased exposure to changes in seasonality and extreme events (Stevens et al., 2014).

Belgium, and especially the Flemish region, faces water scarcity. The country's high population density entails limited drinking water resources per capita (Stevens et al., 2014). Water provision ESS are expected to decrease in Belgium, irrespective the type of the assumed socio-economic pathways (Johnson et al., 2020).

Belgium's Meuse river with its pronounced seasonal variation in discharge (low flows during summer and high flows during winter) is one fresh water system that is vulnerable to the expected climate changes. A future with wetter winters and drier summers will amplify the river's discharge seasonality (de Wit et al., 2007). These altered regimes may be harmful for local aquatic ecosystems that rely on the discharge seasonality. Still, discharge in the Meuse river in dry periods depends also on provision from groundwater reserves, which should be recharged by winter precipitation. Future frequency of critical low flows in summer depends thus on the sequence of dry winters followed by dry summers (de Wit et al., 2007). Although winter precipitation is projected to increase, potential combinations of winters and subsequent summers with below-average precipitation in the future can jeopardize drinking water supply from the Meuse river.

3.3.2. Terrestrial ecosystems

Notwithstanding its limited size and unarticulated topography, Belgium has distinct ecosystem types including semi-natural coastal dunes, wetlands, peat bogs, grasslands, limestone ecosystems (including calcareous meadows, groves and forests), heathland, and deciduous and coniferous forests, each with its own biodiverse community of flora and fauna species. Yet, in our strongly urbanized country, semi-natural areas are not equally distributed. About 80% of the forested areas is for example located in southern Belgium. Also in urban and fragmented areas, biodiversity is essential to sustain ESS (Grootaert, 2014). Climate change is clearly affecting terrestrial ecosystems, although other stressors also negatively affect terrestrial biodiversity (IPBES, 2018). The general impact of rising temperatures – causing geographical shifts, biome shifts and disruption of community interactions – is already established in Belgium. But also changes in precipitation, atmospheric CO_2 concentration, sea level rise and extreme events challenge terrestrial ecosystems.

Flora

Climate change induced droughts (due to increased temperatures and evapotranspiration, and lower summer precipitation) challenge plants and trees and decrease biomass productivity (IPBES, 2018). Specific ecosystems, like the Hautes Fagnes nature reserve with its characteristic peat bogs, are prone to drought and are at high risk of disappearance due to projected climatic changes in combination with other pressures (van Ypersele and Marbaix, 2004). Next to drought, a temperature-driven northward shift of plant species (particularly mosses, algae and lichens) is already clearly established in Belgium. Northward shifts may also include invasive species from more southern regions that compete with (weakened) native species. Haesen and Van Meerbeek (2019) expected continued northern shifts for the majority of 881 studied Flemish plant species (of which 229 signalled as vulnerable on the Red List for endangered species): on average 96 km for pessimistic climate projections (~RCP 8.5) by 2100, and 62 km for more moderate climate projections (~RCP 4.5). Already threatened species will be most sensitive to changes, and see their optimal climatic conditions shift further northward, i.e., by 111 to 168 km for RCP 4.5 and 8.5, respectively (as compared to 36 to 49 km for not yet endangered species). For about 30 of the studied plant species (among which the endangered frog orchid, but also more common species like creeping thistle and common mallow), the potential habitat will disappear in the Flemish region, which will lead to local extinction and overall biodiversity loss. While southern species may colonize our region, those species are highly mobile and may cause competition with native species (Haesen and van Meerbeek, 2019).

Certain long-lived tree species that thrive best in cold climates (including oak, beech and hornbeam) may no longer find a suitable climate niche in our country in the future and locally disappear, especially when further weakened by drought or heat stress (van Ypersele and Marbaix, 2004).

Several of Belgium's most important tree species, including beech and Norway spruce, will be severely threatened by continued rising temperatures and prolonged droughts. Large part of the Sonian Forest would become unsuitable for beech due to climatic changes by the end of the century (under RCP 8.5) (Daise et al., 2011). (More on this subject is found in Section 3.6, which describes impacts on forestry.) Other, currently secondary trees in our region, such as *Acer* species and other deciduous trees, may therefore become more dominant in the future (De Frenne et al., 2014). Following European wide projections, Norway spruce would not be able to thrive in 50% of its current habitats (Hanewinkel et al., 2013).

Overall forest productivity may however also benefit from elevated CO_2 concentration and prolonged growing periods in northern latitudes (EEA, 2019a), especially when migration of species is supported for example by introducing southern species in conservation areas of nurseries (Van der Veken et al., 2008). Johnson et al. (2020) expected an increase in forestry production ESS in Belgium, in a scenario where energy-sober behaviour and high availability of low-carbon technologies (~RCP 2.6) is combined with conservation efforts, whereas decreases were expected if no specific efforts for conservation are made or in a scenario with less energy sobriety (~RCP 8.5).

Just like other species, trees respond to the climatic changes by adjusting their phenology. Those changes affect forestry and ESS delivered by forests, as well as human health by altered timing and duration of the pollen season. The pollen season has been seen to start 10 days earlier and last longer in Europe as compared to 60 years ago. For the future years ahead, several dominant European tree species are expected to produce new leaves earlier (at a rate of up to 2 days per decade), while leaf senescence is expected to be delayed by the same rate. Earlier spring leafing and later autumn senescence will affect species competition (EEA, 2017).

In agriculture, biodiversity is critical for food security as it contributes to the increased productivity and resilience of agricultural systems (Thrupp, 2000). In typical hedgerows in Belgium, species richness is expected to collapse by the end of the century under RCP 8.5, even when migration of southern species is considered. Other ESS provided by the hedgerows, including food provision, pollination potential and shade casting ability (as determined by Van Den Berge et al. (2018) and Verheyen et al. (2012)) are also expected to change, with the direction and magnitude of change being hedgerow- and ESS-specific (Berckmans et al., 2020; Vanuytrecht et al., 2020).

Fauna

Belgian fauna typically consists of temperate European species. Next to common small species, wild boar and deer, wild birds make up a large part of the animal population (NCC, 2013). As within the whole of Europe, local bird species communities increasingly include species dependent on higher temperatures ('southern species'). The number of European land bird species whose populations are negatively affected by climatic change largely exceeds the number that is positively affected (EEA, 2017). Observed lower numbers of wintering (water) birds in Flanders (Figure 3-31) have also been ascribed to climate change.

Arrival of different summer migrants on the other hand have been monitored to advance in the past 20 years by a week on average (Grootaert, 2014; Figure 4). More and more, milder winters enable migratory birds to hibernate further north and decrease the number of winter migrants in Belgium, and future changes will increasingly continue to do so. A shift in the occurrence of European bird species by 550 km to the northeast with a 3°C temperature increase by 2100 is expected (EEA, 2017). By the end of the century, Wallonia will be a range limit for 60 species, including 19 newly immigrated species, while an equal amount of currently present species will have disappeared. Projected temperature rises are likely to induce earlier arrival of summer migratory species. Yet, since adaptation of bird species does not follow the phenological adaptation of their food sources (e.g., caterpillars), several species are at risk of considerable population decline or even extinction (Grootaert, 2014). In Flanders, the brambling (*Fringilla montifringilla*) and common redpoll (*Acanthis flammea*) are endangered with extinction due to rising temperatures during their reproduction phase (Dumortier et al., 2009).

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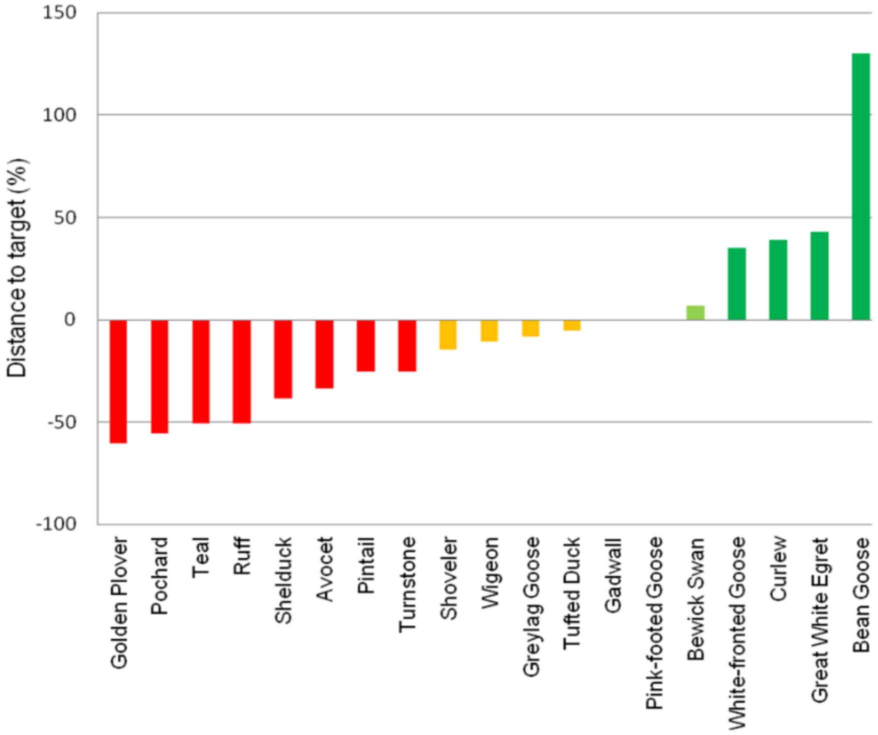

Figure 3-31. Gap to population targets of wintering water bird species in Flanders. Source: Grootaert (2014)

In Wallonia, analysis of historic observations showed – in agreement with European and world-wide observations – on average an advancement of spring migration of different bird species with years and a change in species composition favouring more southern species, which was associated with temperature rise (Laudelout and Paquet, 2014; Paquet, 2016). While there is a clear average trend, responses are species-specific with species communities that thrive better in more boreal climates (or occurring at higher elevation) showing more pronounced changes and some species showing responses opposite to the average response. While some species are on decline in Wallonia (e.g., the meadow pipit (*Anthus pratensis*), fieldfare (*Turdus pilaris*) and great grey shrike (*Lanius excubitor*)), others benefit from climatic changes (e.g., the African stonechat (*Saxicola torquatus*) and the melodious warbler (*Hippolais polyglotta*)), leading to an increase in nesting bird species richness, hence biodiversity, by 18% in 30 years, which is at least partly due to rising temperatures (Jacob et al., 2010; or 13 species more per 80 km^2; Laudelout and Paquet, 2014). While future rises in temperature are expected to further induce similar trends as observed in the past, other pressures like habitat degradation will also further impact bird populations.

In the recent past, an increase in insect species (dragonflies (*Odonata spp*)) that are endemic to more southern regions has been noticed in Belgium (Grootaert, 2014; Termaat et al., 2019). Also butterfly, spider (e.g., wasp spider (*Argiope bruennichi*)) and bird (e.g., European bee-eater (*Merops apiaster*)) species typical for more southern locations have already migrated to Belgium, and may continue to do so in the future with rising temperatures. Nevertheless, there is a limitation to their future northward shift due to their demanding habitat requirements, their slower mobility than the rate of climatic changes and distorted phenology, which may lead to extinction of species (Grootaert, 2014; NCC, 2013; Van Dyck et al., 2015). On the other hand invasive species – like ticks (*Ixodida spp*), red-eared turtle (*Trachemys scripta elegans*) or processional caterpillar (e.g. *Thaumetopoea processionea*) – also benefit from temperature rise, which will require intensive prevention plans (NCC, 2013).

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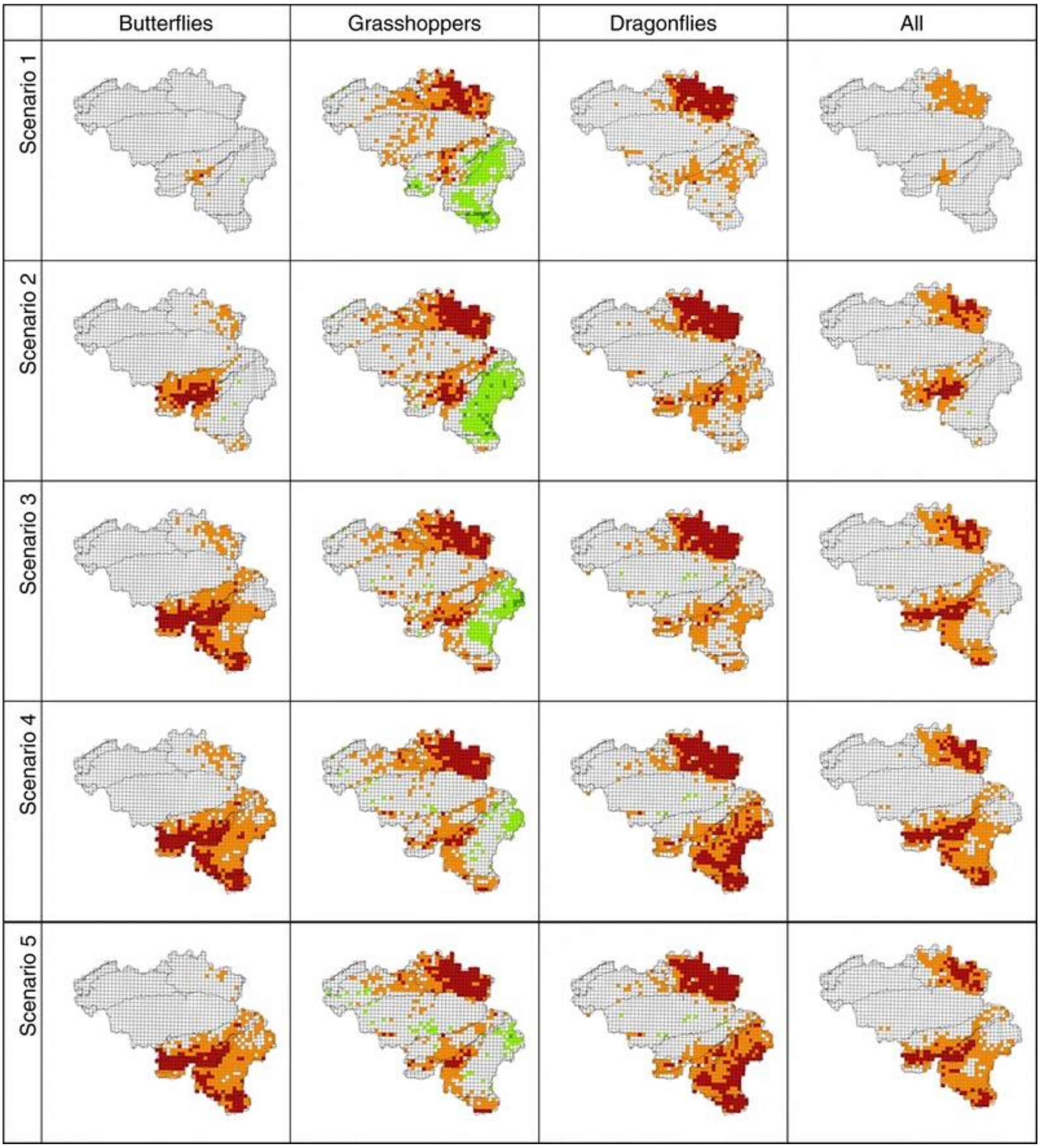

Figure 3-32. Insect diversity changes in five climate change scenarios (from S1 to S5 increasing year-round temperature by 1°C to 5°C and decreasing summer precipitation by 10% to 50%) for butterflies, grasshoppers, dragonflies and for all species together in Belgium (red: > 30% species loss, orange: 15–30% species loss, light green: 15–30% species gain, dark green: > 30% species gain). Source: Maes et al. (2010)

For several future climate scenarios, a decreased insect species richness (of butterflies, grasshoppers and dragonflies) has been predicted in Belgium compared to present-day richness, and a shift of species-rich locations to higher altitudes (Maes et al., 2010). While a general decline in insect biodiversity is expected, the magnitude and evolution of the decline is species-, scenario- and location-specific. Yet, changes in species composition are more pronounced with more severe climate projections, i.e. higher year-round temperature rises and lower summer rainfall (Figure 3-32). The most important losses are expected in regions that are currently species-rich, consisting of large nature reserves with rare and threatened types of biotopes, where some of the most endangered insect species in Belgium occur (Maes et al., 2010).

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For bumblebees (*Bombus spp*), which are important providers of pollination, 110 years of observations of range shifts divert from what has been observed for other insects. Within Europe, there has not been a climate change related northward expansion of the distribution area of bumblebees, while important range losses at the southern limits have been observed (up to 300 km), independent of harmful effects of pesticides and land use changes (Kerr et al., 2015). While the Belgian territory is not at a southern limit of many bumblebee populations, warming-related extreme events threaten the populations as their warm thermal tolerance is evolutionary relatively low (Kerr et al., 2015). In Belgium, climatic changes will put additional pressure on the declining bumblebee populations that suffer from urbanization and agricultural intensification (Vray et al., 2019). Shifted flowering period of blossoming plants due to temperature rises may further complicate the pollination potential. Johnson et al. (2020), however, expected an increase in pollination ESS in Belgium, in scenarios with energy-sober behaviour and high availability of low-carbon technologies (~RCP 2.6), versus a decrease in a scenario with low energy sobriety (~RCP 8.5).

Land and soil

Climate change, and in particular prolonged droughts or extreme rainfall events, will cause erosion further to degrade our land and soils and its biotic life, which suffer already from exhausting land use. Droughts and increased evapotranspiration will decrease soil moisture. Several habitats and species that are adapted to a temperate humid climate will not be able cope with frequently recurrent droughts in the future. This will reduce the optimal functioning of habitats, or even lead to disappearance of characteristic ecosystems, and will continue to drive negative impacts on food provision, water provision and quality, wood production or recreational ESS (EEA, 2019a; IPBES, 2018; Van der Aa et al., 2015).

In conclusion, in the above we have demonstrated and discussed observed and expected climate impacts on species, ecosystems and ESS in Belgium, ranging from northward migration and phenological changes due to temperature rise over increased vulnerabilities due to extreme events and prolonged droughts. Still, climate change has an important impact on complex inter- and intraspecific interactions and intertwines with other stressors. This could initiate a cascade of effects that are difficult to predict and adversely impact on the ESS provided by biodiverse ecosystems with serious economic consequences (NCC, 2013).

3.4. INFRASTRUCTURE, TRANSPORT AND NETWORKS

Network infrastructure is crucial for the functioning of today's economy and society, notably infrastructure for energy (e.g., grids, power stations, pipelines), transport (fixed assets such as roads, railways or airports), ICT (e.g., data cables) and water (e.g., water supply pipelines, reservoirs, waste water treatment facilities). Left unmanaged, climate change may significantly affect the operational, financial, environmental and social performance of such infrastructure (EC, 2013).

Overall, there are many interdependencies between the infrastructure sectors, and failure in one area can quickly lead to cascade failure. Energy, water, ICT and transport infrastructure are also often co-located (e.g., power cables laid below roads and beside communications cables, adjacent to water and gas mains and above sewers), especially in urban areas. Extreme weather events and its consequences (such as soil subsidence or erosion) could conceivably affect (or disrupt) all of these infrastructure assets simultaneously.

Main threats to infrastructure assets include damage or destruction caused by extreme weather events, flooding, changes in patterns of water availability, and effects of higher temperature on operating costs. Some infrastructure may not be affected directly but be unable to operate if physical access or services to it (such as electricity and ICT) are disrupted. For instance, disruptions in the energy distribution network may impede the functioning of swing bridges, of safety measures at railway crossings, or of pumping stations that keep tunnels dry, thus impacting transport networks and transport flow (KvK, 2014). Cascade effects such as those can potentially result in very important damages. Crucial to the importance of the effects is the vulnerability of key components in the networks (e.g. bridges over important waterways, transformation stations, data centres, …).

An essential aspect of the resilience of any kind of network is the degree to which the network has built-in redundancy. For instance, are there alternatives for crucial bridges over waterways? Can power supply easily switch to other sources if one or more sources are compromised? Do the tunnels have back-up pumps that use power supplies that do not depend on the grid? Redundancy is generally higher for the road network than for the rail network in Belgium, meaning the latter would be more vulnerable to the effect of local disruptions.

Another important aspect that determines overall damages and cost is the duration of the disturbances. Is the unavailability of networks a matter of hours, days or weeks? Failure or disruption of network infrastructure can cause indirect costs that surpass to a large extent the direct costs to the infrastructure itself, as the economic activities that depend on functioning networks may be affected, sometimes over relatively long periods.

It should be noted that much of the literature on the cost of climate change for infrastructure deals with the impact of catastrophic effects such as floods, extreme heat, etc..., which represents only a part (albeit the most "visible" one) of the costs that climate change will likely cause.

Forzieri et al. (2018) studied the impacts of climate extremes on critical infrastructures in Europe, by combining simulated data on exposure to different hazards with damage information derived from disaster databases. The authors found that, whereas current multi-sector hazard damage relates mostly to river floods (44%) and windstorms (27%), the proportions of drought and heatwaves will rise strongly, to account for nearly 90% of climate hazard damage by the end of the century (vs 12% in the baseline period). This suggests that impacts of climate extremes could change not only in terms of the magnitude of damage, but also in their typologies.

Predicted economic losses were highest for the industry, transport, and energy sectors. The authors found that for the energy sector the largest rise in damage relates to energy production, as a result of its sensitivity to droughts and heatwaves. For the transport sector, heatwaves will also largely dominate future damage, mainly by affecting roads and railways. These modes of transport also suffer losses from inland and coastal flooding. Hazard losses in the industry sector will mainly be due to droughts and heatwaves in the coming decades. The impacts relate mostly to the degradation of water quality and a reduction of the decomposition rate of water and waste management systems, with corresponding higher costs for water and its treatment. The results cited above apply to Europe as a whole. There will however major differences across Europe, with a much higher burden in southern Europe as compared to the north of the continent (see Figure 3-33).

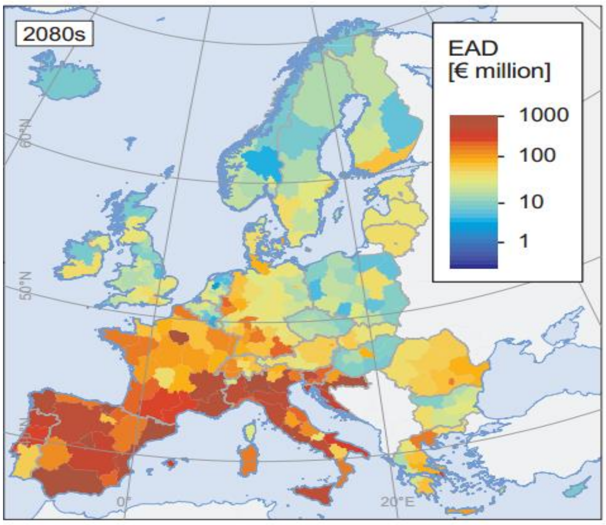

Figure 3-33. Spatial patterns of overall climate hazard risk (expressed as Expected Annual Damage (EAD), in million euro/year) to critical infrastructure in the 2080's under the A1B emissions scenario. Source: Forzieri et al. (2018).

3.4.1. Transport and transport networks

The projected increase in the frequency and intensity of extreme weather events such as heavy rain (e.g., causing floods), extreme heat and droughts can enhance negative impacts on the transport infrastructure, causing injuries and damages as well as economic losses, transport disruptions and delays.

JRC (2102) finds that, at EU27 aggregated level, compared to today, average precipitation-induced normal degradation of road transport infrastructures will only slightly increase in the future. However, more frequent extreme precipitations and floods (river floods and pluvial floods) could result in an extra cost. Some beneficial impacts on transport can also be expected, such as from reduced snowfall and more frost-free days. Those beneficial impacts are likely to be more important in the South (Walloon region) than in the North (Flanders and Brussels) of Belgium. Higher temperatures as a result of climate change could also result in more road accidents as a result of the stress that heat conditions can impose on drivers, or of unsafe situations during periods of extreme precipitation. On the other hand, safer driving conditions during winter (less snow and frost) could result in less accidents. It is unclear which of those tendencies will be more important, and whether the overall impact would be relevant at all.

Climate change has an impact on **rail transport** through rail buckling and the expansion of swing bridges, but also by flooding of the housing of electronic control equipment in case of extreme precipitation, or by the increased energy demand from air conditioning systems on trains, resulting in overheating and failure of the overhead lines. Other potential impacts include overheating of electrical equipment, overhead line sag, earthworks failure, scour of bridges, risk to signalling systems of flooding or extreme heat, track inundation, damage from fallen trees and branches, inadequate ventilation in trains, as well as risks for other infrastructure networks and systems the railway depends on (RSSB, 2016). Research in the Netherlands has shown that at temperatures above 23°C significantly more disturbances in the rail network occur, and that significantly more trains have problems at temperatures above 27°C. At temperatures exceeding 30°C, the number of disturbances in the Netherlands has been reported to increase with 30%. The economic consequences of delays in passenger rail transport have been estimated to be low (KvK, 2014), but this likely will not be the case for goods transport, especially if network and supply chain effects are factored in. Recent articles in the Dutch newspapers mention that at least one billion euros should be spent to make the rail network in the Netherlands resilient to climate conditions in the year 2050.

Operations at **airports** can be affected by strong winds, storms, inundations and damage to runway and apron surfaces at temperatures exceeding 31°C. Also, take-off performance of aircraft may become compromised with increasing temperatures, the lower air density at higher air temperature requiring reduced cargo weight and/or restrictions on fuel load (Coffel et al., 2017).

Operations in **ports** (loading, docking of ships) can be hampered by strong winds, whereas high temperatures can affect personnel handling equipment on container terminals. Maintenance requirements of port infrastructure may increase. As a rule, the impact on supply chains can be expected to be more important than the direct impacts on infrastructure and operations at the ports proper. Droughts can affect inland navigation (see below). Table 3-9 lists climate related impacts on transport and transport networks that may be relevant for the Belgian situation.

It should be noted that Belgium, compared to many other countries, has a very dense network of motorways as well as railways and waterways, and that the corresponding damage and cost is thus likely to be high.

As mentioned before in the chapter about the health impacts of climate change and based on data from the Flemish Climate Portal (VMM), the floodable area in Flanders (under a high impact scenario) would increase 77% by the year 2100, resulting in an additional 130,000 ha that would become floodable (not including coastal flooding as result of sea level rise). The average inundation probability would increase 5 to 10-fold. Average water levels during inundations (with a 1/1000 probability) would increase with 22 cm on average, but the increase could be as high as 120 cm in certain areas.

Those figures make it clear that the future impact of **flooding** on transport infrastructure, especially in low-lying areas along waterways, and in urban areas vulnerable to pluvial flooding, can be important, unless adaptation measures are taken to increase the resilience of the networks. High water levels on rivers can also impede inland navigation.

Figures on the impact of other climate hazards (storms, droughts, extreme heat…) for the Belgian situation are harder to come by, and little systematic research seems to have been done on this topic. As the effects of extreme temperatures will be exacerbated in urban areas, **heat impacts** on transport networks (rail buckling, problems with closing of bridges, road surface deterioration) will probably be relatively more intense in city environments than in the countryside.

Table 3-9. Climate related impacts on transport and transport networks that may be relevant for the Belgian situation. Source: EC (2013).

Type of transport infrastructure	**Type of climate hazard**	**Potential impacts**
Rail infrastructure	Summer heat	- rail buckling - material fatigue - increased instability of embankments - equipment overheating (engine ventilation, air conditioning) - increased probability of wildfires damaging infrastructure
	Extreme precipitation	- damage on infrastructure due to flooding and/or landslides - scour to structures - destabilization of embankments
	Extreme storms	- Damage on infrastructure such as signals, power cable etc. (e.g. due to falling trees, etc).
Road	Summer	- pavement deterioration and subsidence;

infrastructure	heat	- melting tarmac - reduced life of asphalt road surfaces (e.g. surface cracks); - expansion/buckling of bridges - increased probability of wildfires damaging infrastructure
	Extreme rain / floods	- damage on infrastructure (e.g. pavements, road washout); - road submersion; - scour to structures; - underpass and tunnel flooding; - overstrained drainage systems; - risk of landslides; - instability of embankments
	Extreme storms	- damage on infrastructure; - roadside trees/vegetation can block roads
	Sea level rise	- damage infrastructure due to flooding; - coastal erosion; - road closure
Aviation infrastructure	Summer heat	- degradation of runways and runways foundations; - decrease airport lift and increased runway lengths
	Extreme rain / floods	- flood damage to runways and other infrastructure; - water runoff exceeding capacity of drainage system
	Extreme storms	- wind damage to terminals, navigation, equipment, signage
	Sea level rise	- flooding of runways, outbuildings and access roads
Shipping infrastructure (inland)	High river flow	- problems for the passage of bridges; - speed limitations because of dike instability; - restrictions on the height of vessels
	Low river flow	- restrictions on the loading capacity; - navigation problems, speed reduction, functioning of locks to prevent water loss
Shipping infrastructure (maritime)	Change sea conditions	- more severe storms and extreme waves might affect ships
	Extreme storms	- devastation of port infrastructure; - interruptions of port activities

Lower water levels in rivers and canals during **drought episodes** can hamper inland navigation. During the summer of 2018, navigation on parts of the Rhine river almost completely ceased due to low river levels. Middelkoop et al. (2001) have estimated that, as a result of climate change, navigation restrictions on the Rhine could increase to 34 days (as compared to 19 today) in 2050 (ICEDD, 2014). Calculations for Flanders suggest that river discharges during dry summers could by the year 2100 be reduced with between 20% and 70%, depending on the basin and the climate scenario. The Amice-project has estimated that the 7-day averaged low water discharge on the Meuse river (that provides water to the Albert Canal) could decrease with between 10% and 40% as a result of climate change. Van Pelt et al. (2009), using a Regional Atmospheric Climate Model (RACMO2) under the condition of the SRES-A1B emission scenario, in combination with the HBV96 hydrological model found that the

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average summer discharge of the Meuse would decrease with between 13% and 17% by the end of the century. Moeskops et al. (2010), on the other hand, mention a decrease of up to 75% of average summer discharge of the Meuse at Borgharen in the period 2070 -2100.

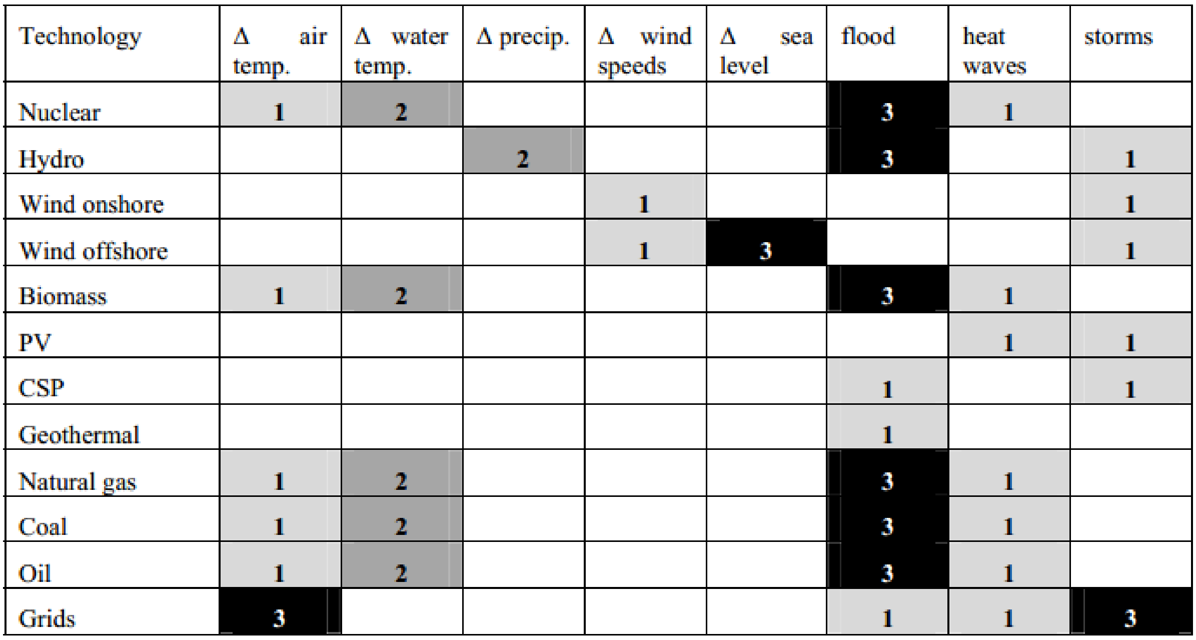
3.4.2. Energy infrastructure

Impacts of climate change, such as an increased frequency of extreme weather events or changing water and air temperatures have effects on energy transmission, distribution, generation and demand.

The transmission and distribution grids are increasingly challenged by direct physical effects of extreme weather events (e.g. storms or floods). Extreme high temperatures also have a negative impact on the capacity of the networks. The generation of electrical energy is affected by efficiency decreases due to climate change (e.g. decreasing availability of cooling water for electricity generators). However, more wind may also lead to new opportunities for wind energy generation.

According to EC (2013) floods are identified overall as a particular threat to electricity generators and related physical assets. In the Netherlands however, simulations have found that the impacts of floods are manageable, as floods can be predicted and affect only part of the national network. Heat events on the other hand can at the same time increase demand and limit production capacity, resulting in network problems that are more difficult to deal with (Bollinger and Dijkema, 2016). Table 3-10 shows the relative importance of the impacts of changing climate parameters on different energy supplies. Table 3-11 lists climate related impacts on energy infrastructure that may be relevant for the Belgian situation.

Table 3-10. Relative importance of the impacts of changing climate parameters on different energy supplies. (Note: 3 = severe impact, 2 = medium impact, 1 = small impact.) Source: European Commission (2013).



Technology	Δ air temp.	Δ water temp.	Δ precip.	Δ wind speeds	Δ sea level	flood	heat waves	storms
Nuclear	1	2				3	1	
Hydro			2			3		1
Wind onshore				1				1
Wind offshore				1	3			1
Biomass	1	2				3	1	
PV							1	1
CSP						1		1
Geothermal						1		
Natural gas	1	2				3	1	
Coal	1	2				3	1	
Oil	1	2				3	1	
Grids	3					1	1	3

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Table 3-11. Climate related impacts on energy infrastructure relevant for the Belgian situation. Source: EC (2013).

Type of transport infrastructure	**Type of climate hazard**	**Potential impacts**
Energy transmission and distribution	Extremely high temperatures	- decreased capacity of electrical transmission and distribution networks - reduced throughput capacity in gas pipelines.
	Heavy precipitation	- mass movements (landslides, mud and debris flows) causing damages
Energy supply	Drought	- shortage in hydropower supply due to low stream flows - reduced cooling water availability for thermal power plants
	Floods	- risk of flood damages due to location of most thermal facilities at water bodies (rivers)
	High temperatures	- loss in solar cell effectivity due to higher ambient temperatures - lower efficiency of thermal power plants due to higher ambient and cooling water temperatures

3.4.3. Other networks

Research in the Netherlands has shown that the material used in water distribution networks (mainly PVC) is generally not very vulnerable to higher temperatures. Soil subsidence as a result of weather phenomena can result in damages to underground pipeline networks for water supply, but also for gas supply, or sewers. Inundations can cause more damage to sewer networks than to e.g. water distribution networks, as the former are generally lighter (when empty) and thus more liable to become dislodged by rising ground water tables. Thermoplastic materials are vulnerable to weakening as a result of extreme temperatures. In the Netherlands, it has been estimated that the increase in damage to water distribution networks will be in the order of (max.) 10% of the “normal” annual damage to the networks (Maas and Vogel, 2014). A study by Wols and van Thienen (2014) found the direct of effect of climate change on future pipe failure to be small (max. +1.9% by 2050, and a decrease in pipe failure frequency by 2100, taking into account changes in pipe material being used).

Next to direct damage to infrastructure, indirect damage due to service disruption should be considered for any kind of network (utilities, communication, data, transport, water, …). The costs of disruption, especially over longer time periods, are likely to be important when compared to the direct infrastructure costs.

3.4.4. Buildings

In Belgium, the average damages covered in case of significant inundations have varied in the past between 40 and 75 M€/year. During the inundations of November 2010, for example, almost 9,000 households were affected, and about 80.8 M€ in damages were paid by the insurance companies. Costs caused by the inundation of the Meuse river in the Walloon region in 1995 surpassed 25 M€, and the flood of the Mehaigne (a small river in the Walloon region) in 2002 caused damages of about 3.5 M€ (ICEDD, 2014). ICEDD mentions a cost of between 41 and 664 €/year and per dwelling for inundation damages to private properties, with individual damages sometimes surpassing 40,000 € per home. Based on the results of the Amice-project and using extrapolations, ICEDD (2014) estimates the extra cost of inundations in the Walloon region due to climate change at about 400 M€ in the year 2100.

As mentioned before, the floodable area in **Flanders** (under a high impact scenario, and as a result of fluvial and pluvial inundations) would increase with 77% by the year 2100, resulting in an additional 130,000 ha that would become floodable. This will result in an additional number of buildings being affected. By the year 2100, 70% more buildings than today would be liable to be affected by inundations. The proportion of buildings that would potentially be affected by inundation levels of more than 70 cm (the supposed limit for serious economic damage) would increase from 2.6% today to 6.9% in 2100 (under a high impact scenario). Locally, up to 20% of buildings in urban areas would suffer inundation levels of more than 70 cm. Climate change would be responsible for an increase from 31,000 main buildings today to 92,000 in 2100 that would potentially suffer inundation depths of 70 cm or more, as a result of fluvial and pluvial inundations.

Sea level rise would, by 2115, result in an additional increase from 17,000 main buildings today that can potentially be inundated by water depths of 70 cm or more to 46,000 such buildings in 2115. The percentage of buildings located in the 18 municipalities potentially affected by inundations caused by the sea would increase from 9% under present meteorological circumstances to 25% when accounting for sea level rise induced by climate change. Conditions would be particularly severe in Nieuwpoort, Ostend and Bredene, where respectively up to 69%, 73% and 100% of buildings would become potentially floodable by 2115 under a medium impact scenario.

Overall, some additional 90,000 main buildings in Flanders would be located in areas where floods[1] with water depths exceeding 70 cm could occur, when accounting for the effect of climate change on the spatial extent and depth of the floods. This represents an increase with 187% compared to the 48,000 main buildings that are concerned when not accounting for climate change.

For the **Walloon region**, climate change has been taken into account by the choice of the “extreme” scenario (SPW, 2018). As indicated before, the calculations performed in the framework of the reporting of the Floods Directive indicate an increase of 50% of the total area inundated in Wallonia by a “normal” 100-year flood compared to a 100-year flood under conditions of climate change.

On the basis of the different flood risk management plans for the Walloon region an estimate can also be obtained of the additional area of “artificial” land use affected due to climate change, by calculating the difference between the T100 scenario and the “extreme” scenario. “Artificial” land use includes urbanised areas, areas for economic activities and areas for public services and equipment. As such, they can be considered as a proxy for the number of buildings being affected. The data are summarized in Table 3-12.

Table 3-12. Area of “artificial land use” potentially affected at T 100 (ha).

Hydrographic unit (sub-basin)	**Area of “artificial land use” potentially affected at T 100 (ha)**		
	Without climate change	**With climate change (extreme scenario)**	**Extra due to climate change**
Scheldt (Wallonia)	5,260	10,540	5,280 (+ 100.4%)
Meuse (Wallonia)	8,630	19,110	10,480 (+121.4%)
Rhine (Wallonia)	270	510	240 (+89%)
Seine (Wallonia)	14	28	14 (+100%)
TOTAL (Wallonia)	14,174	30,188	16,014 (+113%)

Overall, the area with artificial land use potentially affected by inundations in the Walloon region has been estimated to increase with some 113%. This compares to the +187% of buildings potentially

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[1] Including pluvial and fluvial floods as well as floods caused by sea level rise. The figures are not entirely comparable, as calculations for fluvial and pluvial floods apply to a high scenario while those for sea level rise take into account a medium climate change scenario.

affected by inundations exceeding 70 cm of water depth as a result of climate change in Flanders. It should be kept in mind that both figures only give an order of magnitude and have been arrived at using very different methods and assumptions.

3.4.5. Drainage systems

Willems (2013), in a study on design parameters for urban drainage systems in Belgium, found that the 10-year design storm intensity can increase by up to 50 % by the end of this century. Systems currently designed for a 20-year period of flooding might flood every 5 years on average. An increase of sewage storage of 11-51 % was found to be needed to maintain the overflow frequency at the current level.

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3.5. ENERGY

Final energy consumption by vector in Belgium consist mainly of oil products (48.1%), natural gas (26%), electricity (17.5%), renewable energy (5.1%) (Figure 3-34). Final energy consumption reaches 40.3 Mtoe (Megaton of oil equivalent) in 2017 while the EU directive 2012/27/UE relative to energy efficiency's objective is to reach 32.3 Mtoe of final energy consumption. The reduction in consumption is mainly due to efficiency achievements in the electricity production sector (FPS Economy, 2019).

Source d'énergie		Mtep	TJ
Produits pétroliers	■	19,4	812.541
Gaz naturel	■	10,5	438.870
Combustibles fossiles solides	■	0,9	38.123
Electricité	■	7,0	294.903
Chaleur	■	0,4	17.404
Energies renouvelables et déchets	■	2,1	86.419
Total		**40,3**	**1.688.259**

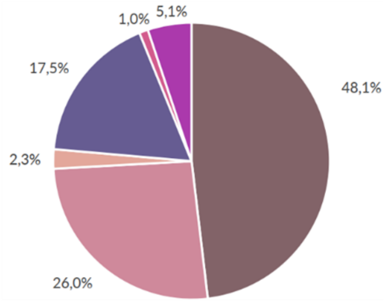

Figure 3-34: Final energy consumption in 2017 in Belgium by energy vector (left) in megaton of oil equivalent (Mteq) or terajoule (TJ), and (right) in percentage. Source: FPS Economy (2019).

Final energy consumption by sector in Belgium (Figure 3-35) is shared among industry (26%), transport (22%), residential (20.1%), services (13.4%) and non-energy use (18.5%) sectors (see Figure 3-35).

Secteur		Mtep	TJ
Industrie	■	10,5	438.655
Transport	■	8,9	370.799
Résidentiel	■	8,1	339.394
Services et équivalent	■	5,4	226.756
Usages non énergétiques	■	7,5	312.656
Total		**40,3**	**1.688.259**

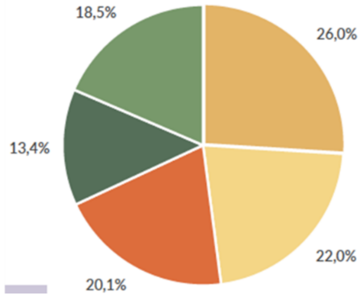

Figure 3-35. Final energy consumption in 2017 in Belgium by sector (left) in megaton of oil equivalent (Mteq) or terajoule (TJ), and (right) in percentage (FPS Economy, 2019).

Electricity production in Belgium is dominated by nuclear (48.8%) and fossil fuel (25.5%). Renewable energy production takes a 18.2% share with wind (10%), biomass and biogas (8%) and solar (5%) (See Figure 3-36).

Electricité		TWh
Nucléaire	■	42,2
Gaz naturel	■	22,9
Combustibles fossiles solides et gaz sidérurgiques	■	2,4
Produits pétroliers	■	0,2
Energies renouvelables	■	15,8
Autres sources*	■	3,0
Total		**86,4**

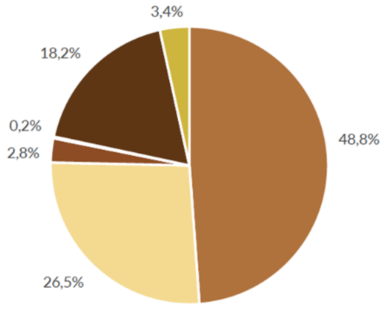

Figure 3-36. Electricity raw production in 2017 in Belgium by origin (a) in terawatt hour (TWh), and (b) in percentage (FPS Economy, 2019).

In a study by Gusbin and Devogelaer (2017) based on the PRIMES model, the energy mix of electricity in 2030 will consist of natural gas (60%), wind power (22%), biomass and waste (11%) and solar energy (6%) (see Figure 3-37). This scenario takes into account the phasing out of the nuclear energy by 2025 but can be understood as a "Business as Usual" (BAU) scenario since there is little shift in the energy mix towards renewables, energy consumption rises, and so do carbon emissions.

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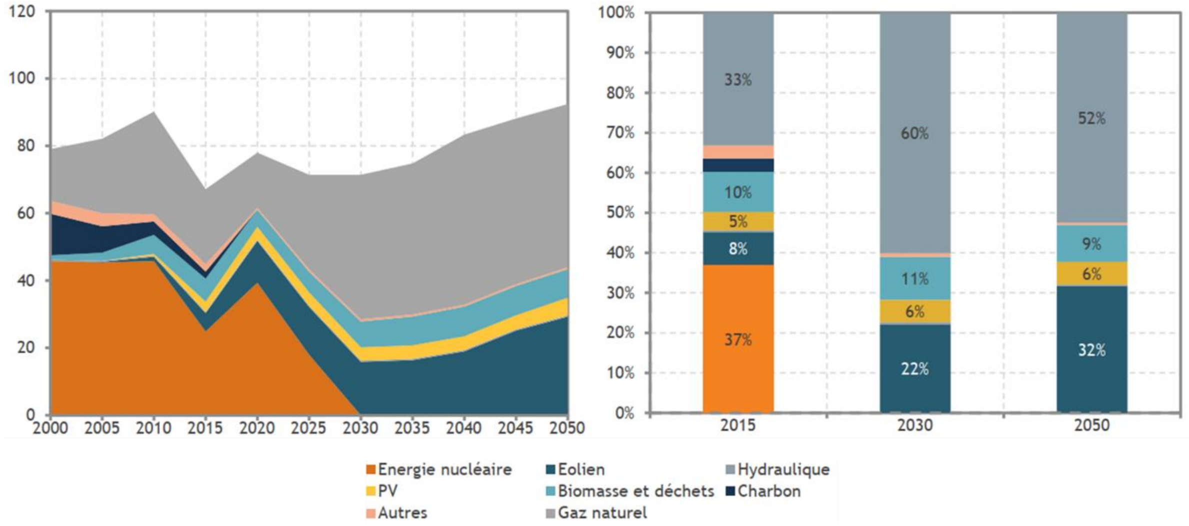

Figure 3-37. Evolution (of the mix) of net electricity production (left) in TWh and (right) in %. (Gusbin and Devogelaer, 2017)

According to the *Scenarios of a Low Carbon Belgium by 2050* study (Cornet et al., 2013) scenarios involving an important energy reduction of 58% to 37% and a fundamental shift in the energy mix towards renewables is possible (see Figure 3-38) while maintaining good economic conditions of growth and employments. Those scenarios allow for a significant decarbonisation of the Belgian economy of 80-95% $CO_{2\text{-eq}}$ compared to 1990 levels because of the combined production shift and demand reduction. While these low carbon scenarios would make Belgium contribute to the global effort of climate mitigation, they are not designed to deal with the local issues of adaptations to climate change in order to reduce climate change impacts in Belgium. These scenarios are more in line with the National Energy and Climate Plan (PNEC[1]) as well as with the National Climate Strategy[2] than the BAU scenario from Gusbin and Devogelaer (2017).

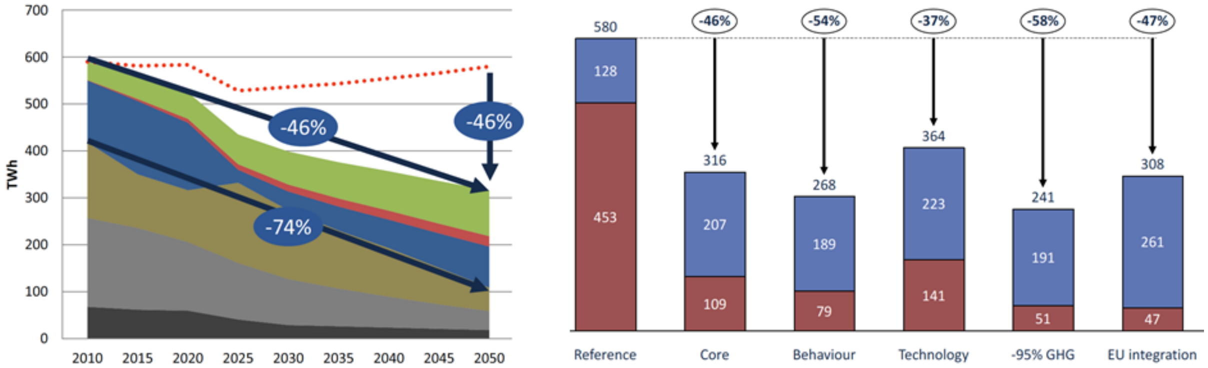

Figure 3-38. Left: primary energy supply by source for the CORE scenario in TWh/yr, biomass (green), environmental heat (red), electricity and net imports (blue), natural gas (brown), oil and petroleum products (grey), coal (black). Right: energy supply by source for different scenarios in TWh/yr, renewables in blue, fossil fuels in red. Source: Cornet et al. (2013).

A further analysis on the Belgian energy mix options has been done in Limpens et al. (2020). They recommend, along with demand reductions, a mix of technical productions within the realm of renewables as the most cost-effective way to reach low carbon emissions.

The phasing-out of nuclear power in Belgium is dictated by a law written in 2003 and edited in 2013 and 2015. It states that reactors will stop being used gradually until 2025: Doel-3 (2022), Tihange-2

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[1] https://www.plannationalenergieclimat.be/admin/storage/nekp/pnec-version-finale.pdf

[2] https://climat.be/doc/national-lt-strategy-fr.pdf

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(2023), Doel-1-2-4 (2025), and Tihange-1-3 (2025)[1]. The phasing-out of 48.8% of the Belgian electricity production will put pressure and the remaining production capacity within the coming five years. Figure 3-37 shows an apparent phase-out of nuclear energy in 2030; this is explained by the fact that the PRIMES model is based on a five-year granulometry, showing the impact of phase-out with a five-year delay in this case.

3.5.1. Climate impacts on electricity production and transport efficiency

Centralized production plants

Centralized production plants include nuclear power plants as well as thermal power plants, fuelled by gas, oil, coal, biogas and biomass. Weather conditions can affect the thermal efficiency and the load of these power plants up to their shutdown via a number of factors. McDermott and Nilsen (2012) established, based on German electricity prices, river temperature and water scarcity from 2002 to 2009, that electricity prices rise about 1% for every degree of daily average river water temperature above 25°C.

An estimate of the combined summer heatwave and drought of 2003 in Europe shows a decrease of about 5% of thermoelectric power utilization rates (van Vliet et al., 2016a). Future trends also show a decrease of the usable water capacity of thermoelectric power up to 15% in Europe by 2050 (van Vliet et al., 2016b; Dumitraşcu et al., 2019).

Linnerud et al. (2011) find that a warmer climate in Europe will result in lower power plants thermal efficiency and in reduced load, including shutdowns. They show that the supply of nuclear power is reduced by 0.5% per degree of warming and by 2.0% in cases of droughts and heatwaves (see Figure 3-39). In case of extreme heat and drought, the shutdown factor plays a role on top of the reduced thermal efficiency and reduced load factors. As an example, during the 2003 European heatwave, 30 nuclear units in Europe were forced to shut down or reduce their load because of river water temperature and availability (lower level and discharge). Warmer water temperatures reduce the efficiency of the thermal cycle, while lower water availability limits the load (because of return water temperature legal limitations to the river) and eventually leads to complete shutdowns. Every thermal unit (nuclear or not) is affected by the same factors but nuclear is more vulnerable as its water requirement per energy produced is higher than most thermal power plants.

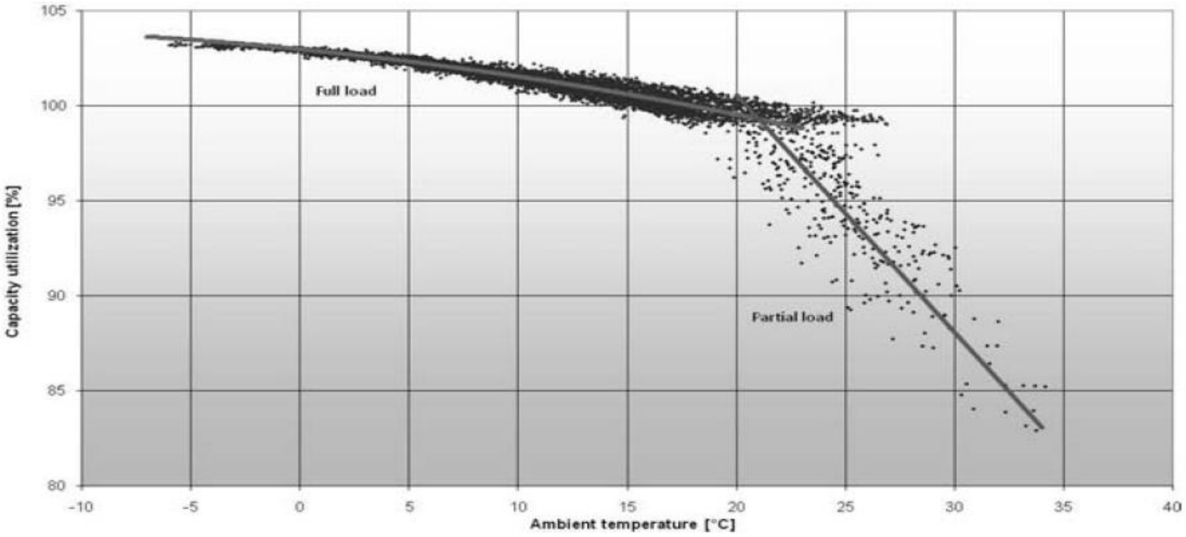

Figure 3-39. Capacity utilization in relation to air temperatures for a nuclear plant, hourly measurements for the year 2007 (Linnerud et al., 2011).

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[1] https://economie.fgov.be/fr/themes/energie/sources-denergie/nucleaire/base-legale-de-la-sortie-du

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Decentralized production

Decentralized electricity production covers all types of renewable electricity production, meaning wind (onshore and offshore), hydro, solar, and biomass (solid and liquid) (see Figure 3-40). Renewable electricity production has risen from 2061 GWh in 2005 to 17,889 GWh in 2019. The rise of renewable electricity in Belgium has been pulled by the development of thermal biomass unit until 2010 and by the development of solar and wind production (onshore and offshore) in recent years (SFP Economy, 2019).

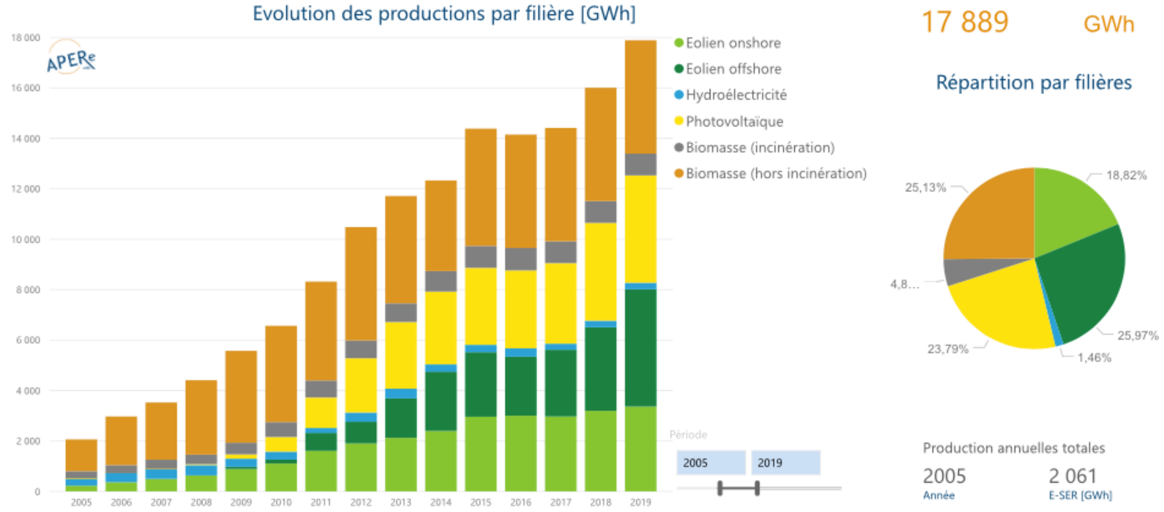

Figure 3-40. Renewable energy production evolution by type 2005-2019. Data come from regional studies: SPW DG04, Bruxelles Environnement, VITO and Eurostat. Source: APERe, 2020.

Belgium has little hydropower due to its lack of relief, which is why its power capacity is mainly concentrated in Wallonia (95%) (APERe, 2020). Its share is decreasing with time as other renewables develop, going from 14.0% in 2005 to 1.5% in 2019 for a constant production (see Figure 3-40). Hydroelectricity's production could be affected by climate change through change in river flow regime, evaporation and dam safety (Mideksa et al., 2010; ICEDD, 2014). However, due to changes in precipitation, the hydroelectric production could rise during the winter and decrease in the summer, especially during droughts, when the hydric stress will be felt the most. This effect will be hard to counter because of the limited storage capacity (ICEDD, 2014). The economic losses due to water flow variability in Wallonia (95% of power capacity of Belgium) are estimated to amount by 2050 to 41% of its production from 2004 to 2012 (Sinaba et al., 2013; ICEDD 2014).

Wind turbines are affected by variation in wind intensity. The power delivered by a wind turbine changes as the third power of wind speed until it has to be stopped for damage control: the cut-in wind speed is around 3 m/s, and wind turbines are shut off above a cut-out speed of around 20 to 25 m/s (Dumitraşcu et al., 2019). Integrated along a year of production, the capacity factor (CF) captures the capacity of a wind turbine to develop its full potential. In Belgium CF is 21.6% for the onshore and 39.1% for offshore wind fields. The overall Belgian wind fleet CF has decreased from around 29% to 25% between the periods 2012-2015 to 2016-2019 (see Figure 3-41). It is unclear how much of this is due to change in wind patterns or dilution of new wind fields placed in less ideal location.

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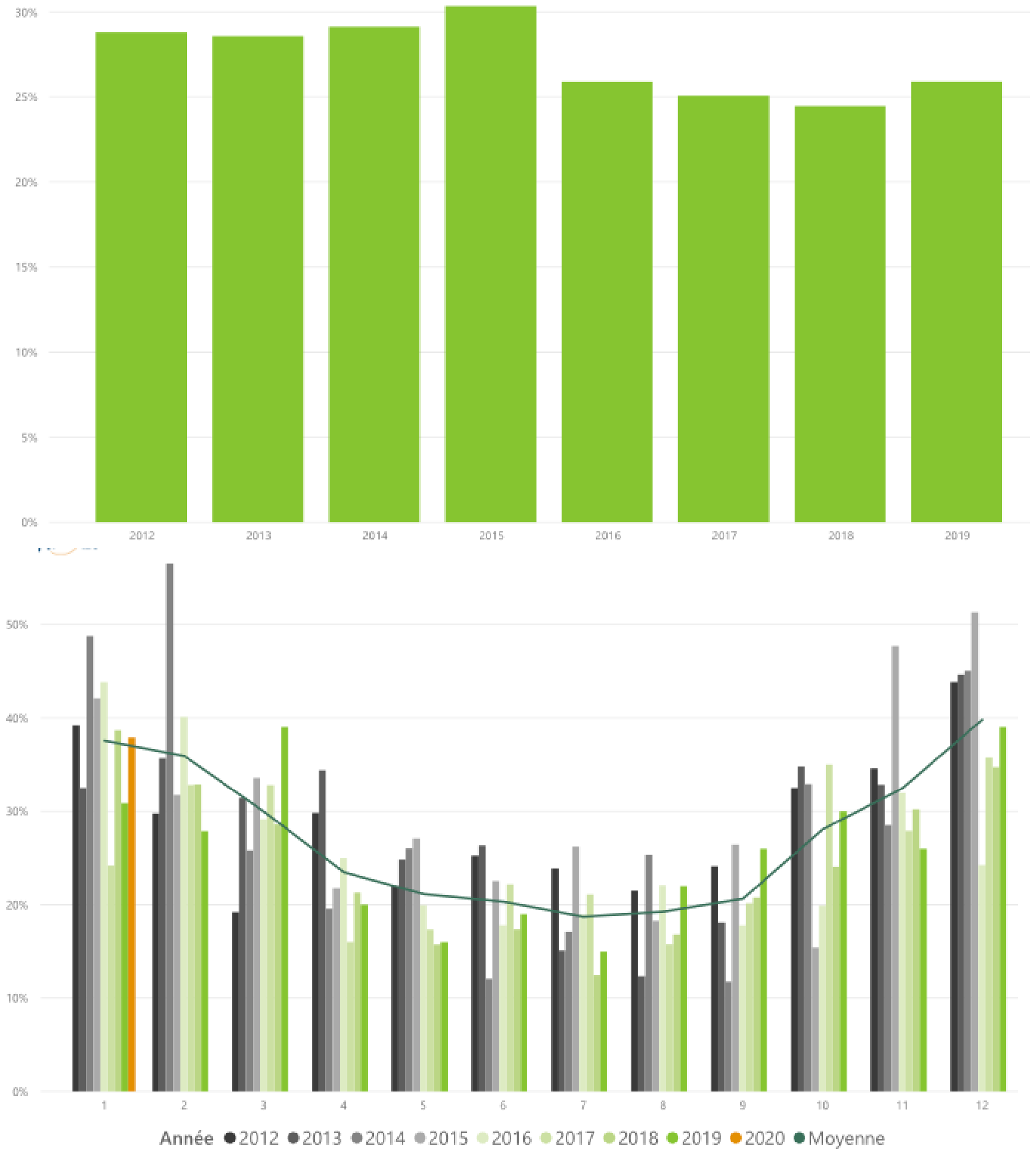

Figure 3-41. Capacity factor (CF) for the Belgian wind electricity production: (top) annual mean CF and (bottom) monthly mean CF (APERe, 2020).

Solar production from photovoltaic cells is also affected by weather patterns, namely sun radiation, cloud cover, wind and temperature. Photovoltaic cells lose roughly 0.4 - 0.5% of production per degree of warming, which seems marginal compared to the rapid technical advancements of the industry (ICEDD 2014; Kaldellis et al., 2014). Cloud cover is a crucial variable, which directly influences solar production; sunshine drop might lead to a drop of 3% to 5% in our region which includes Belgium, Holland and Germany (Jerez et al., 2015).

Electricity transport and distribution efficiency

Elia is in charge of the electricity transportation in Belgium via its high voltage (HV) network of 380 kV, 220 kV and 150 kV. According to ground measurements, losses in the past five years have varied between 1.2% and 1.45%. In the year 2018, Elia estimates its losses to be 717.2 GWh (Elia, 2018). Those losses correspond to heat loss from natural and artificial cooling. In practice, while losses due to electricity transportation and transformation vary with the square of the current being transported. These loses calculated by Elia do not include loses on the distribution side, in the medium voltage (MV) and low voltage (LV) networks.

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Electricity transportation and distribution are affected by air and ground temperatures. The warmer the ambient temperature the higher the loss of power both for the transport (HV), the distribution (MV and LV), and the transformation (voltage reduction) between networks. Electric resistivity is (in first approximation) affected linearly by the temperature of its cables which will mainly be a function of the current load that is being transported under a defined voltage and cable section. Air and ground temperature also play a role in dissipating the cables' temperature.

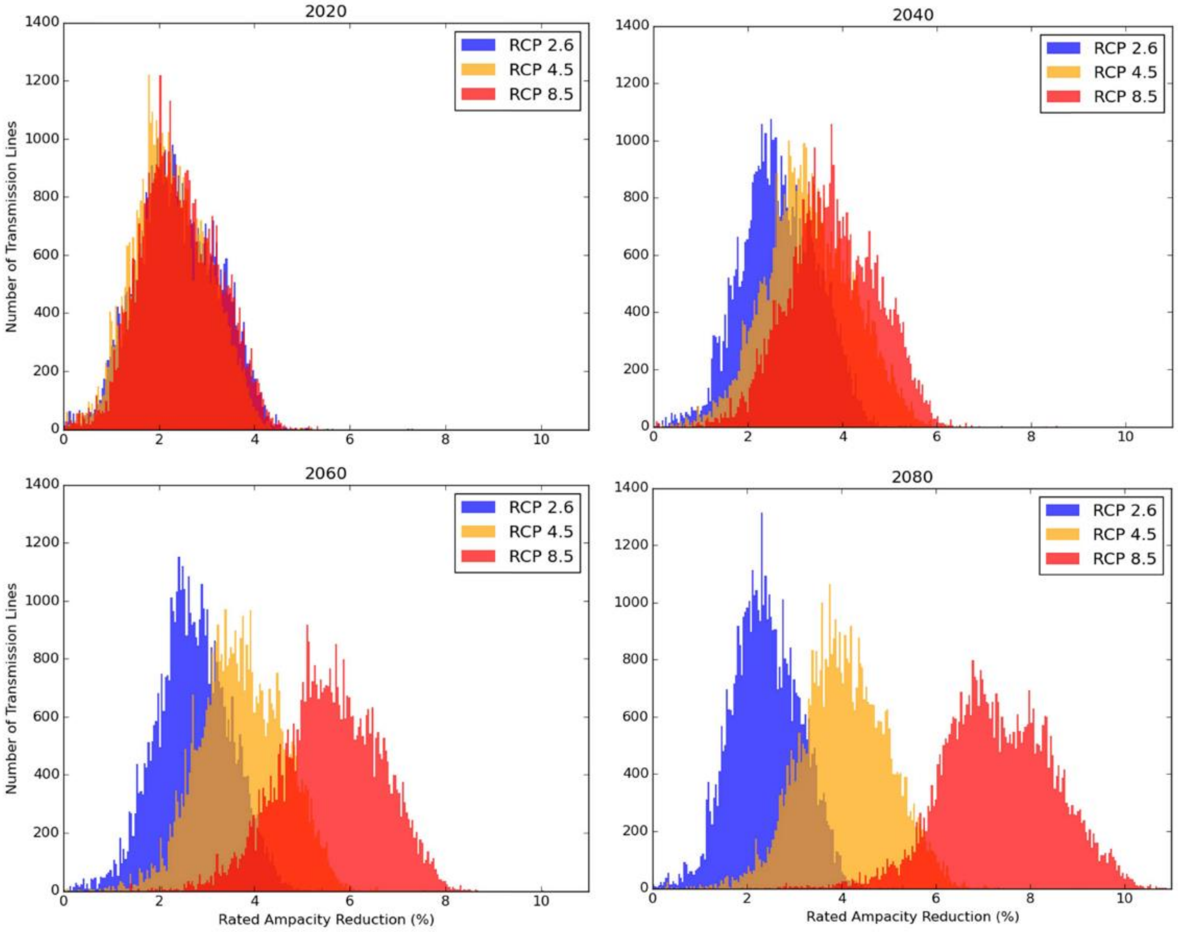

Figure 3-42. Histograms indicating the decreased transmission capacity (in %) for the USA under different RCP scenarios (Bartos et al., 2016).

A rule of thumb made for England in a climate change perspective states that for every degree rise, less than 1% of transport and distribution losses are to be expected. (Surminski et al. 2013; ICEDD 2014). In the US, a study shows that under RCP climate change scenarios, the increase in ambient air temperature during the summer months may result in decreased transmission capacity of 1.9% to 5.8%, for the period 2040-2060 and relative to 1990-2020 (see Figure 3-42). At the same time, during those summer months the demand may rise from 4.2 to 15.0% due to higher air conditioning needs (Bartos et al., 2016).

3.5.2. Impact of higher air temperature on energy demand

Milder winters and hotter summers.

In the energy bill of Belgian households, 73.8% of energy use is dedicated to heating, 12.3% to lighting and electric devices, and 11.7% to water heating (Figure 3-43). Because of its mild summer climate, the energy use in Belgium for cooling is marginal (0.1%). Belgian households are heated principally using natural gas (47.0%) and oil (38.9%). Since 2010, energy consumption for heating purposes has varied between 70% and 77% of total consumption; this is mainly due to variations in winter weather

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conditions (FPS Economy, 2019).

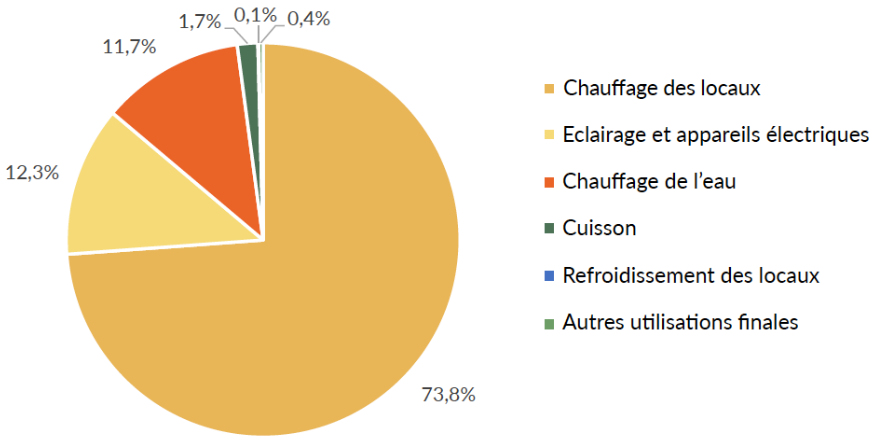

Figure 3-43. Energy usage share of Belgian households in 2017 (FPS Economy, 2019).

Heating Degree Days (HDD) and Cooling Degree Days (CDD) are defined relative to a baseline outdoor temperature below or above which a building is assumed to need heating or cooling. Dumitraşcu et al. (2019) show the following trends regarding HDDs and CDDs over the 1980 – 2017 period in EU countries:

- Population weighted HDDs decreased by 6.5 (corresponding to 0.29% of heating energy consumption) per year. This trend thus has a positive change on the heating needs for buildings (which represent 73.8% of household energy use).
- Similarly, population weighted CDDs increased by 0.9 (corresponding to 1.0% of cooling energy consumption) per year.

These past European trends have therefore had a positive impact on the heating requirements for buildings (which represent 73.8% of household energy use) and a negative effect on the cooling requirements.

For Belgium, EURO-CORDEX simulations forecast a decrease of 4 to 8 HDD per year, and an increase of 0.5 to 1 CDD per year (RCP4.5 and RCP8.5 scenarios) (Dumitraşcu et al., 2019; Spinoni et al., 2018). Looking at HDD and CDD rates of change, we see that the decrease rate of 4-8 HDD per year is 8 times the above-mentioned increase rate 0.5-1 CDD. The ratio of 1/8 becomes 3/8 when considering that primary energy as heating is fuelled by oil and gas, whereas cooling is achieved by electricity. Since air conditioning is powered by electricity, rising CDDs will put extra pressure on electrical networks during heatwaves, coinciding with limited cooling water supply for thermal power generation and heat effect on the power network (Dumitraşcu et al., 2019).

Industry, housing, tertiary sector, and transport sectors.

According to Gusbin and Devogelaer (2017), the energy need has risen by 0.3% per year between 2000 and 2015; this trend is expected to increase to 0.7%/yr by 2030 and 0.8%/yr between 2030 and 2050, further increasing the electricity use as energy vector. The forecasted evolution of final energy consumption by sector in 2050 (with respect to 2015) shows the following trends : industry –11%, housing +10%, tertiary +15%, transport +5%, with a total of +3% final energy demand (see Figure 3-44), and an overall electrification of the sectors (Gusbin and Devogelaer, 2017). This study seems to be contradictory with the evolution of HDDs and CDDs mentioned above as housing demand should decrease in time with the reduction of HDDs.

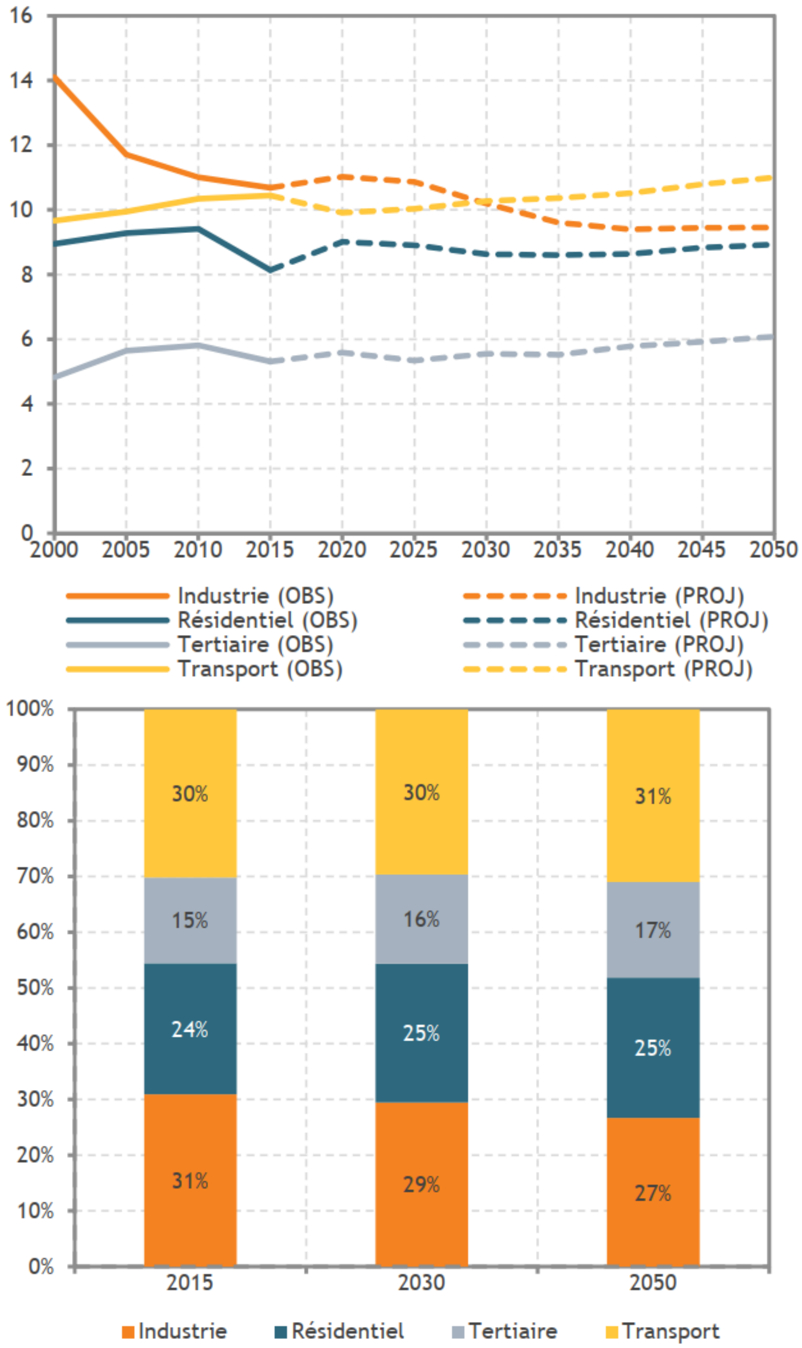

Figure 3-44. Evolution of final energy consumption in the industry, residential, tertiary and transportation sectors (top) in Mtoe and (bottom) in %. Source: Gusbin and Devogelaer, 2017.

Under the low carbon scenario CORE (Cornet et al., 2013) that uses behaviour and technology as levers for change, the picture becomes rather different with important reduction in demand for most sector. This leads to a reduction of total demand from 435 TWh to 270 TWh (see Figure 3-45).

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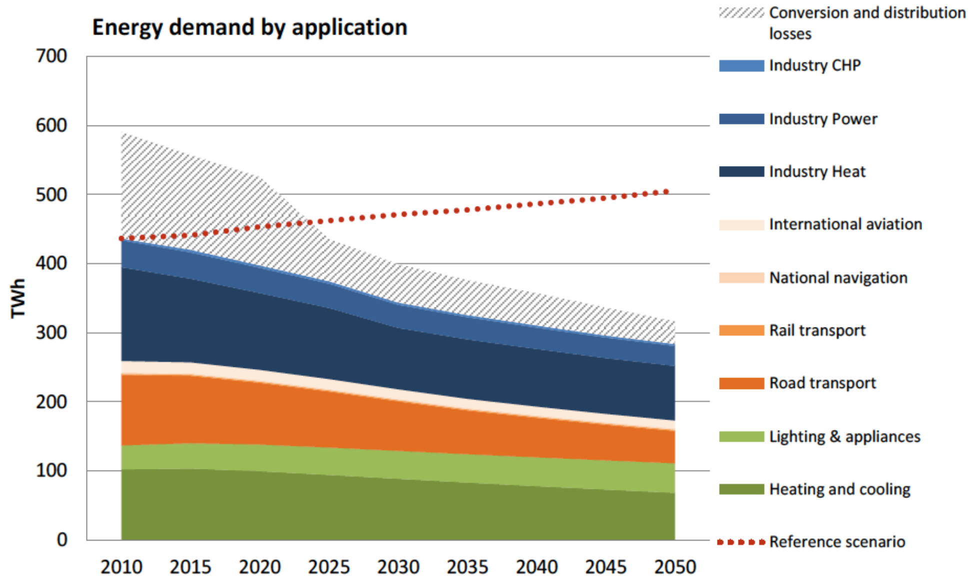

Figure 3-45. Evolution of final energy consumption (in TWh) by sectors under the CORE scenario of Cornet et al. (2013).

3.5.3. Reduced transport capacities for fossil fuel from low-level waterways

Droughts can cause inland waterways to close due to low water levels during droughts. Lower water level can cause the use of smaller ships and partially loaded ships which will rise the shipping costs (Koetse and Rietveld, 2009). Föster & Lilliestam (2010) estimate a reduction of average river flow of 20% (2021-2050) and 44% (2071-2100) for the Meuse river.

3.5.4. Climate change impact on trans-national electricity availability

Rising energy imports from neighbouring countries

The imports referred to relate to regional extreme events such as cold and warm spells, droughts and storms, among other. Belgium is a net importer of electricity, the imported amounts depending on our national electricity production capacity and international electricity prices. Figure 3-47 shows the imports, exports and net imports (red line) in TWh and Figure 3-47 shows the country of origin of the imported electricity (TWh).

The phase-out of nuclear power plants will likely increase our dependency to electricity production from neighbouring countries. Future trends from the PRIMES model show a peak demand for electricity imports of 25 TWh between 2030 and 2040, then decreasing to 21 TWh in 2050 (Gusbin and Devogelaer, 2017).

The energy mixes of exporting countries, which also have their own signatures in terms of climate vulnerability, were as follows in 2016 (EC, 2013):

- The Netherlands: – gas (49%), solid fuels (31.8%), renewables (12.8%);
- France – Nuclear energy (72.4%);
- Luxembourg – renewables (85%);
- England – gas (42%), renewables (25%) and nuclear (21%).

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Figure 3-46. Energy imports, exports and net imports in Belgium, 2005-2017 (in TWh). Source : FEBEG, 2018[1]*.*

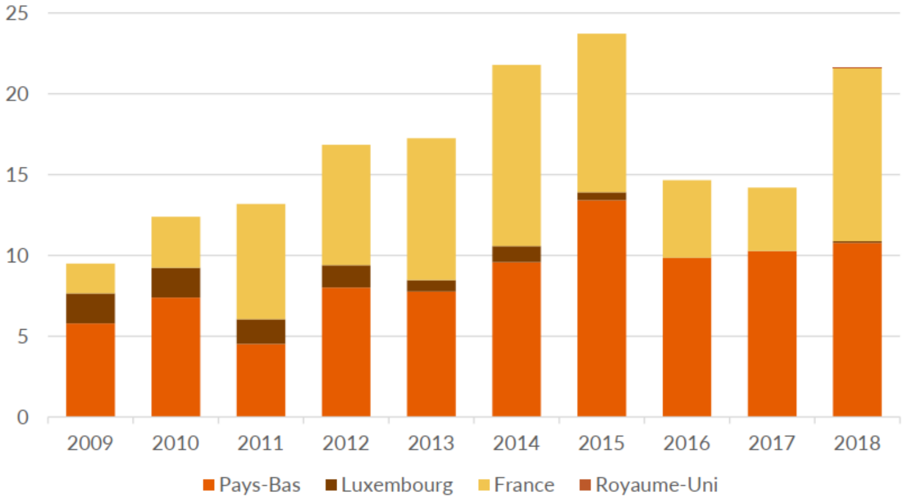

Figure 3-47. Electricity imports to Belgium in TWh by country, from 2009 to 2018 (FPS Economy, 2019).

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[1] https://www.febeg.be/fr/statistiques-electricite

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3.6. FORESTRY

3.6.1. Belgian forestry

The Belgian composition in forest surfaces is different in each of the regions (see Table 3-13 and Figure 3-48) based on OEWB (2019), and the National Forest Accounting Plan (ULiège, 2018):

- **Flanders** has a forest covering about 11% of its surface, of which 30% is privately owned and with a vast majority of deciduous stands (92%) (OEWB, 2019). Homogenous pine forest covers about a quarter of the forested area, decreasing from 40% in two decades, allowing for all the other mixed types of forest to increase.
- **Wallonia** has a larger forest cover (33%), with an even share of public/private owned area. Stands are distributed between deciduous (57%) and coniferous (43%) (OEWB, 2019). Spruce stand area has decreased by 20% over the 2001 – 2012 period. Douglas stands increased by 53% and the total area of the broadleaves stands increased by 4,5%. The composition of stands can evolve with time because of natural competition: Norway spruce and Douglas mix shift to pure Douglas stands for example.
- In **Brussels**, the forest cover is 14%, among which 95% of forests surface are public, with a vast majority of deciduous stands, due to the presence of the Sonian Wood (OEWB, 2019) The main forest stands in the Brussels region in 2010 were pure beech (59%) followed by oaks stands (12%).

This brings the total forest cover for Belgium at 23%. About a third of these forests are protected as part of the Natura 2000 network.

Table 3-13. Forest areas, forest cover, types of owners and group of species (leafy in % and coniferous in %). Source: OEWB, 2019.

Pays/Régions	Surfaces totales (ha)	Surfaces boisées (ha)	Taux de boisement (%)	Forêts publiques (%)	Forêts privées (%)	Feuillus (%)	Résineux (%)
Bruxelles	16 140	2 240	14	95	5	92	8
Flandre[1]	1 352 230	146 381	11	30	70	50	50
Wallonie	1 684 430	557 909	33	49	51	57	43
Belgique	**3 052 800**	**706 530**	**23**	**45**	**55**	**56**	**44**

3.6.2. Forest functions

Our forests play multiple roles: as resources (wood, non-wood products and recreational activities) and as eco-systemic service provider (biodiversity conservation, soil erosion protection etc.).

Forest resources

The average wood harvest volume per year in Belgium for the 2000-2009 reference period is 4.70 million m^3. Future projections for 2021-2025 foresee an increase in harvest of 3% (5.63 million m^3) to 5% (5.67 million m^3) (ULiège, 2018). Laurent and Lecomte (2007a) found out in their study on data from 1999 to 2003 that the harvest volume covers less than 50% of local consumption needs in Belgium.

Forests also serve for recreational activities (tourism and hunting). About 45% of people declare to have visited a forest during the last 12 months for recreational purposes: hiking, flora & fauna observation, biking, pick-nick, scout movement, horse riding, ... (European , 2006; Frisson et al., 2011). The Belgian Ardennes basin, with a forest cover of about 50% attracts a lot of tourists (Laurent and Lecomte, 2007a; based on data from 1994 to 2005). The most popular activity (20.5%) practiced by visitors in Wallonia is hiking and biking (Wallonie tourisme CGT, 2016).

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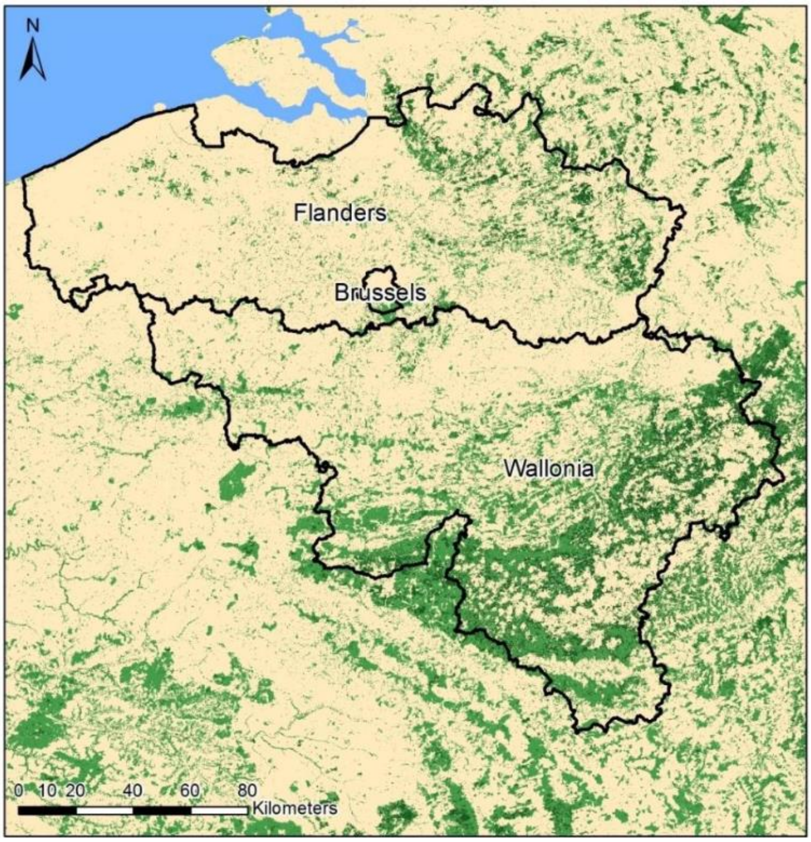

Figure 3-48. Forest cover in the three regions of Belgium in green (ULiège, 2018).

Belgium counts 23,000 hunters (0.22% of total population) (DJV, 2017). Economic profits of hunting account for 17.4% of the gross revenue for the concerned forests (Laurent and Lecomte, 2007b). Chevassus-au-Louis et al. (2009) state a profit of 20 €/ha each year.

Forests also have a positive impact on overall human well-being and health, by reducing stress and mental disease of urban populations (Juvanon du Vachat, 2015), as well as a function of 'natural air conditioning' providing nature enthusiasts shade and cool air during their hike.

Regarding non-wood forest products (NWFPs), such as mushrooms or berries, it appears from a European survey that 8.4% of Belgian households picks (collect) NWFPs (Vidale et al., 2015). Another survey performed in 2006 in Brussels and in Wallonia observed the percentage of forest visitors harvesting NWFPs occasionally: mushrooms (33% of respondents), fruits (30%) and flowers (27%) (Colson, 2006; Frisson et al., 2011).

Eco-systemic forest function

Forests play an essential role as ecosystem service provider (Laurent and Lecomte, 2007b; Frisson et al., 2011), among other being useful

- in the protection of sloping soils erosion;
- in the regulation of water streams in rivers;
- as carbon sink and filter of fine particles in the air;
- as a biodiversity reservoir;
- in the replenishment and filtering of groundwater.

With respect to the latter, Benoit and Simon (2011) show that forest plants need 450 times less phytosanitary treatments than major crops. Forest also have a positive effect on underground water collection for human use, by increasing water quality thus reducing filtering costs of nitrates and phytosanitary products. A model developed for France by Fiquepron et al. (2013) shows that 11.7 M€ are saved in water potability for every additional % forest cover, France having a forest cover of 28%.

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In Belgium, Vivaqua (2012) has since long used afforestation among other strategies in their prevention/protection zones defined above underground water collection area, 1,500 ha being concerned in Wallonia.

3.6.3. *Climate vulnerability*

Direct climatic impacts

Under 'direct climatic impacts' we understand impacts such as storms, droughts and stand optimum change, among other.

Figure 3-49 shows the share (in %) of damaged forest trees in Flanders. The criteria for tree damage is a loss proportion of more than 25% of leaf or needle (INBO, 2018). Following this criterion, 22.8% of trees are damaged in Flanders. Both droughts and storm happened in 2018; storms caused damage to conifers in various areas, while droughts and successive heatwaves caused deciduous stands to show discoloration and early leaf drop.

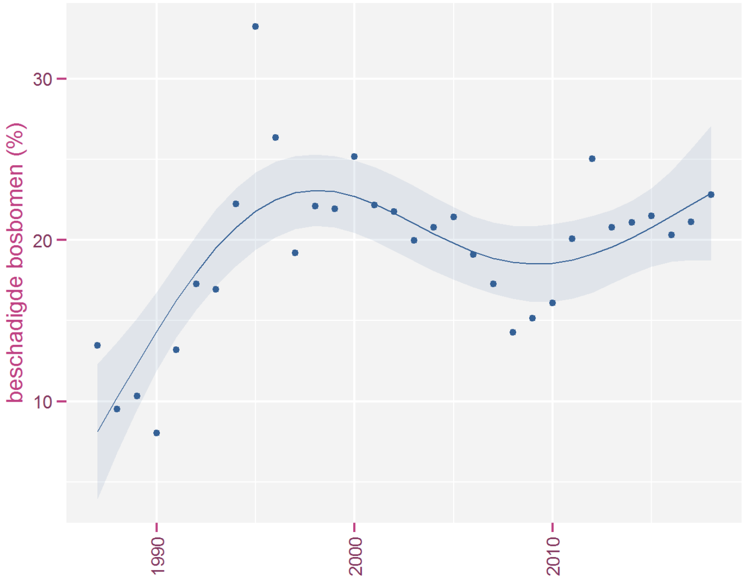

Figure 3-49. Share of damaged forest trees in Flanders (in %). The line shows the trendline of the measures, and the grey surface represents the uncertainty of the trendline (INBO, 2018).

The effect of storms on logging volumes are clearly identified in 2010 in Wallonia (Figure 3-50), while the logging peak of 2002 is a consequence of pest outbreak (bark beetle) and softwood blanking after the storm of 1999 (SPW-DGO3-DNF (IPFRW), 2018). High seed production years (mast years) also reduce the leaf occupation. Reducing atmospheric depositions and increasing good forest management practices increase the forest health, while climate change may further affect it.

Brouwers et al. (2015) show that the temperature anomaly during the 21st century might be 0.5°C higher in the South-East of Wallonia compared to the centre of our country. Climate change will affect the potential area of principal forest species at a very fast pace compared to the natural migration rate of trees (see Figure 3-51). Our region will be more suitable for Mediterranean oak in the future, while the suitable beech area will be strongly reduced. Aside from a translation to the north, there will also be a translation of forest species in altitude; an elevation of 100 m in altitude corresponds climatically to a displacement in the plain of 100 km towards the north (Juvanon du Vachat, 2015). This will pose a major challenge, as the migration rate of trees during previous glaciation/warming cycles throughout history was about 200 to 300 meters per year, while catching up with the pace of current climate change will require a migration speed of at least 1 km per year (Gitay et al. 2001; Fischlin and Migdley 2007; Frisson et al., 2011).

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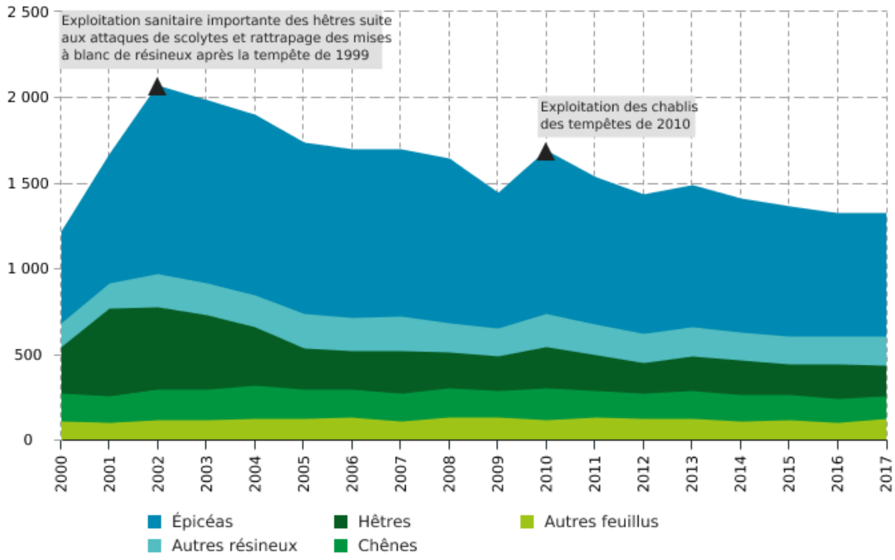

Figure 3-50. Wood harvest volumes (in x1000 m³) from public forests in Wallonia (source: SPW–DGO3–DNF (IPRFW), 2018)

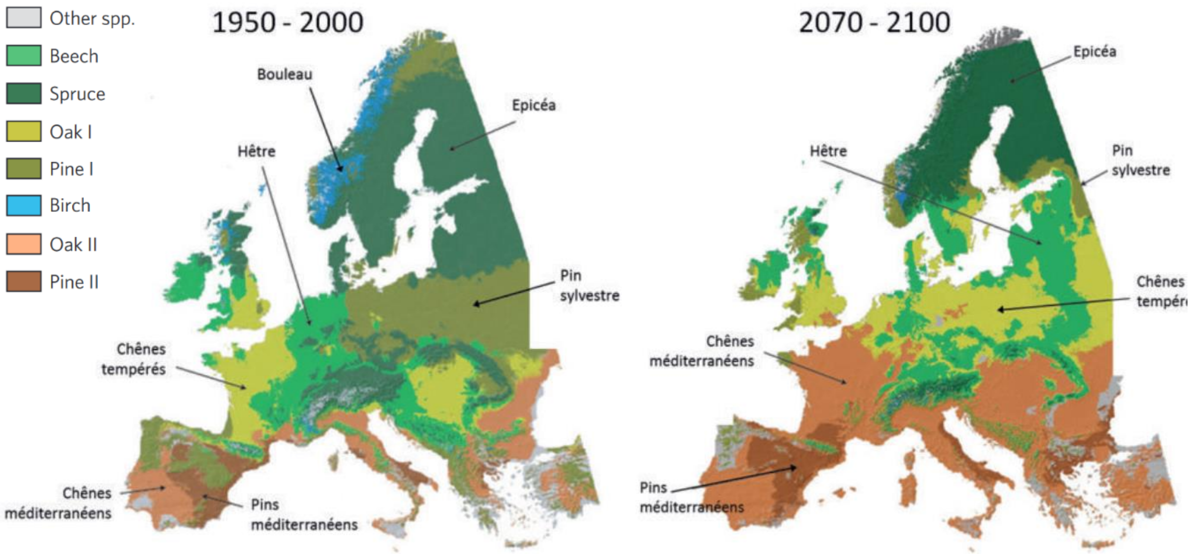

Figure 3-51: Change of potential area of principal forest species in Europe in the past (1950 – 2000) and future (2070-2100) for the A1B scenario (Hanewinkel et al. 2013; Himpens et al., 2017)

About 7% of stands in Wallonia show signs of damage due to climate events (storms, frost, sticky snow …), with a higher proportion found in beech and spruce stands, because of their slender shape and shallow root depth (Laurent and Lecomte, 2007c; Frisson et al., 2011). With increasing spring temperatures, earlier bud burst will be increasingly at risk of late frost damage, which has an effect on growth (Bréda et al. 2000).

Severe and repeated water stress and droughts have a strong impact on tree growth and resistance against pests and pathogens (Frisson et al., 2011). Not all essences are equal to water stress and droughts; the situation of the beech population (in Flanders, Brussels and Wallonia) is a good example: it has seen a rise of radial growth up to the 1960's, then a decline of growth rate because of the rising inadaptability to drier and hotter summers. Ring-width minima correspond to years witnessing droughts (Latte et al., 2015, 2016), also see Figure 3-52.

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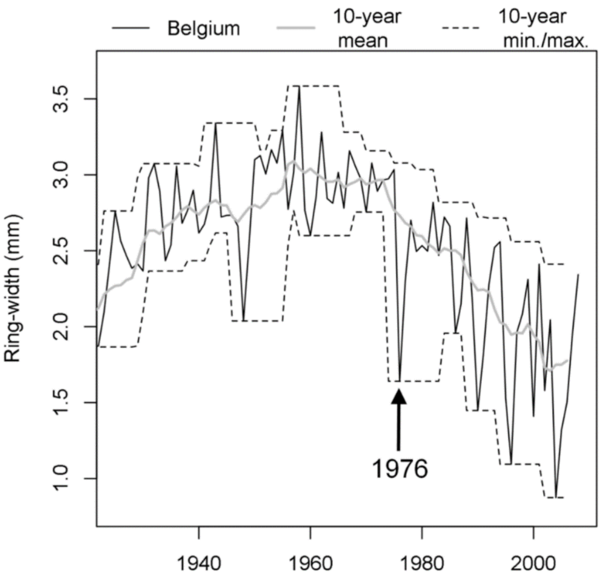

Figure 3-52. Beech dendroecology: variability in ring width (in mm) of beech trees in Belgium, as influenced by climate conditions. Due to extreme weather such as droughts the ring width's trendline is downward. The minima in the curve corresponds to years with extreme weather. Source: Latte et al., 2016.

Daise et al. (2011) illustrate this challenge through the emblematic case of the Sonian forest, which consists for 59% of beech stands. The beech potential stand area, as a result from the above elements, evolves from a 'tolerant' status towards a 'strong exclusion' situation by 2100 (see Figure 3-53), thus rendering the stands vulnerable to pests (Claessens et al., 2012).

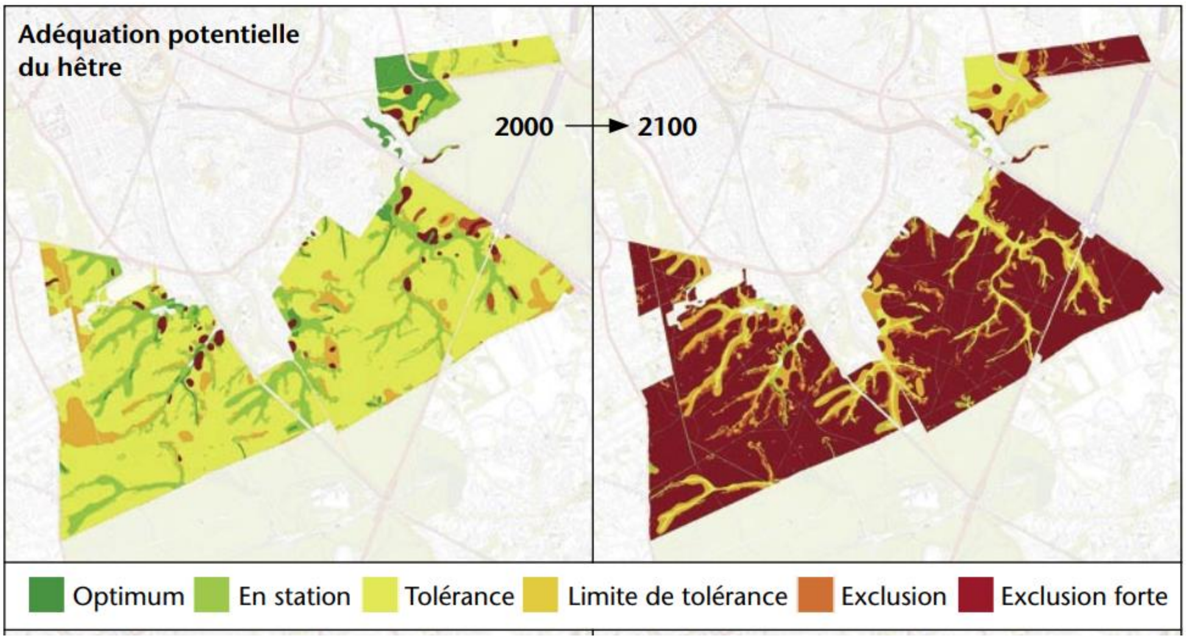

Figure 3-53. Potential area of beech stand zoom on the Brussels part of the Sonian Wood in 2000 and 2100 (according to the A1B scenario). Legend (from left to right): Optimum, in station, tolerance, tolerance limit, exclusion and strong exclusion (Daise et al., 2011; Claessens et al., 2012).

Forest fire risk

Several Western European countries have experienced more large forest fires in areas where these fires were not prevalent in the past. The unprecedented forest fires in 2017 and 2018 coincided with droughts and heat extremes. Also for Belgium, more extreme weather conditions that can stimulate fires, and substantial expansion of (dry) fire-prone areas are projected for the future (de Rigo et al.,

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2017; EEA, 2017). According to Dantec and Roux (2019), fire risk in the northern parts of France (bordering Belgium) might become as extreme or worse than is the case currently in the fire prone Mediterranean regions. This will affect Belgium's scarce forested areas as well as vulnerable heath and other ecosystems. Furthermore, substantial investments in improved fire prevention and suppression measures to protect vulnerable ecosystems are required.

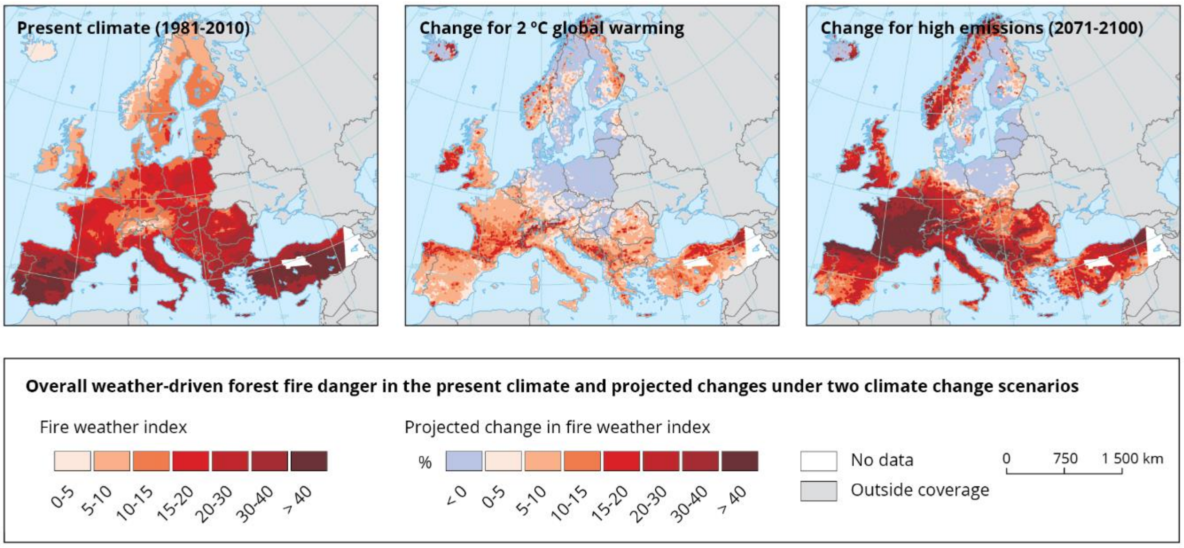

Figure 3-54. Climate change impact on the Fire Weather Index (FWI) in Europe, showing the median FWI from five climate models, the FWI being defined as the 90% quantile of computed daily FWI time series for each period/scenario (high emissions scenario being RCP8.5). Source: de Rigo et al. (2017).

Pests and invasive species

Most pests and invasive species were introduced by man, voluntarily or accidentally. Naturalized exotic plants find suitable conditions for dispersion with climate change and a lack of competition and/or predation. The Belgian Biodiversity Platform (2020) identifies 101 different species (fauna & flora, among which 13 species are in the 'alert list') with growing proportions on their website. Some of the exotic species have only just been introduced in Belgium but are already naturalized in neighbouring regions (Frisson et al., 2011), highlighting the need for an international answer to this phenomenon. In the Sonian forest, identified invasive species (also identified elsewhere in Belgium) include: Himalayan balsamine (*Impatiens glandulifera*), knotweed (*Reynoutria japonica*) and black cherry (*Prunus serotina*). In addition to threatening native flora, the Giant hogweed (*Heracleum mantegazzianum*) can also cause a health threat to the public, causing burns by photosensitization (Sonian Forest Platform, 2017).

Phenological mismatch

Temperature increase also creates phenological changes in the interactions between species such as the hatching of buds (which arrive 5 to 15 days earlier than 50 years ago), desynchronizing insects and their hosts and the food chain along with it[1].

Pullulation[2]

Pullulating organisms are native parasites and diseases that have spread naturally. Cycles of pest outbreaks have always existed, but recently their occurrence has risen due to the milder winters, as is the case for xylophagous and defoliator insects (European spruce bark beetle/ *Ips Typographus*,

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[1] https://climat.be/en-belgique/climat-et-emissions/consequences/biodiversite

[2] For this topic we have been in contact with Pierre-Olivier Bonhomme, forest manager at the Royal Forest Society of Belgium, regarding the recent pullulation issues encountered in Belgium.

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Xylosandrus germanus, ...) and fungus (*Phytophthora cinnamomi*). Some parasites can cope well with higher temperature, seeing their production rate increase, e.g., from one to three generations in a year for the *Ips Typoraphus* (Frisson et al., 2011). The *Ips typographus* has caused a lot of damage since 2018, with about 600,000 m³ contaminated spruce stands in 2018, and about one million m³ in 2019 (RTL INFO, 2019). Despise respecting good practices regarding the stop of proliferation of *Ips typographus* in the Condroz (early cuts in the season), it is hardly possible to stop its spread (Bonhomme, personal communication, n.d.). Apart from the endemic *Ips typographus*, other insects are also well present in recent years in Belgium: *Pityogenes chalcographus* on pines, firs, douglas fir, larches; *Ips cembrae* on larches (Bonhomme, personal communication, n.d.).

A study by Sioen et al. (2017) states records for the fungus *Hymenoscyphus fraxineus* on ash trees in Flanders. The first symptoms of the disease date back to 2007. Symptoms include crown defoliation, crown dieback and other symptoms on the leaves, the branches and the stem. Trees that recently died could also be hosting bark beetles (*Leperisinus varius*) and honey fungus (*Armillaria spp.*) exploiting their host's weakness (Sioen et al., 2017). As a consequence, the average defoliation of ash trees is about 10% higher (34.8%) than the average defoliation of broadleaved trees (25.2%) in the Flemish region (Sioen et al., 2017). The increase of bark beetles is expected to come in waves over large areas, further triggered by storms and droughts (see Section 2.7; Hlásny et al., 2019; Marini et al., 2017).

Physico-chemical condition modification

Eutrophication is an important threat to natural ecosystems, causing biodiversity to decrease if critical loads are trespassed. The phenomenon is caused through atmospheric nitrogen fallout (NO_x and NH_3 pollutants) and the lack efficient fertilizer management, causing population decrease of spruce and beech stands (Frisson et al., 2011). Negative effects of wood logging have repercussion on the exploited forest: soil compaction through machines and clear-cuts causing soil erosion (Laurent and Lecomte, 2007a).

Rising temperature influences the decomposition of organic matter (Frisson et al., 2011), which increases the dissolved organic carbon concentrations in the upland waters, along with declining acid deposition (Evans et al., 2005). New physico-chemical equilibriums in the future are hard to predict (Frisson et al., 2011).

3.6.4. Climate impact on forest functions

Table 3-14 summarizes the climate vulnerability of different forest functions in regard of their conditions and climate-related risks.

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Table 3-14. Vulnerability of forest functions with respect to climate change. (based on Frisson et al., 2011). Legend: '-' no or little vulnerability, '+' medium vulnerability, '++' high vulnerability.

Forest functions		Climate vulnerability	climate change impact
resource use	wood production	- Change of stand optimum - Fire risk - Pullulations & pest outbreaks - Extreme weather: storms and heavy rains, droughts	++
	recreation	- More limited access due to fire risk and storms - increase of visits, ppl escaping cities' heat	+
	NWFPs	N/A	-
eco-systemic	biodiversity reservoir	- Pest & invasive species - Phenological mismatch	+
	climate regulation	- Soil erosion due to high winter rainfall - Soil compaction due to wood harvest machines - Physico-chemical equilibrium modification	+

Recreation

With respect to the recreative use of forests, due to fire risk and increasing storm frequency, some forests might be closed for recreative use more often. On the other hand, the number of visits might also increase during the summer in forest close to cities, people escaping from the heat (Frisson et al., 2011).

Non-wood forest products (NWFPs)

No clear impact of climate change on NWFPs harvest or consumption was found.

Climate regulation

The wood harvest period usually takes place during the winter, when the soil is moist and sensitive. Therefore, the rising winter temperature could make the exploitation location more difficult to access and damage the soil. The wood industry will have to react by spreading the harvest period (Departement LNE, 2012)

Water pollution load might increase with current precipitation projections: the heavy rain during winter will increase the erosion, while the decreasing precipitation in the summer will cause less dilution. However, the impact is expected to be relatively limited, given the efforts to improve water quality that have already been and will be carried out (Departement LNE, 2012).

The interaction between tree species in forests also influences the ecosystem properties. Overall the resistance to environmental stresses of mixed-species forest compared to mono-culture forest is far greater (Isbell et al., 2011; Sousa-Silva et al., 2018).

3.6.5. Climate change awareness among forest owners and managers

In a survey addressing forest owners and managers in Belgium, thus before the consecutive summer droughts of 2018 and 2019, 71% of respondents expressed concern regarding climate change. Interviewees interpreted the following extreme weather events in their forests to be the most linked with climate change: strong winds and storms (35% of respondents), droughts (30%) and extreme precipitation (21%) (Sousa-Silva et al., 2016), also see Figure 3-55 and Figure 3-56. 32% of the interviewed adapted their management practices; among them, 96% established mixed stands and 92% planted better-adapted species (Sousa-Silva et al., 2016)

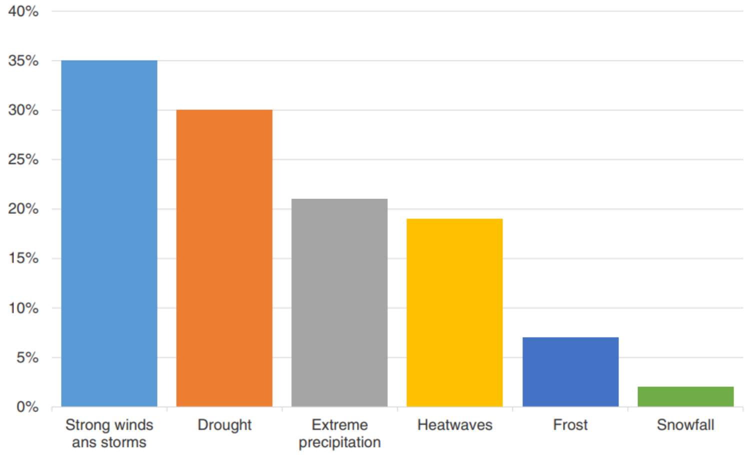

Figure 3-55. Experienced climate change related (or perceived) extreme events. Percentage of respondents who answered to the question: 'What is your experience regarding extreme weather events in your forests that you interpreted as caused by climate change?'. Source: Sousa-Silva et al. (2016)

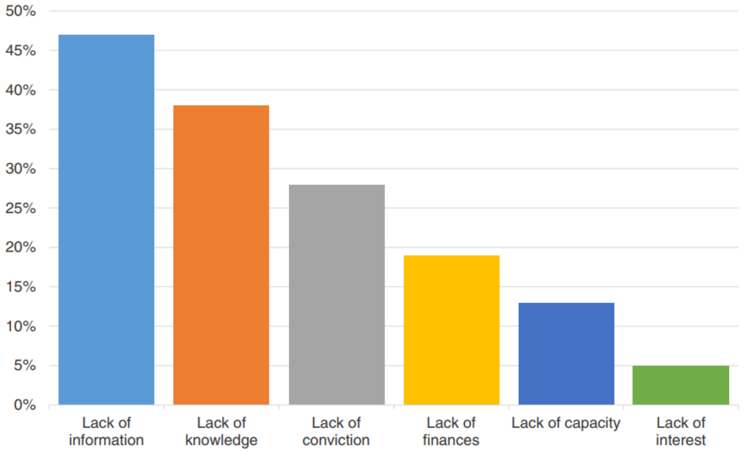

Figure 3-56. Constraints limiting climate change adaptation. Percentage of respondents who answered to the question: 'What are the greatest constraints limiting your ability to undertake climate adaptation actions?'. This question was asked to respondents who had previously answered that they didn't adapt their management practices regarding climate change. Source: Sousa-Silva et al. (2016).

About 68% of the interviewees did not modify management practices in answer to climate change (Sousa-Silva et al., 2016). The main reasons for this gap between concern and action were found to be the lack of information, technical knowledge, and conviction (Sousa-Silva et al., 2016), as also shown in Figure 3-56. Knowledge sharing regarding climate adaptation actions on forest areas are thus a key element to help forests towards more resilience.

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3.7. AGRICULTURE

Based on research and field observations, EEA (2019b) concludes that climate impacts have already led to poorer harvests and higher production costs, affecting price, quantity and quality of farmed products in Europe. Climate modelling shows that conditions for growing crops will improve in parts of northern Europe, while crop productivity in southern Europe will decrease. According to projections using a high-end emission scenario, yields of non-irrigated crops like wheat, corn and sugar beet are projected to decrease in southern Europe by up to 50% by 2050. This could result in a substantial drop in farm income by 2050, with large regional variations. In a similar scenario, farmland values are projected to decrease in parts of southern Europe by more than 80% by 2100, which could result in land abandonment. Trade patterns are also impacted, which in turn affects agricultural income. While food security is not under threat in the EU, increased food demand worldwide could exert pressure on food prices in the coming decades.

In the following paragraphs, observed and expected impacts of climate change on agriculture in Belgium are described, preceded by a brief overview of the characteristics of the Belgian agricultural sector.

3.7.1. Agricultural sector in Belgium

According to Statistics Belgium (2018) agricultural lands account for 44% (or 1,353,770 ha) of the land surface of Belgium. In 2018, the total amount of agricultural land consisted of 63% arable land, 35% permanent pastures and grassland and 2% permanent crops.

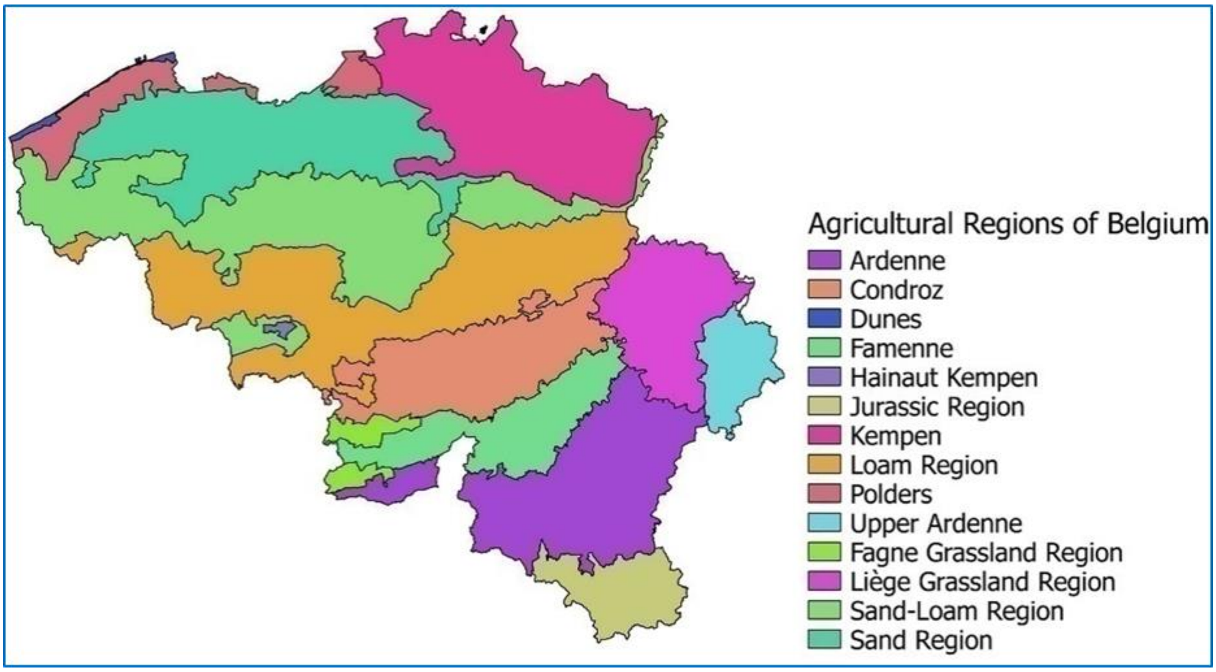

Figure 3-57. Agricultural regions of Belgium. Source: Geopunt.be.

Belgian agriculture is specialised in cereals, industrial crops, forage plants, vegetables and horticultural crops, potatoes, livestock and milk production. Although agricultural land occupies the greater part of the territory (44%), the number of farms has continued to decrease in recent years, while the average farm size has increased. The share of agriculture in the Belgian economy continues its decline and is now less than 1% of GDP. The major arable crops that occur in Belgium are grain (and fodder) maize, sugar beet, potato, winter wheat, and winter barley (Statistics Belgium, 2018). The major livestock production mainly concerns cattle, pigs and poultry. In northern Belgium intensive pig, poultry and dairy farming, vegetables, fruit and horticulture are the dominant activities, while southern Belgium is characterised by arable farming and extensive land-related livestock farming.

Figure 3-57 gives an overview of the main agricultural regions of Belgium (Geopunt Vlaanderen, 2020) and Figure 3-58 shows the Corine Land use cover data for Belgium (NGI, Geo.be). Arable land can be found mainly in the Loam region, Sand-loam region, Condroz and Polders.

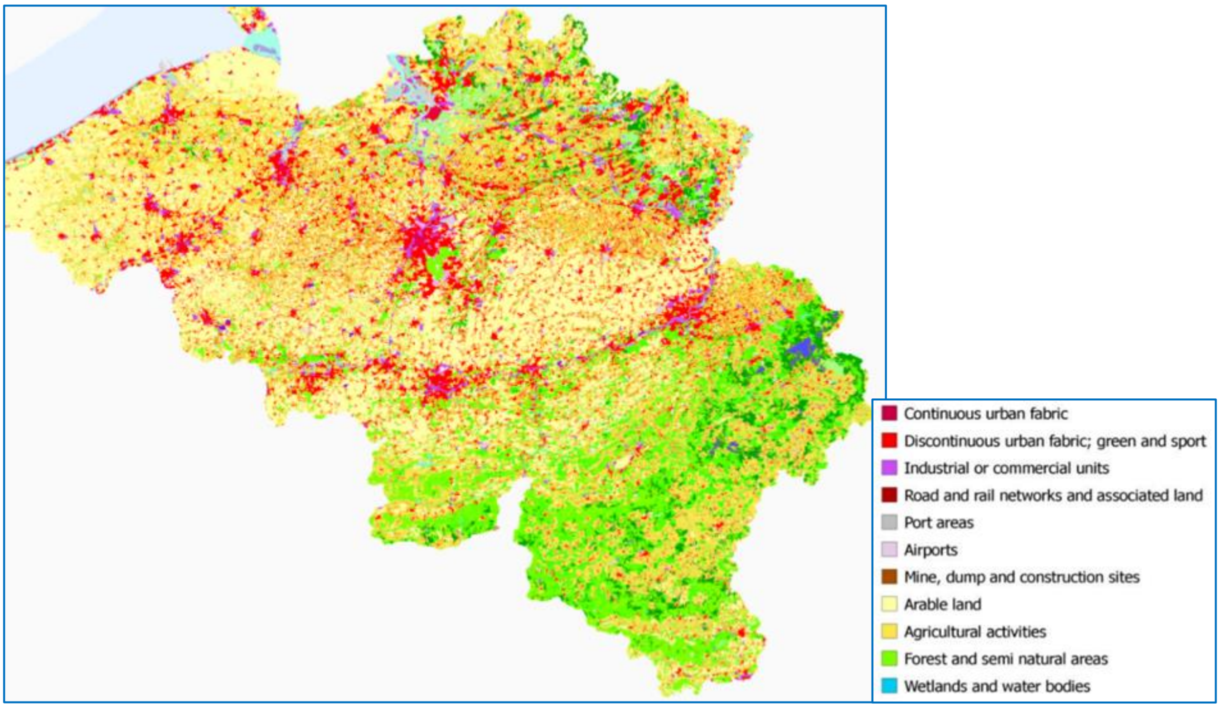

Figure 3-58. Land use map of Belgium. Source: NGI, Geo.be)

3.7.2. Vulnerability

The agricultural sector is very sensitive to the impact of changes in environmental conditions such as temperature, precipitation levels, amount of sunlight, water availability, CO_2 concentration levels, soil and plant evaporation, soil and water quality, among other. Optimal growth of agricultural crops and yield relies strongly on specific temperature ranges and precipitation levels (Vanuytrecht, 2020). Observed changes in mean temperature and precipitation as well as changes in weather and climate extremes are already influencing crop yields and livestock productivity in Belgium. As a further increase in the number of extreme weather and climate events is predicted, agriculture will face higher interannual variability in yield and product quality, with increased risks of crop losses and negative impacts on livestock production, and consequent price volatility (Chen and Villoria, 2019).

The main driver of the climatic changes is the increase in atmospheric greenhouse gases, of which CO_2 is one. Since plants use atmospheric CO_2 to produce biomass, crop production can be boosted by elevated CO_2 concentration. Yet, the CO_2 fertilisation effect can only be realised under optimal conditions, when sufficient water and nutrients are available (Vanuytrecht, 2020; Vanuytrecht et al., 2012). Moreover, the quality of food (and feed) crops can be negatively influenced by growth at higher CO_2 concentration, because the concentration of nitrogen (important for protein production, Lam et al., 2012) and micro-nutrients in grains (Broberg et al., 2017) is decreased (Vanuytrecht, 2020).

Extreme events in particular, such as more frequent of prolonged heatwaves, droughts and flooding, combined with major changes in mean temperature, precipitation regime and atmospheric CO_2 concentration for plants, have a major impact on agriculture:

- persistent periods with extremely high temperatures and increased evapotranspiration can cause drought, which puts pressure on both crops and farm animals and leads to loss of efficiency and lower productivity;
- episodes of extreme temperature can lead to sterility, reduced productivity (both in terms of quality and quantity) and lethality for both crops and animals;

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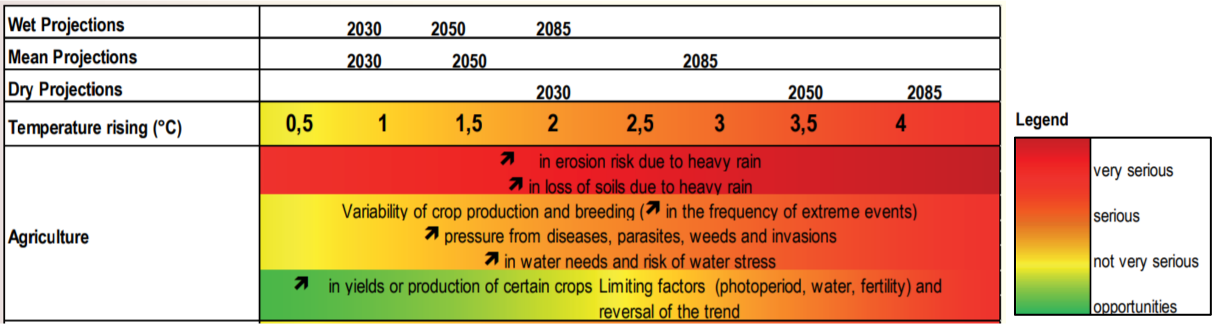
- reduced precipitation, particularly in summer causes a reduction in the quantity and quality of freshwater sources (surface water and groundwater) and consequent water stress for both crops and animals;
- periods with high precipitation rates in the winter season as well as during extended periods in the summer season cause flooding and lead to harvest losses;
- climate change induced disruptions of ecosystems include development of pathogens, spread of invasive species, imbalance between pests and their natural enemies, phenological mismatches between the life cycles of crops and associated pollinators (i.e. mismatches in the timing of periodic life cycle events of species);
- direct and indirect impacts on the health and welfare of farm animals: temperature rise, increased risks of flooding and droughts have a direct impact; the reduced availability of water and feed and the spread of vector-borne infectious diseases that are highly dependent on climatic conditions exert an indirect impact.

Northern Belgium is especially vulnerable for drought because of the unsustainable management of rivers, waterways and groundwater in the past and the high degree of urbanisation and compaction and sealing of the soil.

An overview of the expected main impacts of projected climatic changes concomitant with increasingly rising temperature and their severity for crop production in Belgium is shown in Figure 3-59 (NCC, 2017). The rise in temperature will occur more rapidly and extensively according to the different climate change projections considered.



Wet Projections		2030	2050	2085				
Mean Projections		2030	2050			2085		
Dry Projections				2030			2050	2085
Temperature rising (°C)	0,5	1	1,5	2	2,5	3	3,5	4
Agriculture	↗ in erosion risk due to heavy rain ↗ in loss of soils due to heavy rain Variability of crop production and breeding (↗ in the frequency of extreme events) ↗ pressure from diseases, parasites, weeds and invasions ↗ in water needs and risk of water stress ↗ in yields or production of certain crops Limiting factors (photoperiod, water, fertility) and reversal of the trend							

Legend

very serious

serious

not very serious

opportunities

Figure 3-59. Summary of the main impacts on the agricultural sector in Belgium (Source: NCC, 2017).

These general findings are also confirmed by various European studies (EEA, 2017; EEA, 2019b). In EEA (2017) an indicator-based assessment of past and projected climate change impacts and vulnerabilities of and risks to agriculture, among others, is presented. The report identifies regions that are experiencing particularly severe climate change impacts. Conclusions are based on a wide range of observations and model simulations.

Concerning agriculture, for Europe in general, an increase in the duration of the thermal growing season has led to a northward expansion of areas suitable for several crops. In cereals, changes in crop phenology, including the advancement of flowering and maturity dates have been observed. Reduction in yield of some crops caused by recent heatwaves, droughts, extreme precipitation and hail has been noticed. An increased frequency of extreme events is expected to raise the risk of crop losses and to impose risks for livestock production throughout Europe.

In southern Europe, with its prevailing considerable competition between different water users, irrigation demand is projected to increase. An improvement of the suitability of northern Europe for growing crops and a reduction of crop productivity in large parts of southern Europe is expected in the future. Projections based on different climate models agree on the direction of the change, but with some variation in its magnitude. Effects will also vary between crop types and livestock categories and they are and can be moderated by short- and long-term adaptation efforts.

Table 3-15 summarises the direction of the key observed and projected climate change impacts on agriculture for the temperate region. Northern Belgium belongs to the Atlantic region, southern

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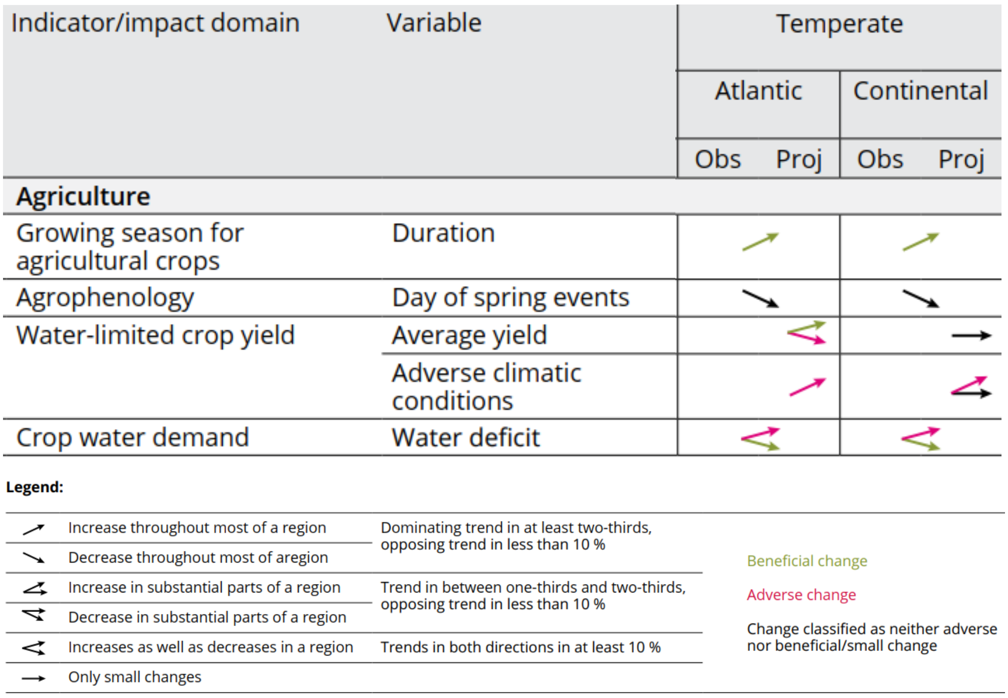
Belgium to the continental region.

Table 3-15. Overview of past trends and projected changes for indicators of climate change of relevance to the temperate region (Source: EEA, 2017)



Indicator/impact domain	Variable	Temperate			
		Atlantic		Continental	
		Obs	Proj	Obs	Proj
Agriculture					
Growing season for agricultural crops	Duration	↗		↗	
Agrophenology	Day of spring events	↘		↘	
Water-limited crop yield	Average yield		↗↘		→
	Adverse climatic conditions		↗		↗→
Crop water demand	Water deficit	↗↘		↗↘	

Legend:

↗	Increase throughout most of a region	Dominating trend in at least two-thirds, opposing trend in less than 10 %	Beneficial change
↘	Decrease throughout most of aregion		Adverse change
↗→	Increase in substantial parts of a region	Trend in between one-thirds and two-thirds, opposing trend in less than 10 %	Change classified as neither adverse nor beneficial/small change
→↘	Decrease in substantial parts of a region		
↗↘	Increases as well as decreases in a region	Trends in both directions in at least 10 %	
→	Only small changes		

On average, when considering impact on agriculture, in the Atlantic region (northern Belgium) an increase in heavy precipitation events, in river flow and in risk of river and coastal flooding and damage risk from winter storms are expected and in the continental region (southern Belgium) the most important impacts on agriculture are an increase in heat extremes and in risk of river floods and a decrease in summer precipitation. In the coastal zone, sea level rise and intrusion of saltwater need to be considered (EEA, 2019b).

In general, agriculture in Belgium has ample adaptation possibilities that allow to cope with a change of climate, at least up to a temperature rise of around 3°C (Van Ypersele and Marbaix, 2004). For crop production, advancement of sowing dates and use of longer growing cultivars can be effective adaptation measures, that already have been applied (Olesen et al., 2012; Vanuytrecht et al., 2016). The evolution of agriculture will also heavily depend on socio-economic policy. Adaptation becomes more difficult and more expensive the more radical climate change becomes. Above certain physiological thresholds, the fertilising effect of CO_2 reaches a ceiling and yields decrease, regardless of the adjustment measures, because the temperature becomes extremely high or because of a lack of water.

3.7.3. Impact of rising temperatures, extreme heat stress and drought

Mean temperature rise

Between 1992 and 2008, the length of the average thermal growing season in Europe has increased with approximately 11.4 days due to temperature rise (climat.be). The delay in the end of the growing season has been more pronounced than the advance of the start of the season. The increase in length is less pronounced in western and southern Europe than in northern and eastern Europe. Taking into account the projected greenhouse gas emission and concentration scenarios, and concomitant temperature rise, a further increase throughout most of Europe is expected, with an earlier onset of growth in spring and a later senescence in autumn. A longer potential growing season may, in many cases, allow for the introduction of new crop cultivars that were previously unfavourable (because of low temperatures or too short growing seasons), mostly by adopting cultivars and species that were previously grown in more southern regions. Yet, climatic changes and prolonged growing periods may also cause an increase in incidence of plant/animal diseases and the spread of weeds (Olesen et al., 2011). In addition, the date of the last frost in spring is projected to advance by about 5–10 days by 2030 and by 10–15 days by 2050 throughout most of Europe. Northwards expansion of warm-season crops to areas that were previously not suitable for these crops becomes possible. In western France, the Benelux and parts of south-eastern Europe, yield reductions from hot, dry summers without the possibility of shifting the crop production into the winter seasons are expected (EEA, 2017).

While a rise of the average temperature may lengthen the potential growing season, it simultaneously tends to lower the yield of many currently growing crop cultivars. This decrease results from faster plant growth at higher temperatures, hence shorter growing stages, less radiation interception and reduced biomass accumulation. Also, chilling and vernalization requirements of winter crops (i.e. the number of days of low temperatures needed to induce cold hardiness) may not be met when the average temperature rises (Vanuytrecht, 2020). Adaptation measures (at farm level) such as changes in crop choices, changes in sowing dates, altered field practices that lead to improved organic content of soils and investment in irrigation infrastructure can help to mitigate the negative impact of climate change and lead to fewer yield losses.

For livestock farms, a benefit of higher temperatures is the reduction of heating requirements in stables due to the milder winter period, but this effect can be counteracted by increased cooling or ventilation requirements in summer.

Heat

Heat stress (daily maximum temperatures above 30-35°C), particularly during reproductive growth stage, is harmful for crops and can reduce the number of flowers, fruits or grains. In addition, during clear and hot summer days sunburn can lead to visual damage and reductions in product prices (Vanuytrecht, 2020). In Belgium, 2019 was a remarkable year as three heatwaves occurred, at the end of June, July and August. 2019 was the fifth year in a row with at least one heatwave. In terms of the number of heatwaves, only in 1947 more consecutive heatwaves were recorded (four). The heat and drought in July had a clear impact on crop growth, partly temporarily, partly also definitively. Potato, maize, vegetables and grass stopped growing or accelerated to ripening. In the fruit sector, mainly apples but also pears were affected by sunburn, making them unsaleable. Irrevocable damage has mainly occurred with fruit and vegetables, some potato varieties and with maize that was in bloom during the heat. Other crops recovered partly or completely due to rain showers in August. An undesirable sprouting effect occurred in some potato varieties following the rain induced cooling effect. Plants had formed new tubers during the heat stress. The majority of Bintje plots were therefore treated with maleic hydrazide (an herbicide) to inhibit sprouting.

Besides crops also farm animals may suffer from warm and dry summers. When persistent high temperatures are accompanied by drought, animals are particularly affected by heat stress, both in the stable and outside. During heatwaves more animals die. Measures are needed in the stable to limit temperature rise. In the meadows, animals must be able to protect themselves against the sun through shelter, artificial or natural. In addition, farm animals should have sufficient drinking water and good quality feed. If there is insufficient quality meadow grass, supplementary feeding is necessary. During heatwaves, cows produce less milk, while beef cows start to gain less weight. Optimal production temperatures for dairy cows are 12 - 15 ° C. The digestion of cattle produces a lot of heat, under heat stress farm animals will therefore eat less, which may lead to rumen acidification. As a result, cows will produce less milk and a higher risk of rumen acidification and hoof problems will occur. Drought and heat stress can have an impact on feed prices and production results, and therefore also on the profitability of farms.

Drought

Under a warmer climate, periods of drought can become more frequent because evaporation of soil moisture and transpiration from crops increase. Drought can be defined as the unusual and temporary deficit in water availability. When the available water resources become insufficient to satisfy long-term average water requirements crop yield will decrease. Drought in summer will have a negative impact on crops, particularly those with superficial roots, such as sugar beet and potato. More frequent and more severe periods of drought were observed in the last decade. Drought is considered as one of the most impacting disasters nowadays and will become even more substantial with the projected global warming. Dantec and Roux (2019) state that, while the impact of drought (in France) might be manageable until the 2050s, extreme drought may become a major threat in the absence of suitable adaptation measures.

The agricultural sector is one of the major users of land and water in Belgium. Agriculture is dependent on precipitation and for agricultural processes, ground and surface water as well as tap water are used. A water shortage due to drought can lead to lower physical crop yields and a decrease in quality of products. Irrigation for agricultural crops with ground- and surface water can also be hampered during severe drought periods. A specific problem for animal husbandry is the withering of grassland, as a result of which the supply of animal feed decreases, and less manure can be spread. The effect of drought on agriculture depends on several factors: the frequency and timing of the drought, the region and soil type, the crop type, the available amount of (stored) water in the water system and the possibility to irrigate (Ecorys, 2019). In 2018, the cattle breeding sector in Western Europe was severely affected by drought, with estimated losses in France alone amounting to 1.5-2 B€ (Dantec and Roux, 2019). Marked shortages in fodder, and the associated price increase, forced many farmers to proceed to premature slaughtering, which gave rise to lower meat prices.

Drought and heat stress are among the two most important environmental factors influencing crop growth and yield. Gobin (2012) studied the impact of drought and heat stress on arable crop production in Belgium by comparing meteorological data between two periods (1947-1987 and 1988-2008). The study showed that the observed impact on crop growth is twofold, owing to the sensitive stages occurring earlier during the growing season and to the changes in weather patterns with climate change. Since crop development is driven by thermal time, comparison of the data of the two periods revealed that crops matured earlier during the warmer 1988–2008 period than during the 1947–1987 period. Gobin (2012) concluded that the sum of vapour pressure deficit during the growing season is the single best predictor of arable yields at the national scale. Water and heat stress, in particular during the sensitive crop stages, occur at different times in the crop season. Soil water deficit increases towards harvesting, in such a way that earlier maturing winter crops may avoid drought stress that occurs in late spring and summer. Summer crops may benefit from earlier planting dates and subsequent beneficial moisture conditions during early canopy development, but will suffer from increased drought and heat stress during crop maturity. Though average yields have risen continuously between 1947 and 2008, there is no evidence that relative tolerance to adverse weather conditions such as atmospheric moisture deficit and temperature extremes has improved.

In 1976, 2011, 2017, 2018 and 2019 extreme drought periods in summer occurred in Belgium. The temperature rise and the lack of rain during several consecutive weeks caused more evaporation of soil moisture with significant damage to summer crops in Belgium. With a projected decreasing amount of rain in summer, extreme drought can occur more often and more intensively in the future. Economic consequences of drought can be considerably higher than the other climate effects in the agricultural sector.

Beriaux et al. (2018) studied the impact of the exceptional drought in Wallonia in July 2018. The crops most affected by the drought were spring-sown crops like maize, potato and pastures. The 2018 drought affected summer crops like corn and potatoes during the flowering and growing period, being the most sensitive stages in plant development, leading to an irreversible negative impact on the final yield. The agricultural drought of 2018 in Wallonia was monitored on the basis of two indices from Sentinel-2 satellite images of the European Copernicus programme:

- NDWI: normalised difference water index which is sensitive to the water content of plant

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cover and
- NDVI: normalised difference vegetation index which is strongly correlated with the amount of green biomass.

This was done for three types of land use that were likely to be the most impacted: pastures (47% of the declared agricultural area in Wallonia), potatoes (5.9%) and maize (8.1%). The two indices were used as yield indicators and provided an overview of the spatial distribution of the state of the vegetation in relation to the drought in Wallonia in 2018. As confirmed by weather data, 2018 was a year that stood out from the previous years for the crops studied. It emerged from the study that the impact of drought followed a gradient from the North (more pronounced drought) to the South of Wallonia.

Drought conditions in 2018 in Belgium hit the production volumes of a number of crop products. In particular, the harvested production of potatoes (down by 31.0% to 3.0 million tonnes), of sugar beet (down 12.6% to 5.2 million tonnes) and of cereals (down 10.2% to 2.5 million tonnes) were all substantially lower in 2018 than in 2017 (Eurostat, 2019). Crops on sandy soils in the northern part of Belgium are more sensitive because these soils have a lower water holding capacity, with more risks of harmful consequences for crops (food and fodder). Winter crops had their flowering and growing period long before the heatwave and the drought period in 2018, which led to a better harvest for these crops than in 2017. The winter crops could also be harvested 1 to 2 weeks earlier than average.

Besides yield reduction (and a direct impact on a farmer's income), droughts will also result in an increased demand for irrigation water. In 2018 and 2019 a severe shortage of water in agricultural areas during summer occurred, resulting in an increased conflicting demand for water by different sectors (public health, shipping, industry, agriculture, nature, …), which also suffered from decreased (drinking) water availability (Stroomgebiedbeheerplan Schelde, 2016-2021). Irrigation is however not applied on a large scale in Belgium. Only 1.8 percent of the agricultural area is irrigable (Eurostat, data 2016). Eurostat makes a distinction between irrigable (equipped for irrigation) and irrigated (effectively irrigated) land. The latter can fluctuate significantly, depending on, for example, the weather conditions or the water requirements of different crops. On average Belgian arable land receives enough rain and therefore needs little or no irrigation. The amount of irrigated agricultural land in 2016 was only 0.8%.

An increasing drought risk is also expected to reduce livestock productivity through negative impacts on grassland productivity and animal health. The consequences of the extreme drought can be very different, not only due to the occurrence of different soil types (their water holding capacity and the content of soil organic matter) but also due to variation in precipitation patterns and precipitation shortages and due to differences in the amount of available roughage stocks from previous years. Permanent grassland appears to be more vulnerable to extreme drought than temporary or young grassland. In addition, (red) clover appears to be more resistant to drought than English ryegrass. The consequences of drought for the farm consist of extra feed concentrates and roughage, extra irrigation, extra grass seeds and extra weed control. On the other hand, there is a saving on fertiliser and feed extraction. Drought will also have adverse consequences in the period after the drought, on the development of grass and feed value, in particular during the first cut of the following year, due to the deterioration of the sod quality.

Wreford et al. (2020) focus on livestock in the United Kingdom, as Belgium a temperate region likely to experience at least moderate changes in climate that will require changes in agricultural systems operation. They summarised projected climate changes in this region, identified the main impacts likely to affect livestock agriculture and discussed potential adaptation options at the farm level. The adaptation options were categorised by the types of costs they incur, emphasising that many of these options involve management changes rather than investments, and therefore no financial cost. Finally, the need for longer term planning to prepare for changes that have not yet been observed is discussed. The focus in this study was on the UK, but the approach, as well as many of the proposed measures (adaptations), can be applied in other (temperate) areas.

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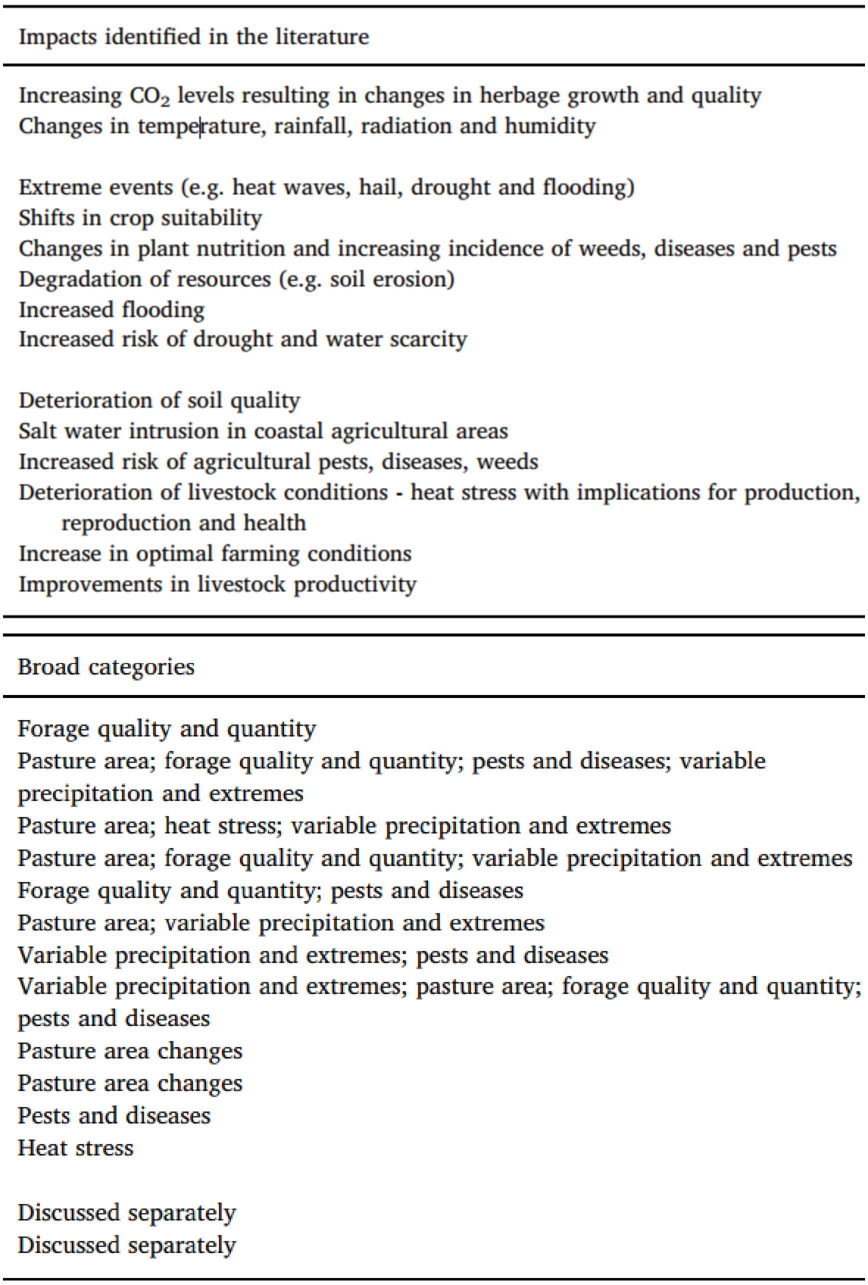
Table 3-16. Potential impacts of climate change on UK livestock systems related to heat stress, variable precipitation and climate extremes, pests and diseases, pasture area and forage quality and quantity changes (Source Wreford et al., 2020)



Impacts identified in the literature
Increasing CO_2 levels resulting in changes in herbage growth and quality
Changes in temperature, rainfall, radiation and humidity
Extreme events (e.g. heat waves, hail, drought and flooding)
Shifts in crop suitability
Changes in plant nutrition and increasing incidence of weeds, diseases and pests
Degradation of resources (e.g. soil erosion)
Increased flooding
Increased risk of drought and water scarcity
Deterioration of soil quality
Salt water intrusion in coastal agricultural areas
Increased risk of agricultural pests, diseases, weeds
Deterioration of livestock conditions - heat stress with implications for production, reproduction and health
Increase in optimal farming conditions
Improvements in livestock productivity

Broad categories
Forage quality and quantity
Pasture area; forage quality and quantity; pests and diseases; variable precipitation and extremes
Pasture area; heat stress; variable precipitation and extremes
Pasture area; forage quality and quantity; variable precipitation and extremes
Forage quality and quantity; pests and diseases
Pasture area; variable precipitation and extremes
Variable precipitation and extremes; pests and diseases
Variable precipitation and extremes; pasture area; forage quality and quantity; pests and diseases
Pasture area changes
Pasture area changes
Pests and diseases
Heat stress
Discussed separately
Discussed separately

Future droughts will also result in decreasing water flows in streams and waterways, in drying watercourses and in frequently empty water buffers at more locations. This will, among others, lead to poorer water quality (e.g., salinisation, fish mortality) and may also pose a threat to the water supply of livestock.

In general, increasing year-to-year variability of crop productivity is expected (Vanuytrecht et al., 2016) due to the greater frequency and severity of extreme climatic events (heatwaves, droughts, but also heavy precipitation…), which are worsened by other pressures such as pests and diseases (Vanuytrecht, 2020), which proliferate generally under warm and humid environments and move northwards with rising temperature (Bebber et al., 2013).

3.7.4. Elevated atmospheric CO_2 concentration

In Belgium, the fertilising effect of the increased atmospheric CO_2 concentration may compensate for

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some crops the yield reduction that is expected due to climatic changes mid-way this century (Vanuytrecht et al., 2016). Vanuytrecht et al. (2011, 2012) studied the impact of elevated CO_2 concentrations in the atmosphere on crop growth. Higher atmospheric CO_2 concentration increases crop productivity and improves the efficiency of water use in many plants, so that more yield can be produced with the same amount of water, or equal amounts of yield with less water (Vanuytrecht et al., 2012). Under a warming scenario of 1.5-2° C by 2050 (~RCP 8.5), the combined effects of climatic changes (altered rainfall, soil water availability and temperature) and atmospheric CO_2 concentration on mean crop production in our country were modelled to be limited or even positive for certain crops such as winter wheat, potato and sugar beet (Figure 3-60 and Figure 3-61). Yield gains up to 10 - 20% can be achieved, depending on crop and future climate scenarios, if the CO_2 fertilisation effect can manifest itself under optimal fertility conditions. Crops like maize cannot benefit from the CO_2 fertilization effect, since this crop functions already with maximal efficiency at current CO_2 levels. Adapted management (AM), including sowing earlier and growing cultivars with longer growing periods, can lead to higher gains in mean yield. Even though mean crop yields in Belgium may remain stable or even increase in the future by benefitting from the CO_2 fertilisation effect, yield variability over years, and the associated risks for farmers, will also increase in the future (Vanuytrecht et al., 2016).

Notwithstanding potential yield gains and higher water efficiency, the water availability in the soil is expected to decrease in the future, especially when growing periods will extend (Figure 3-61). In wetter years, the CO_2 effect can compensate lower water availability in summer, which can have a negative impact on crop growth particularly for spring-sown crops. Yet, in years with extended drought, yields will fall below current low levels and affect farm income (Vanuytrecht, 2013, 2014). In the longer term, as more extremes are expected, the effects of droughts and heats are expected to intensify.

Although elevated CO_2 concentrations may lead to yield gains, yield quality may be negatively affected. With increasing production, concentrations of nitrogen, proteins and nutrients in plant leaves and yield decrease in general, while starch and sugar concentrations increase. Those altered element concentrations have a serious impact on food and feed nutrition (Vanuytrecht, 2020). Increases in fertilizer application to sustain increased crop growth may only partly overcome lower element concentrations in plants and may in addition create problems to the environment due to leaching when unsustainably used.

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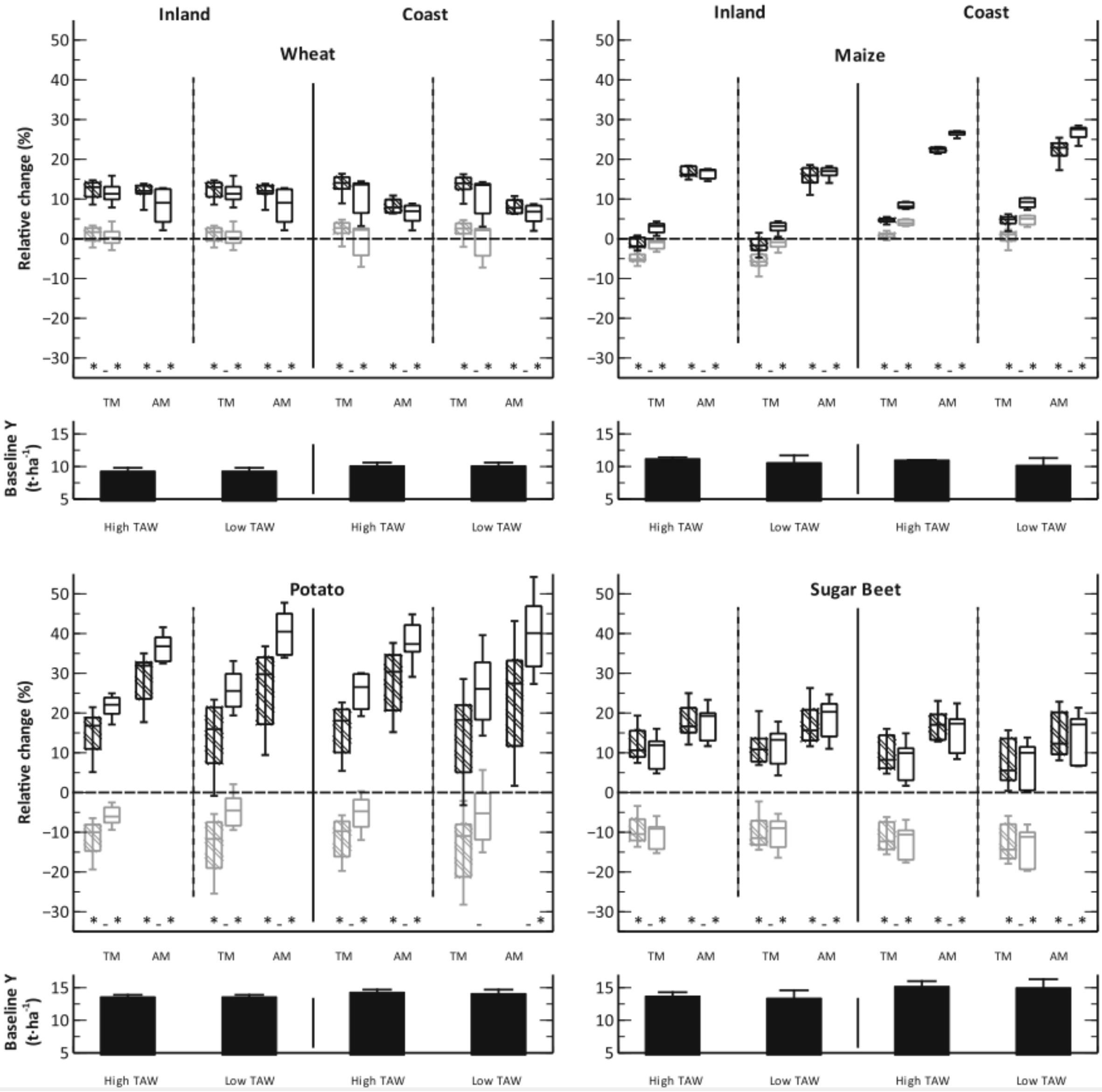

Figure 3-60. Expected changes in field crop yield in the Flemish Region towards 2050, under RCP 8.5. The graph shows simulated current mean yield (in black in bottom graphs) and changes in mean yield towards 2050 (top graphs) for four important field crops in the Flemish Region: inland (left panel) and near the coast (right panel), for traditional (TM) and adapted (AM) management on soils with a high water holding capacity (silty texture; high TAW[1]) and a low water holding capacity (sandy or clay texture; low TAW). Grey box plots represent scenarios that do not consider the CO_2 fertilization effect. Hatched and white boxplots represent different groups of climate projections (downscaled GCMs versus RCMs) and the uncertainty within groups. Source: Vanuytrecht et al. (2016).

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[1] Total available water (in the soil)

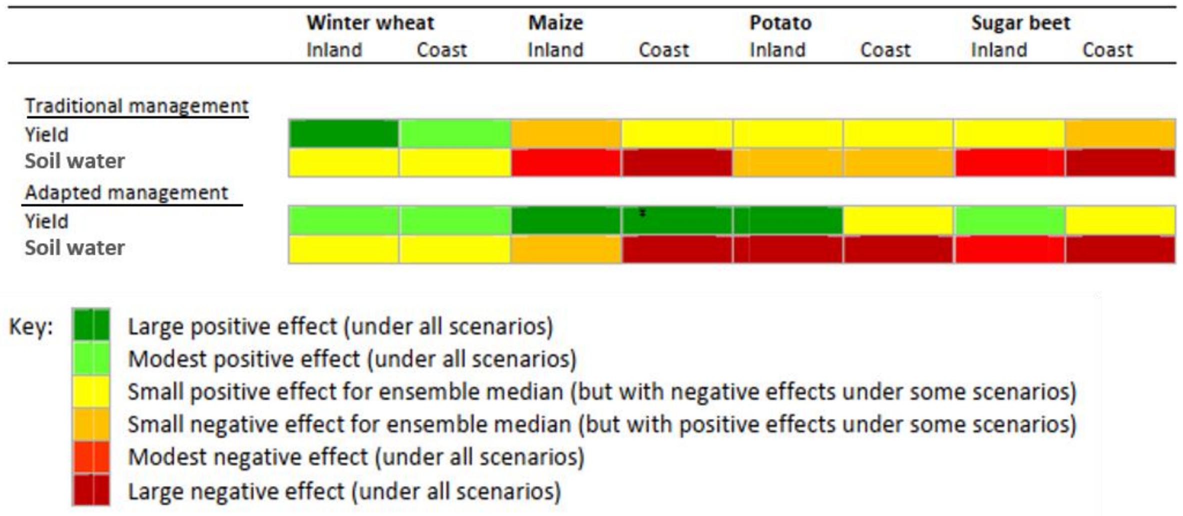

Figure 3-61. Modelled impacts on mean crop yield and seasonal soil water content towards 2050 (~RCP 8.5) for key crops in the Flemish Region. Source: Vanuytrecht, 2013.

3.7.5. Peak precipitation, river flooding and hail

Heavy precipitation events are becoming more frequent with climate change, both in summer and in winter. In Belgium, a slow but significant increase in the annual average amount of precipitation is caused by wetter winters with more precipitation days. There is no increase in precipitation in summer expected, but there will be more intense summer storms. This changed precipitation pattern has an impact on the water system, increases soil sealing, erosion and mud flows, and affects water management projects on the watercourses.

Peak precipitation

Excess precipitation events can lead to crop damage and soil erosion in agricultural fields. Extreme weather events will have the greatest impact on soils where the organic matter content of the soil is low, and the risks of water erosion are high. Soils with less than the critical threshold of 2% organic material are located mainly in the silty and sandy-silty regions. It is there that the risks of soil erosion are particularly high. In these regions, the highest amount of specialized crop operations is observed. In Belgian Lorraine, clay soils with low permeability favour water runoff and make the region also prone to erosion. Still, the soils of this region are traditionally occupied by permanent meadows, which limits the risks of erosion. In addition, excessively wet soils can directly damage crops, due to anoxic conditions, increased risk of plant disease and pests, delayed planting, sowing or harvesting and contamination of ground- and surface water due to leaching of nutrients and pesticides.

According to CPDT (2011), the projected increase in extreme climatic events combined with a low rate of organic matter due to intensive farming practices will further accentuate land erosion (especially in sandy-silty and silty areas) and will cause an increase of agriculture's dependence on synthetic fertilizers. But in general, the negative impacts of these climate changes on agriculture would be modest, and would be felt first in cultivated areas and then in breeding areas. Specialised farms will be the most affected by climate change, unlike mixed farms, which will have more possibilities for adaptation measures, because they can intervene on different fronts.

Adaptation measures, such as a change in the choice of crops, sowing periods (particularly winter crops have significant anti-erosion potential), a return to longer rotations, or correction of the content of soil organic matter, could help to reduce the adverse effects of climate change. The agro-environmental programmes in Belgium include appropriate measures to respond to the consequences of certain extreme climatic phenomena. Measures aimed at preventing the erosion of agricultural soils (including hedges, winter soil cover, grassy headlands, …) are, for example, already available for farmers.

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River flooding

Peak flow rates and the risk of flooding, both from the sea (see below) and the rivers, and indirectly from sewers have increased since the past few decades. In some areas in Northern Belgium, increased peak flow rates have already caused damage more than once every ten years (see the Flemish Climate Portal[1]). In addition, the quality of the water may deteriorate, partly due to the temperature change in the water, the salinization (see below) and the increased concentration of pollutants as a result of an increased sediment supply and evaporation, and lower water levels.

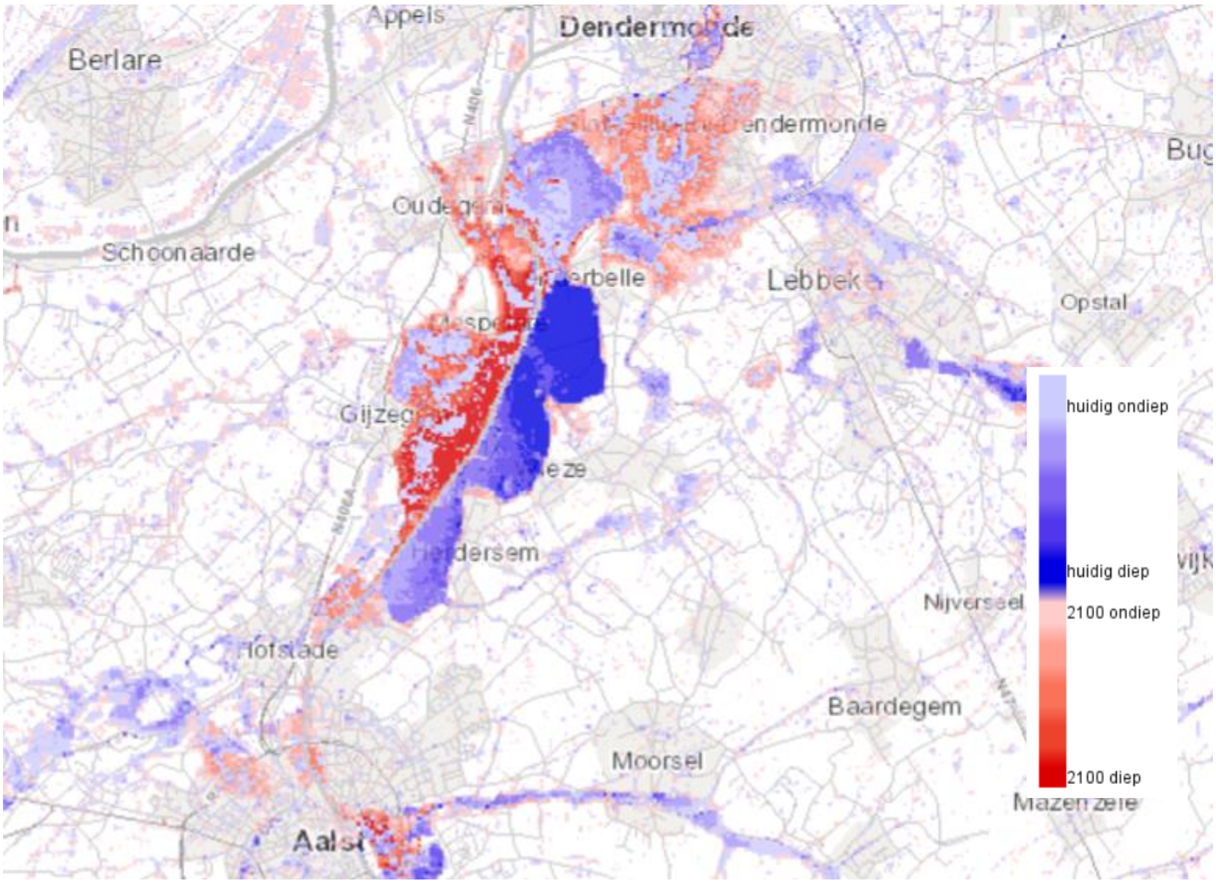

Figure 3-62. Increase in floodable area under a high impact scenario (2100).

Morris et al. (2014) identified different impacts of flooding for agricultural systems. At the field scale different impacts were determined, including emergency evacuation of livestock, prevention of access to (spring) grazes pastures requiring animals to be housed or relocated to other flood free areas, damage to pastures and grass production in the worst affected areas involving complete loss of grazing or silage/hay making, loss of yield and quality of arable crops, damage to drainage systems and field infrastructure, loss of beneficial soil invertebrates (e.g. earthworms) and increased risk of animal disease. In (northern) Belgium the deterioration of water quality in the flooding areas must also be taken into account, since the quality of surface water does not yet meet the standards. At the farm scale a range of impacts comprising extra costs, lost revenue and other impacts can be identified. Extra costs mainly involve the replacement cost of grass feed for grazing or winter feed and the likely need to reseed pastures in the most damaged areas. Losses of revenue are associated with reduced net income from livestock, reduced hay sales and loss of yield from (arable) crops in general.

The Flemish Climate Portal shows flood hazard maps for Northern Belgium. These maps are compiled on the basis of fluvial flood maps, which show the floods stemming from the water courses, and pluvial flood maps, which give floods as a result of the direct runoff from land. Figure 3-62 provides a zoom

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[1] klimaat.vmm.be

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on the Dender river area between Aalst and Dendermonde.

Hail

Hailstorms also cause damage to agricultural crops in most of Europe, but the most vulnerable regions to hail events are the Mediterranean area and the greater Alpine region (EEA, 2019b). Although some climate models suggest that hailstorm frequency will increase in central Europe by the end of the century, future projections of hail events are subject to large uncertainties. In Belgium, hail can cause a reduction in the production of permanent crops, such as fruit trees and grapevines. Damage from hailstorms can be very costly but losses vary considerably both temporally and regionally, and major losses are related to hail events during crops growing seasons, although variability in species sensitivity to damage is observed. Hailstorms can also significantly damage greenhouses, causing serious damage to the greenhouse horticulture sector.

3.7.6. Sea level rise

Climate change will also lead to sea level rise, induced by the melting of land ice sheets and glaciers, volume changes of sea water due to temperature rise and changed storage of water on land. Sea level rise will have consequences for the water levels in northern Belgium. Sea level rise will increase the seepage pressure and inland water level, as such affecting the agricultural land there. Regular water level management in the coastal polders will probably compensate for the increased soil moisture level caused by the expected gradual rise in sea level. Greater damage is expected as a result of storm events associated with the flooding of the coastal polders. Direct crop losses, reduced grazing areas, drinking water problems for livestock and hindered tillage (during harvest or the sowing season) need to be taken in consideration. In the future, more storm events, more flooding, coastal erosion and even the intake of low-lying areas by the sea are to be expected. Sea level rise has an immediate effect on agriculture, agricultural crops and land loss, but the magnitude of the effect depends on the protective measures that will be taken (e.g., Master Plan Coastal Safety). The inland impact of coastal storm events on agriculture is determined by the flooded area, the frequency, duration and time of occurrence of the flood.

In addition to rising water levels, salinization will also increase. External salinization by salt seawater in the polders is expected to increase in the medium term. Salt water intrusion affects water quality and water usage. Attention should also be paid to the combination of rising temperature and reduced fresh water volumes, causing a reduction in soil moisture and salinization. Salinization causes contamination of fresh groundwater resources (with impact on access of fresh drinking water for cattle), contamination of fresh surface water due to saline seepage (with impact on surface water use for irrigation, drinking water, ecology, …), deterioration of soils, and crop yield losses. Currently the groundwater of the coastal area, Meetjesland and Linkerscheldeoever is already salinised. The damage caused by salinisation and drought is closely intertwined and difficult to treat separately. Drainage can cause irreversible salinisation. Adjusted drainage or elimination of drainage can lead to delayed fresh water runoff and with insufficient drainage capacity, heavy rains, especially in winter, will cause a temporary peak in freshwater supply and flooding.

Higher (ground) water levels and increased salinization in the polder areas will necessitate adjustments to the drainage system, water level management, pump capacity and local freshwater management, and or will cause changes in applied crops (more salt tolerant crops) or land use (time of harvesting or sowing). Accumulation of water in the tidal rivers caused by sea level rise will require dike raising, dike reinforcement and the creation of flood areas (cf. Sigmaplan).

In addition to the expected harmful effects of salinization in conventional crop cultivation and in livestock farming, new opportunities may also arise. The extent to which those opportunities have potential depends to a large extent on how and when - whether or not on time - climate change is anticipated by crop selection, crop choice and water management. Freshwater and saline farming can coexist or can be connected by gradients (Zwaenepoel et al., 2016).

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Until 2020, Belgian farmers could apply for compensation for crop damage caused by drought, frost, storm, hail and excessive rain via the disaster fund[1]. From 2020 onwards, this is also possible via a specific weather insurance policy. If farmers still want to be compensated for crop damage in the future as a result of the aforementioned phenomena, they have to call upon he private insurance market. This system should make the disaster fund redundant in the long term. This so-called broad weather insurance is not mandatory, but is encouraged by the government. For this, the insurance premium is repaid by the government for a maximum of 65 percent during the first three years. Farmers who have taken out insurance for at least 25 percent of their farm land from a recognised insurance company can still count on the disaster fund until 2025 for their uninsured crops. Afterwards, support through the disaster fund will come to an end. Wreford et al. (2020) argue however that insurance is a contested adaptation measure as it transfers rather than reduces risk, and potentially disincentivises farmers from taking adaptive measures to reduce risk.

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[1] Vlaams parlement commissievergadering: In 2017, 3,196 drought damage claims have been submitted by farmers, for a total amount of 29 miljoen euro. In 2018, 12,000 claims were submitted, totalling 155 million euro.

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3.8. TOURISM

The impact of climate change on tourism in north-western Europe is generally thought to be positive on balance, but differences exist between regions, between cities and countryside, and in function of activities and subsectors. For this reason, we devote a separate short section to each of the three Belgian regions.

It should be noted that an improvement of climate conditions in Belgium does not automatically and by itself result in more (foreign) tourists, as conditions may improve in other countries as well and as the demand for tourism services as a whole obviously has a ceiling. Domestic tourism may increase however as result of weather conditions in Belgium becoming more clement, at the same time as conditions worsening in the classic (e.g., Mediterranean) destinations.

(Negative) impacts that have been discussed under the Health and Infrastructure sections in this report are of course applicable, mutatis mutandis, to the tourism sector. For instance, touristic infrastructure is as vulnerable as any infrastructure to inundations, and an increase in vector borne disease may affect tourists as well as anyone else.

It should also be noted that climate change may increase the environmental (and climate) impact of the tourism sector: in absolute terms, as the number of tourists increase, but also in relative terms, for instance because of more electricity (for cooling) and water being used per bed night as the climate gets warmer. This may also affect the costs and the profitability of the tourism sector.

3.8.1. Flanders Region

In 2018, tourism in Flanders represented a gross added value of 8,9 B€[1], or 4.3% of the gross added value of the region. About 6.4% of the Flemish population was employed in the tourism sector (Weekers and de Maesschalk, 2020). In 2018, tourists spent about 26,127,000 bed nights in Flanders (Statistics Belgium, 2018). Main attractions in Flanders are the Belgian coast and the 'Art Cities' (Antwerpen, Gent, Brugge). Small-scale tourism in nature and countryside (hiking, bicycling, ….) is also of some importance.

Impacts of climate change on tourism in Flanders may be both positive and negative. On the positive side, warmer temperatures overall may lengthen the tourism season, and drier (and warmer) summers may make the region more attractive. Technum (2012), based on Ciscar (2009), mentions an increase, by the end of the century, of the number of bed nights with 2%, for an increase in average temperature of 1.78°C. This would amount to a gain of 168 M€.

Extreme heat as well as the urban heat island effect on the other hand may make cities less comfortable, especially in summer. Those effects should be less important at the coast, as the predicted increase in temperature is smaller and the urbanisation generally less dense. On the other hand, increased erosion as a result of sea level rise and (possibly) more intense storms may limit the attractiveness of beaches and dunes and/or substantially raise the cost of maintaining them.

Regarding health aspects, Vibrio infections, linked to the warming of the coastal waters, are a particular point of attention in the coastal region.

3.8.2. Brussels Region

In 2018, tourism in Brussels represented a gross added value of 3.7 B€, or 5.3% of the gross added value of the region. About 9.3% of the Brussels population was employed in the tourism sector. In 2018, tourists spent about 7,000,000 bed nights in Brussels (Statistics Belgium, 2018). The main tourist attraction in the Brussels region is the city of Brussels itself, while the MICE-subsector is also important; 'professional tourism' represented in 2010 48% of all bed nights. For this reason, the main touristic season in Brussels is not summer but rather spring and autumn.

As in the cities in Flanders, higher average temperatures can make Brussels more attractive in general,

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[1] Estimated with the TSA (Tourism Satellite Account) method.

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but extreme heat and the urban heat island effect may counteract this during the summer months.

Pouria et al. (2012) identified an improvement of weather conditions for summer tourism as an opportunity for the tourism sector in the Brussels region, while acknowledging that this would be accompanied by an increase in electricity demand. The impacts on tourism in other seasons were considered limited or uncertain. Other factors that are not exclusively linked to tourism, but that the region is vulnerable to and that, according to the authors, may play a negative role in determining the attractivity of the Region for tourists, are changes in the reliability of water supply, health impacts related to heat, increase in infectious diseases (all medium vulnerability) and health impacts related to air quality (high vulnerability).

3.8.3. Walloon region

The tourism sector contributes about 5% of the gross domestic product of the Walloon region. In 2018, tourists spent about 8,200,000 bed nights in Wallonia (Statistics Belgium, 2018). A majority (55%) of visitors spending a night in the region are inhabitants of Belgium, while the contribution of the Netherlands (23%) is also important.

As in the rest of Belgium, an increase in average temperature as well as drier summer months is expected to have a positive impact on tourism in Wallonia, although a negative impact may be expected in winter in certain regions on typical activities such as cross-country skiing[1]. As tourism in Wallonia is more concentrated in rural and nature areas than in the cities, excessive heat in urban environments will, as a whole, have less of an impact (although the effect can be important for cities such as Liège e.g.).

Low water levels in the rivers in Wallonia as result of dryer summers may have a negative impact on water-related recreation activities such as fishing, swimming and kayaking[2], and water shortages in general may lead to a competition between tourism and other users such as agriculture. Lower water levels in surface waters could also mean a deterioration of the water quality and possibly an increase in health impacts associated with recreational activities. Nature areas and landscapes in general may also change with the possibility of becoming less biodiverse and less attractive; this could for instance be the case for the Hautes Fagnes region, which could be susceptible to droughts and as such loose its unique qualities of upland peat area. River inundations may in particular affect camping sites that are very often situated close to water courses.

CPDT (2014) presents a systematic analysis of the vulnerability of the tourism sector in Wallonia for different climate impacts (without quantifying it). A high vulnerability is expected to the impacts of summer droughts (lower water levels in rivers and less water available in general), of inundations, and of wetter and warmer winters (with less snow). The vulnerability of the sector due to heat stress, deterioration of air quality (ozone), deterioration of surface water quality (with increase in disease incidence), shortages in potable water supply, the impact of changes in precipitation and in temperature on the natural environment, and the impact of summer heat on human comfort and health is considered of medium importance. Opportunities for the tourism sector are expected as a result of higher temperatures and less rain in summer, higher surface water temperatures, a longer touristic season, and the cooling effects of forests and surface water bodies which would make the region more attractive.

Based on results of the PESETA-project (Ciscar, 2009, i.e. the same source that was used by Technum), ICEDD (2014) estimates an increase of about 1% in the number of tourist bed nights[3]. Although this is not explicitly mentioned it appears that this figure derives from the figure for a 2.5°C increase of

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[1] Noting that even today good conditions for those activities are far from guaranteed.

[2] While the demand for such activities may increase because of higher temperatures and more heat spells.

[3] It is worth mentioning that Ciscar et al. consider that "*the results presented must be treated with great care, as the uncertainties are very large. The predictive value of the models is not very large*" and that "*the impacts of climate change on tourism in Europe may well have been overestimated*".

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average annual temperature by 2080. The 1% figure would correspond to a monetary increase of about 5 M€ per year. The CPDT study has the merit of pointing out the fact that reality is more complex, with many more factors besides an increase in average temperature being implicated, but comes to the logical conclusion that the real impact on the Walloon tourism sector is highly dependent on the climate scenario chosen, as well as on the evolution in the characteristics of the tourism demand in other countries and in the offer of competing regions.

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4. TRANSBOUNDARY IMPACTS OF CLIMATE CHANGE – CASES

4.1. INTRODUCTION

All territories have commercial exchanges which allow them in particular to supply themselves with resources which they do not have or in too small quantity. Understanding the material flows for Belgium highlights a strong dependence on imports (import dependency rate[1] : 72%, calculation based on Eurostat, 2017), see Table 4-1.

Table 4-1. Belgium's dependency on imported flows (in tons, for the year 2017) for four categories (data from: Eurostat – Material Flow accounts, 2017)

	Imports	**Direct materials input**	**Dependency rates**
TOTAL	**252,546,538**	**349,022,803**	**72%**
Biomass	50,482,847	87,146,791	58%
Metal ores (gross ores)	41,678,028	41,678,028	100%
Non-metallic minerals	35,944,970	95,757,290	38%
Fossil energy materials/carriers	112,183,011	112,183,011	100%

The next segment analyses the flows imported for Belgium (cereals, fruit, timber, copper) as an example to highlight the influence of climate in the evolution of prices. Next, the effects of climate change on the transport modes of imported goods are presented in order to consider the consequences for Belgium (knowing that this will also apply to internal traffic). And finally, a presentation of a possible domino effect of a climatic incident affecting an economic partner is proposed.

4.2. RAW PRODUCTS

4.2.1. Cereals

Most impacting events in the cereal industry are natural disasters such as droughts, heatwaves, frosts, floods or fires, with probable increase in their frequency and severity as the climate changes (IPCC, 2011).

For instance,

- In France, in 2003, crop production decreased by 13.6% compared to 2002, due to a belated frost and droughts in summer which led to a price increase of 17% for wheat and 26.7% for corn (INSEE, 2004). Being the second most important provider for Belgium, this event had certainly a significant impact on the Belgian market.
- In 2010, the drought in Russia, one of the biggest wheat producers, forced the country to declare an embargo on its exportation, creating a price increase of more than 70% at the Chicago Board of Trade between July and August (Neu, 2012).

According to the U.S. Department of Agriculture (USDA), drought conditions affected approximately 80% of U.S. agricultural land in the summer of 2012 (Adonizio et al., 2012). Because the United States is the world's largest producer and exporter of corn, crops damage had important implications for global corn supplies and prices. As seen in Figure 3-60, the export price index for corn rose 32.5% from June to August as drought conditions worsened (based on an index from approx. 275 to 360).

Another factor impacting the commodity price are natural disasters affecting logistics. For instance, in 2004, 54% of the grain exported from the U.S. were moved through the Mississippi River,

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[1] we define an "import dependency rate" as the ratio between the imports and the direct materials input

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demonstrating the river's importance to the U.S. cereal trade. After Hurricane Katrina, barge deliveries via the Mississippi region decreased considerably and had not returned to normal levels, even two months following the storm.

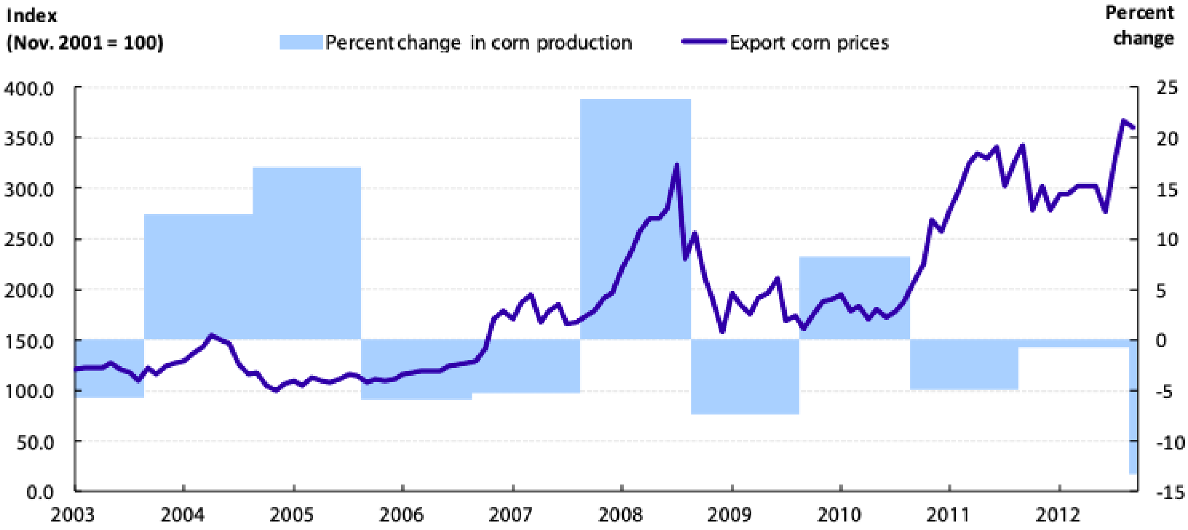

Figure 4-1. Corn export price index by market year (September-August) and corn production percentage changes, January 2003 – September 2012 (source: Adonizio et al., 2012)

4.2.2. Fruit

Regarding the Belgian fruit industry, two types of fruits are interesting to differentiate: the local fruits and the ones produced overseas. Their distinction relies on the supply and availability on the Belgian market and the price is therefore impacted in a different manner by climate change. To understand which factors alter this price, we analyse here the two most consumed fruits in Belgium: apples and bananas (VLAM, 2016).

In 2015, apple was the most eaten fruit in Belgium with an average of 8.79 kg per year and per person (VLAM, 2016). The country produces it largely itself, having a positive trade balance of 143.247 M$. Imports mainly stem from neighbour countries: the Netherlands, France, Italy and Germany, with a slight exception being New-Zealand representing around 23% of the imports (International Trade Centre, n.d.). Acknowledging this fact, we need to be attentive on how the climate affects Belgium's neighbours and how that is passed on to the commodity price. If we look at France for instance, which represents 18% of Belgian importations, it suffered in 2006 from a very hot July followed by a very wet month of August. The consequences of this unforeseen event were the following: predictions had forecasted important yields, cutting the importations, which led to an instant supply shortage due to the excess of water. This offer deficit made the apple price rise by 31% and the pear price rise by 34.6% (INSEE, 2007).

The second most eaten fruit in 2015 is the banana with an average of 7.54 kg per person per year (VLAM, 2016). The particularity for banana is that Belgium faces a negative trade balance of €385 million in 2018. Indeed, banana is the most imported fruit in Belgium with 1.3 million tons of bananas, compared to 0.2 million tons of apples and pears imported (International Trade Centre, n.d.). The majority of these bananas comes from much further: Colombia, Costa Rica and Ecuador (International Trade Centre, n.d.). Those countries are prone to face considerable natural disasters and crop disease:

- **Natural disasters**: for instance, Hurricane Irma stroke the Dominican Republic – exporting 39,000 tons of bananas to Belgium – in September 2017 and reportedly destroyed 50% of the country's banana harvest (FAO, 2018). In Ecuador, some regions were devastated by important flooding which led to a noticeable price increase and reduced their exports by 31% in 2017 (FAO, 2018). While the increase in hurricanes occurrence due to climate change is uncertain among scientists, warmer ocean temperatures and higher sea levels will more confidently

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aggravate their intensity and impacts (Center for Climate and Energy Solutions, n.d.).

- **Diseases**: another problem related to bananas production and climate change is the increasing occurrence of diseases. In the first half of the 20th century, the panama disease, which attacks the banana plant and contaminates the soil, had destroyed large areas of banana plantations in Latin America, with an economic impact of around $2.3 billion (Ploetz, 2005). Thereafter, a new breed, more resistant, was created: the Cavendish banana. It now represents practically the only breed available on the international market (Ploetz et al., 2015a). This homogeneity is very dangerous as diseases spread more easily which consequently impacts the price. The black streak leaf disease for example accounted in Latin America for 25% of the purchase price because of the extra infrastructures and equipment needed for its management (Ploetz et al., 2015b). As climate change gets more important and temperatures and humidity rise even more, diseases will develop more easily (Ahanger et al., 2013), passing the cost increase for maintenance on prices.

4.2.3. Timber

According to WWF-Belgique (2018), Belgium is one of the most important importers of wood in the European Union, representing 24 million m^3 and a budget of €8.2 billion annually. In other words, a slight change in the resource price would have tremendous effects on the Belgian industry.

The timber market has direct impact on sectors such as construction, energy production (pellets or wood fuel) and paper. Driven by offer and demand, its market undergoes the influence of different factors, in a direct or indirect manner. The first factor positively affecting the industry is of a legislative nature: the EU has recently placed important goals towards sustainability encouraging the wood use thanks to environmental policies in the construction or energy sector. For instance, the 27th point of the Green Deal resolution (European Parliament, 2020) ‘encourages the promotion of timber construction’ and the 42nd promotes an energy reconversion towards sustainability, including pellets and wood.

- The wood offer is also affected by natural incidents such as insects and diseases. The expansion of wood production sites and the use of wood stands that are not native for certain regions has fostered the increase of invasive insect species and of uncommon diseases. The most common insects having an increasing impact nowadays is the bark beetle, affecting tremendously the European wood production (Hlásny et al., 2019). The bark beetle damages the wood and forces the producers to harvest and process it earlier in order to maintain its value. The market is then deregulated due to the uncertainty of the supply. In Sweden for example, insect outburst is forecasted to kill 2-12 millions of m^3 of spruce trees in 2018 (EOS, 2018), on a total of around 85 million m^3 of trees are cut each year in the country, which underlines the gravity of the thread.
- Increase of extreme events frequency like droughts, hurricanes or storms has consequences which are punctual and specific to certain regions, thus unpredictable and riskier for the producers. The result is an increase in the wood price, majorly affected by superior costs due to a difficult access to the territory, to reparations for the roads and infrastructures needed, to direct damages to the trees etc. (Kirilenko and Sedjo, 2007). For instance, in the Aquitaine region (France), storms, jointly with bark beetles, have strongly impacted production and resulted in a doubling of the price of the logs over 2 years (EOS, 2018). Even though storms occurrence is not expected to increase significantly in France over the next decade (Déqué, 2011), being the most important suppliers of Belgium, it could have critical impacts (WWF Belgique, 2018).
- In the same vein, wood supply is also related to forests fires. The climate change having modified the frequency and the intensity of forest fires, it has also increased the risk of timber scarcity. During the past two decades, the extent of burnt territory in Canada, the United States and Russia has significantly increased (Kirilenko & Sedjo, 2007) and therefore affected the timber price. For instance, after the forest fires of North America in summer 2017, the

timber price had risen by 5.5%. Indeed, to prevent any shortages, producers add a risk cost in their price. If this practice is replicated by large wood exporters such as Russia or Brazil, where fires are also increasingly happening, it could represent around a yearly 500 M€ loss in the Belgian budget.

To conclude, the growing risks regarding the quality and supply of timber is forcing the producers to face many problems and adapt their price. If the intensity of those changes is to increase, prices might skyrocket, which would take a heavy toll on related Belgian industries.

4.2.4. Mining

The mining industry is considered here as a conglomerate of different sectors such as the ferrous and non-ferrous metal industries, the clay industry or the industrial minerals industry. They have been put together as they all gather specificities similar in terms of how their price reacts to climate change:

- **Water shortages**: A big challenge that the mining industry will encounter is the water scarcity. According to CDP (2017), a quarter of mining production could be exposed to water shortages and drought by 2030. When we know that Belgium majority depends on foreign resources and has a negative trade balance for almost all the unwrought metals like aluminium, copper, nickel, etc. (International Trade Centre, n.d.), it is interesting to evaluate how the industry evolve. The first problem related to water shortages is the operational scarcity. In Chile for example where the industry consumes 12.7 m^3 of water per second, the equivalent of almost twice the water consumption of a city like Paris, water desalination has been made mandatory for the Chilean mining industry, which has forced the big companies to invest in desalination plant (Jamasmie, 2019). According to Morgan Stanley & co. (2015), these investments, due to a rising competition for water resources, increased the copper price by 6 to 8%, passing from 3.05$/lb to 3.28$/lb. Knowing that Belgium imports more than 1.8 B$ worth unrefined copper, even a 6% change can have a significant impact on Belgian economy.
- **Natural disasters**: More frequent and intense natural disasters may damage mines, transportation, energy infrastructure and equipment. Heavy rain and increased erosion may affect slope stability of the open pits, and rising sea level may make coastal facilities harder to access. But there are also indirect effects that affect the different steps of the supply chain. For instance, in 2006, the company Diavik Diamond Mines had, to transport its supply by air rather than over the ice roads, because of permafrost thaw, costing the company an extra US$ 11.25 million (Nelson and Schuchard, 2009). The link between natural disasters and the resource price is harder to establish here as, in some cases, climate offers new opportunities to companies such as the access to new exploration zones, now reachable thanks to warmer arctic and subarctic temperatures (Nelson and Schuchard, 2009).

4.3. FREIGHT AND IMPORT

Goods imported into Belgium, whether raw products, semi-finished products or finished products, are mainly transported by truck, train, barge and cargo. All these transport modes are more or less sensitive to climatic hazards with obviously different consequences depending on their organization: ranging from effects on operating costs to service disruption. According to Bowyer et al. (2020), in connection with climate change, operating costs will be higher[1] due to:

- **Trucks**: thermal degradation of roadways (and less winter degradation), heavier wear of equipment, maintenance of structures, etc.
- **Train**: premature wear of equipment, restriction on the volume transported, etc.
- **Barge**: seaworthiness management (low water and flood)
- **For all modes of transport**: extra need for cooling, health and safety at work during extreme temperatures, among other.

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[1] Total operating cost not reported per ton.km

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More specifically, the transport of goods on the Rhine, a communication link with Belgium by canals and Meuse, could experience an increase in its operating costs for navigability from + 70% to + 192% only for the support for low water periods according to Kievits (2019).

Figure 4-2 presents different functional criticalities which can lead to service breakdown between two spatial points (before leading to a modal shift which is not always achievable). It is obvious that the postponement possibilities are easier to set up in the case of transport by truck (deviation), while the alternative solutions are reduced (train) or even non-existent (barge) (CEREMA, 2019).

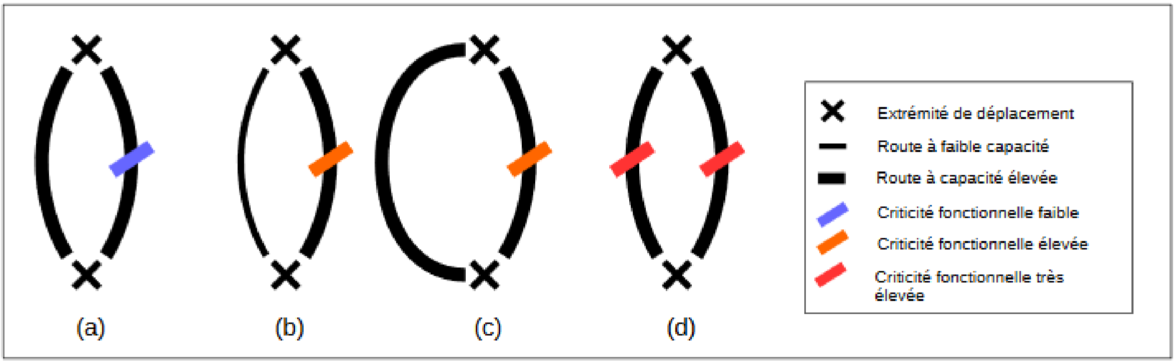

Figure 4-2. Functional criticality from a performance point of view (CEREMA, 2019)

According to Bowyer et al. (2020), in connection with climate change, service disruptions from a few hours to several months depending on the modes of transport of goods can be as follows:

- **Truck**: route loss / destruction, temporary route blockage;
- **Train**: equipment failure, buckling of the rails, signalling problem, loss / destruction of the railway, temporary blockage of the railway;
- **Barge**: occasional or even seasonal stopping of navigation.
- **Cargo**: damage to port infrastructure (72% of all freight port facilities assess are vulnerable to a 122 cm rise in relative sea level, Finley et al, 2013)

For import freight to Belgium, climate change will therefore have consequences on logistics costs but also on the direct consequences on the supply chain, all the more so for sectors with little stock such as the automobile.

4.4. SEINE FLOOD, A DOMINO EFFECT FOR BELGIUM?

If it is difficult to return to the economic consequences beyond France during the episode of the 1910 Seine flood, it is nonetheless possible to establish the local consequences of a new episode and compare them with trade relations established between these two countries. According to OECD (2014), a flooding of the Seine would impact 5 million people, many businesses and could even disrupt the functioning of the state, institutions and networks converging on the region. The impact on GDP would be more than 4% since the Ile-de-France region concentrates 1/3 of the country's economic activities; a return to normal situation could take several months or even years for the metro (Mairie de Paris, 2012). Imports from and exports to France represent 9.73% and 14.06% respectively (Comtrade, 2019) an economic slowdown of this trading partner would then inevitably have repercussions for the Belgian economy.

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5. IDENTIFICATION OF ANALYSIS METHODS AND SOCIO-ECONOMIC INDICATORS

5.1. INTRODUCTION

The purpose of this section is to review the methodology and indicators used by other studies focusing on the social and economic costs of climate change in order to guide and validate the methodology and indicators used in our study. For this exercise, we have reviewed a large number of studies (> 60), among which 13 were subject to a detailed analysis. In addition, two interviews were conducted with authors of those studies: Adriaan Perrels from the Finnish Meteorological Institute (Perrels et al., 2005) and Franz Prettenthaler from Joanneum Research (Steininger et al., 2015) in Austria.

5.2. STUDIES ANALYZED

The studies chosen for a detailed analysis of methodology and indicators are listed in Table 5-1. More details on the cross-sector studies can be found in a series of tables (Table 5-2, Table 5-3, Table 5-4, Table 5-5) at the end of this section.

Table 5-1. List of chosen studies for a detailed analysis of methodologies and indicators used.

REFERENCE	TITLE	SCOPE	SECTOR
Trade Union, 2019	Adaptation and the world of work: framing the discussion	Europe	Labour
ECMWF, 2017	Windstorm Information Service (Copernicus): WISC Risk and Loss Indicator Descriptions	Europe	Building
CISL, 2019	Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios	World	Insurance
WBG, 2017	Sovereign climate and disaster risk pooling	World	Insurance
IAIS, 2018	Issues Paper on Climate Change Risks to the Insurance Sector	World	Insurance
Bolton et al., 2020	The green swan - central banking and financial stability in the age of climate change	World	Banking
EEA, 2019	Climate change adaptation in the agriculture sector in Europe	Europe	Agriculture
Kahn et al., 2019	Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis	World	GDP
Woetzel et al., 2020	Climate risk and response: Physical hazards and socioeconomic impacts	World	GDP
Ford et al., 2017	RAMSES - Reconciling Adaptation, Mitigation and Sustainable Development for Cities. Title of report : D3.3: extension of detailed system-based isk analysis	London	Urban economy
ICCED, 2014	L'identification et l'évaluation des coûts de l'inaction face au changement climatique en Wallonie: Partie 1 – Les coûts de l'inaction	Wallonia	Cross-sector
Technum, 2012	Adaptatie aan klimaatverandering: Globale kosten en praktische voorbeelden	Flanders	Cross-sector
Dantec & Roux, 2019	Rapport d'information sur l'adaptation de la France aux dérèglements climatiques à l'horizon 2050.	France	Cross-sector
Steininger et al., 2015	Economic Evaluation of Climate Change Impacts:Development of a Cross-Sectoral Framework and Results for Austria	Europe Austria	Cross-sector Cross-sector

5.3. CLASSIFYING THE STUDIES

Among the 60+ studies that have been reviewed titles differ widely. Studies take names such as "Impacts of climate change, "costs of climate change", "adaptation to change", "vulnerability and risk assessment", "Economic losses from climate-related extremes", etc. However, all of these studies fall into certain classifications.

All studies have a scope at global, continental, national, regional or city scale. The continental or global scale studies remain on a macroscale standpoint and a low level of details (e.g. WBG 2017, ECA 2009, Bergamaschi et al., 2019). On the other side of the spectrum, studies at a city scale like Copenhagen (KK, 2011), or London (Ford et al., 2017) show an important level of details with tangible costs estimates.

Studies can be split into sector and cross-sector studies. **Sector** studies can be found for any scale of scope and we found a diversity of sectors covered: insurance (WBG, 2017), social vulnerability (Kazmierczak, 2015), nature (Rounsevell et al., 2018), labour (Trade Union, 2019), real estate (CISL, 2019), banking (Bolton et al., 2020), cities (Stevens et al., 2015) or agriculture (EEA, 2019b). **Cross-sector** studies can also be found for any scale from city to world: Copenhagen (KK, 2011), Wallonia (ICCED, 2014), Belgium (NCC, 2017), France (Dantec and Roux, 2019), Europe (Trade Union, 2019), and World (Golnaraghi et al., 2014).

The studies found often follow a **general structure** that could be summarised in four steps. First, the assessment of climate scenarios for the region of interest (ROI); second, the assessment of the impacts of the changing climate on selected sectors relevant to the ROI; third, the estimation of negative (and positive) effects on the chosen sectors; and fourth, the adaptations measures and implementation plans for some of them (e.g. KK, 2011).

Similarly, four stages of **precision and depth** in studies are found. The first stage is a climate change description for the area of interest in relation with global predictions. The second stage covers qualitative impacts of climate change on various sectors (e.g. more infrastructure costs from river and sea flooding, more parasite-related disease occurrence from mosquitoes, ticks and other vectors). Many studies only go so far into their analyses. The third stage of studies will show a quantitative impact assessment of climate change on various sectors (e.g. GDP losses on flooded infrastructures, number of excess mortality due to increased/new occurrences of parasites). The fourth stage of studies will also provide adaptation measures to counter balance the effect of climate changes, eventually accompanied by cost-benefit analyses and decision-making models. This level of completion is found for only a few studies (e.g. ECA, 2009; KK, 2011; WBG, 2017).

5.4. ANALYSIS OF METHODOLOGICAL CHOICES

On top of the scope on sectors, methodological choices have been made in each of these studies. In climate change impacts studies, the **socio-economic-demographic** world can be taken as constant (static) or dynamically changing (dynamic), such as increasing population or a changing share of elderly persons, or an increase in the share of residential buildings located in flood-prone areas. Most of the time, the static option is taken to avoid making assumptions into a difficult to predict socio-economic future. Sometime a combination of both approaches is given to provide as much insight to the decision makers as possible, as in Ciscar et al. (2018a).

In terms of **climate modelling** there is a range of approaches for the impacts of climate change on the physical world (temperature, precipitation, species habitat, extreme events, etc.) and then on the economic sectors (agriculture, forestry, flooding, etc.). Some use global climate models (GCM), other use regional climate models (RCMs) and their related spatial resolutions. Some use single model, other use ensemble of models. None have coupled atmospheric, land models, and impact models; thus, all take atmospheric outputs as prescription for later steps. Some use average climatic outputs, some include dedicated extreme models in their analysis. As an example, the PESETA III study (Ciscar et al., 2018a) uses an ensemble of 11 RCM simulations from EURO-CORDEX[1] at 12.5 km^2 grid cell size, that in turn feed the impact models (process-based or empirical) for each sector. It should be mentioned that most studies use climate simulation forced by RCP emission scenarios from the IPCC Fifth Assessment Report (AR5) (Ciscar et al., 2018a; Woetzel et al., 2020; Trade Union, 2019).

For the **economic cost estimation**, it is not always clear what methodology is used. Some studies use complex modelling approach like computable general equilibrium (CGE) economic models (Ciscar et al., 2018a), other more often use available market price figures (for electricity, food production, transport, etc.) and scenarios to make projections (e.g. ICCED, 2014). When available, figures can be found in the insurance industry (e.g. Dantec and Roux, 2019). For some studies, costs analyses are made without any human-related factors taken into account. Often, social costs are included in terms of number of casualties (Dantec and Roux, 2019) which can also be associated with a value of life year

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[1] http://euro-cordex.net/

(ICCED, 2014; Steininger et al., 2015). A few studies have focused on the social vulnerability to climate change, like for the city of Helsinki (HSY, 2015).

Depending on the studies, the **time horizon** varies and can be 2030, 2050, 2100 or a combination of the three. A short time horizon (2030) has the advantages of allowing for realistic socio-economic scenarios, as well as giving a sense of urgency for adaptation measures. However, such short time horizon lacks the ability to give the full scale of climate impacts as the 2100 time horizon would (Franz Prettenthaler, pers. comm. 2020). Medium and long-time horizons do not allow to include infrastructure measures into later adaptation plans. In a static approach where the socio-economic situation remains identical to the present day, long-term cost estimates might become unrealistic because of socio-economical change. A good compromise seems to take medium time horizons such as 2050 (Franz Prettenthaler, pers. comm. 2020).

According to Adriaan Perrels (pers. comm. 2020), economic models are also limited in their ability to model **indirect impacts** of climate change as well as **rupture points** and their interactions with the rest of the economy.

5.5. ANALYSIS OF INDICATORS

When looking at indicators, a first distinction has to be made between input and output indicators. The **output indicators** are target variables required to support policy makers (e.g., GDP losses by sector). The **input indicators** are the data used to estimate the output indicators. Therefore, it makes sense to choose input indicators as close as possible to the desired output indicators, e.g. choose yield rather than soil erosion to estimate agricultural losses (Franz Prettenthaler, pers. comm. 2020).

According to Franz Prettenthaler (pers. comm. 2020), output indicators should be as **simple** and **comprehensible** as possible. A complex indicator, although scientifically meaningful, will be of no use, if it cannot be easily apprehended by policy makers or the wider audience. The number of people affected by negative effects of climate change or the number of heatwave days are simple yet powerful indicators.

In complement to this view, and according to Adriaan Perrels (pers. comm. 2020), usual output indicators should be complemented by more **meaningful indicators** such as quality of life or excess mortality, or income losses (and their distribution) for GDP.

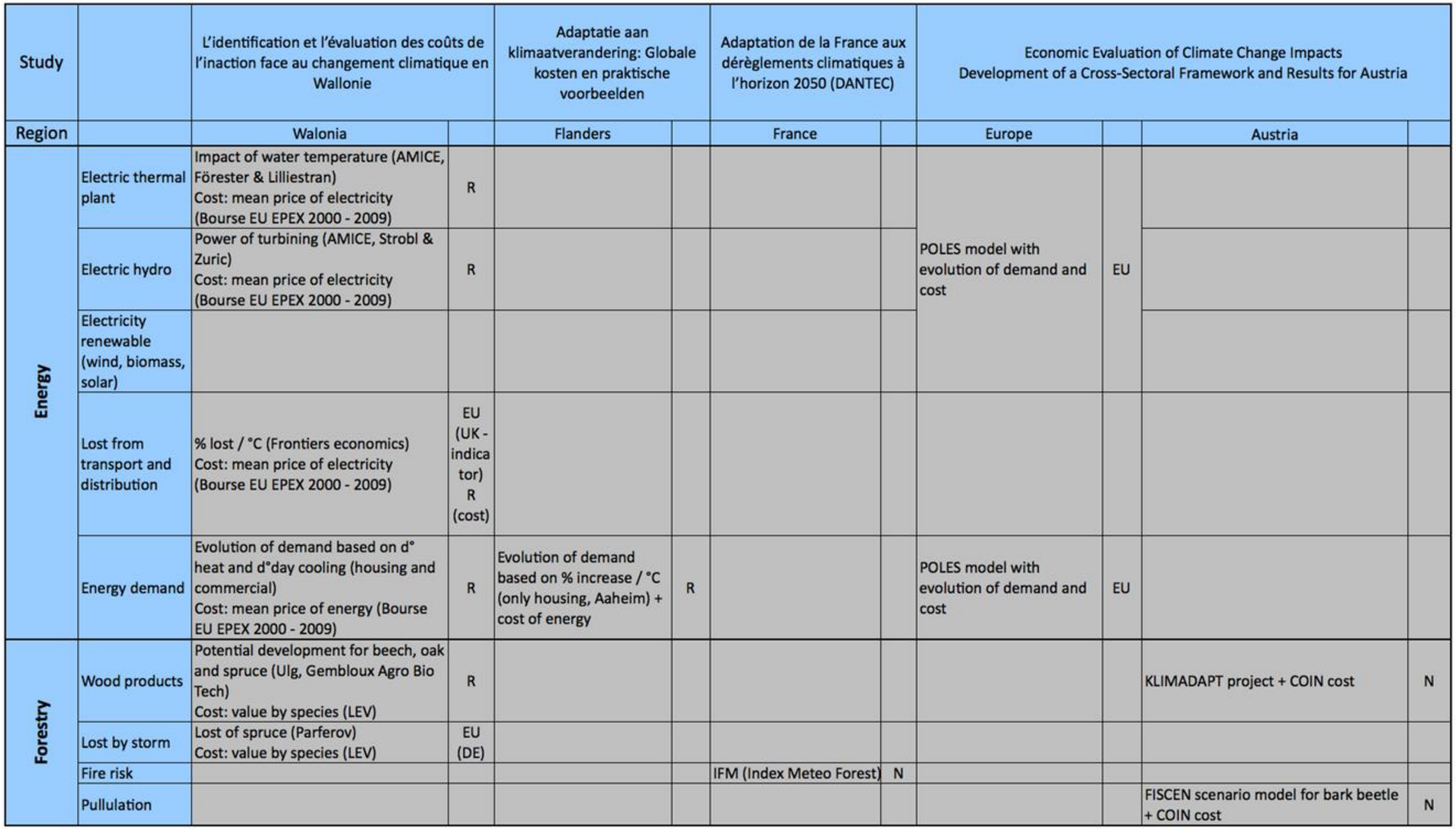
As input, it is interesting to **focus on extreme events**, since according the European Environment Agency these accounted for 83% of European monetary losses of 426 B€ in the period 1980-2017 (EEA, 2019c). The figure for Belgium for this period amounts to 4.3 B€.

When **comparing** different countries or regions, losses are better expressed in a standardized manner, e.g. in € per capita or €/km^2.

Table 5-2. Analyses of the agriculture and biodiversity sectors in five studies for regional (R), national (N), European (EU) and World (W) scales.

Study		L'identification et l'évaluation des coûts de l'inaction face au changement climatique en Wallonie		Adaptatie aan klimaatverandering: Globale kosten en praktische voorbeelden		Adaptation de la France aux dérèglements climatiques à l'horizon 2050 (DANTEC)		Economic Evaluation of Climate Change Impacts Development of a Cross-Sectoral Framework and Results for Austria			
Region		Walonia		Flanders		France		Europe		Austria	
Agriculture	Yield	Evolution of yield with Model EPIC - Grid + CCI Hydr (AMICE) for: Corn, wheat, barley, beets, potatoes and meadow Cost: Eurostat	R	Cost of dommage (Gobin)	R			DSSAT crop simulation model	EU	EPIC bio-physical process mode with CC scenario and cost	N
	Erosion										
	Pest and invasive										
	Change of culture										
Biodiversity	Carbon sequestration	Evolution of land use (Project ATEAM) Cost: € / ton CO2 (function of land use)	EU								
	Recreational activity in forest	Evolution of land use for forestry (Project ATEAM) Cost: WTP (willingness to pay)	EU								
	Water regulation	Evolution of land use (Project ATEAM) Cost: meta-analytic regression model	EU (Indicator) W (cost)								
	Pollinisation									Combination of Pest Control (formula by Losey and Vaughan) and pollinisation (formula by Gallai) in 4 scenarios with associated value	N
	Pest control										

Table 5-3. Analyses of the energy and forestry sectors in five studies for regional (R), national (N), European (EU) and World (W) scales.

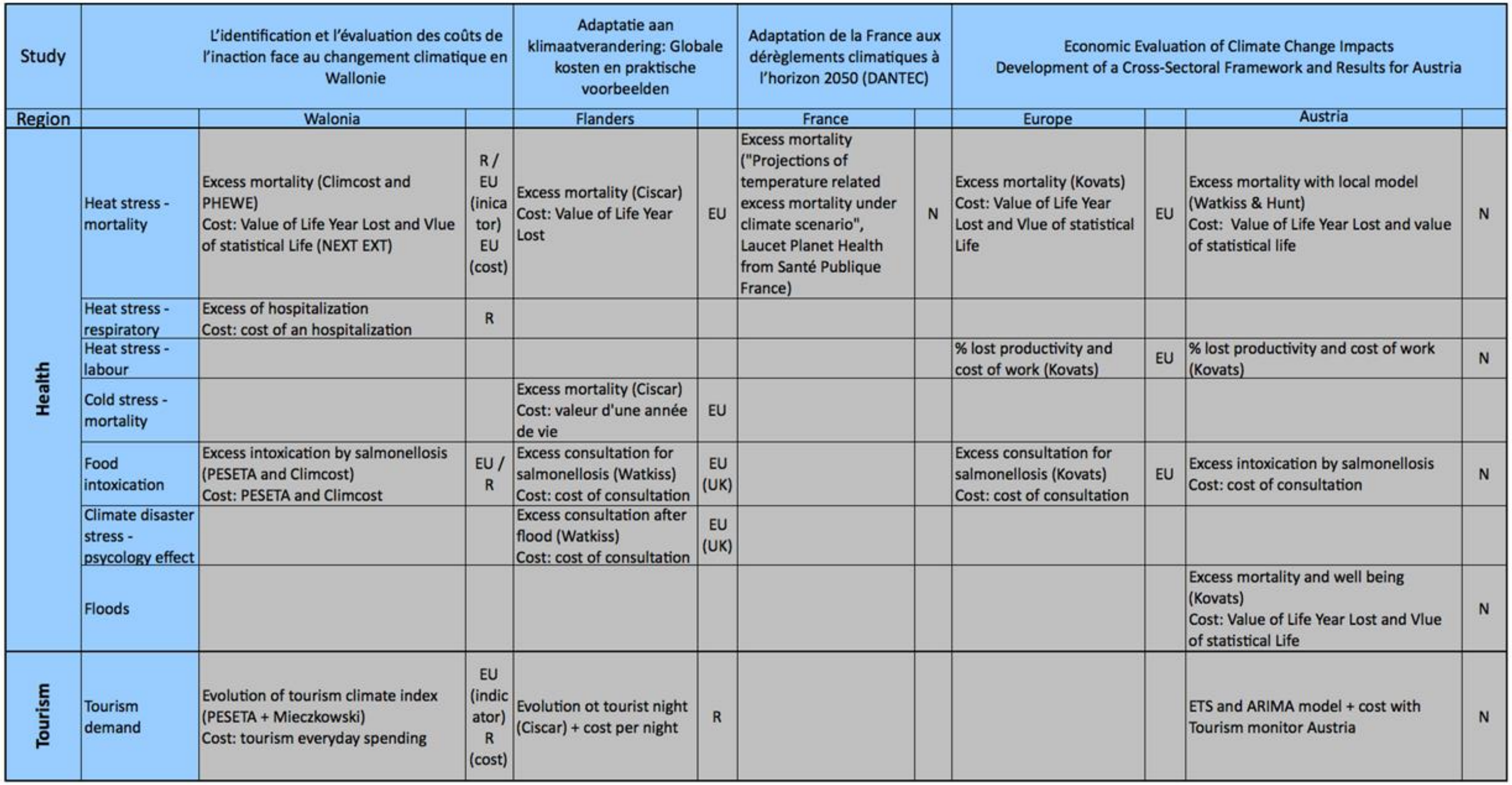


Study		L'identification et l'évaluation des coûts de l'inaction face au changement climatique en Wallonie		Adaptatie aan klimaatverandering: Globale kosten en praktische voorbeelden		Adaptation de la France aux dérèglements climatiques à l'horizon 2050 (DANTEC)		Economic Evaluation of Climate Change Impacts Development of a Cross-Sectoral Framework and Results for Austria			
Region		Walonia		Flanders		France		Europe		Austria	
Energy	Electric thermal plant	Impact of water temperature (AMICE, Förester & Lilliestran) Cost: mean price of electricity (Bourse EU EPEX 2000 - 2009)	R					POLES model with evolution of demand and cost	EU		
	Electric hydro	Power of turbining (AMICE, Strobl & Zuric) Cost: mean price of electricity (Bourse EU EPEX 2000 - 2009)	R								
	Electricity renewable (wind, biomass, solar)										
	Lost from transport and distribution	% lost / °C (Frontiers economics) Cost: mean price of electricity (Bourse EU EPEX 2000 - 2009)	EU (UK - indicator) R (cost)								
	Energy demand	Evolution of demand based on d° heat and d°day cooling (housing and commercial) Cost: mean price of energy (Bourse EU EPEX 2000 - 2009)	R	Evolution of demand based on % increase / °C (only housing, Aaheim) + cost of energy	R			POLES model with evolution of demand and cost	EU		
Forestry	Wood products	Potential development for beech, oak and spruce (Ulg, Gembloux Agro Bio Tech) Cost: value by species (LEV)	R							KLIMADAPT project + COIN cost	N
	Lost by storm	Lost of spruce (Parferov) Cost: value by species (LEV)	EU (DE)								
	Fire risk					IFM (Index Meteo Forest)	N				
	Pullulation									FISCEN scenario model for bark beetle + COIN cost	N

Table 5-4. Analyses of climate disasters and urban green in five studies for regional (R), national (N), European (EU) and World (W) scales.

Study		L'identification et l'évaluation des coûts de l'inaction face au changement climatique en Wallonie		Adaptatie aan klimaatverandering: Globale kosten en praktische voorbeelden		Adaptation de la France aux dérèglements climatiques à l'horizon 2050 (DANTEC)		Economic Evaluation of Climate Change Impacts Development of a Cross-Sectoral Framework and Results for Austria			
Region		Walonia		Flanders		France		Europe		Austria	
Climate disaster	Water avaibility					Evolution of groundwater recharge, river flow, low-water mark (Explore 70)	N				
	River flooding	Increase of domage based on known cost for flood (AMICE)	R	Cost based on excess person concerned (Ciscar)	R	Increase of climate disaster cost for flood, storm, snow, hail, drought (swelling clay), coastal flooding. (insurance federation)	N	Direct physical losses (€) with LIFEFLOOD model	EU	Direct physical losses (€) with LIFEFLOOD model	N
	Coastal flooding			Direct cost based on Julie study	R			Land and building lost, salinization with DIVA models (with cost)	EU		
	Storm										
	Snow										
	Hail										
	drought (swelling clay)										
Urban Green										Improved prevention against lost of climate comfort in urban environment (Corine Land Cover - EEA and Urban Atlas Land Cover - EEA) + cost for greening city (€ / m²) and maintenance (€ / ha)	N

Table 5-5. Analyses of the health and tourism sectors in five studies for regional (R), national (N), European (EU) and World (W) scales.



Study		L'identification et l'évaluation des coûts de l'inaction face au changement climatique en Wallonie		Adaptatie aan klimaatverandering: Globale kosten en praktische voorbeelden		Adaptation de la France aux dérèglements climatiques à l'horizon 2050 (DANTEC)		Economic Evaluation of Climate Change Impacts Development of a Cross-Sectoral Framework and Results for Austria			
Region		Walonia		Flanders		France		Europe		Austria	
Health	Heat stress - mortality	Excess mortality (Climcost and PHEWE) Cost: Value of Life Year Lost and Vlue of statistical Life (NEXT EXT)	R / EU (inicator) EU (cost)	Excess mortality (Ciscar) Cost: Value of Life Year Lost	EU	Excess mortality ("Projections of temperature related excess mortality under climate scenario", Laucet Planet Health from Santé Publique France)	N	Excess mortality (Kovats) Cost: Value of Life Year Lost and Vlue of statistical Life	EU	Excess mortality with local model (Watkiss & Hunt) Cost: Value of Life Year Lost and value of statistical life	N
	Heat stress - respiratory	Excess of hospitalization Cost: cost of an hospitalization	R								
	Heat stress - labour							% lost productivity and cost of work (Kovats)	EU	% lost productivity and cost of work (Kovats)	N
	Cold stress - mortality			Excess mortality (Ciscar) Cost: valeur d'une année de vie	EU						
	Food intoxication	Excess intoxication by salmonellosis (PESETA and Climcost) Cost: PESETA and Climcost	EU / R	Excess consultation for salmonellosis (Watkiss) Cost: cost of consultation	EU (UK)			Excess consultation for salmonellosis (Kovats) Cost: cost of consultation	EU	Excess intoxication by salmonellosis Cost: cost of consultation	N
	Climate disaster stress - psycology effect			Excess consultation after flood (Watkiss) Cost: cost of consultation	EU (UK)						
	Floods									Excess mortality and well being (Kovats) Cost: Value of Life Year Lost and Vlue of statistical Life	N
Tourism	Tourism demand	Evolution of tourism climate index (PESETA + Mieczkowski) Cost: tourism everyday spending	EU (indicator) R (cost)	Evolution ot tourist night (Ciscar) + cost per night	R					ETS and ARIMA model + cost with Tourism monitor Austria	N

6. ECONOMIC IMPACTS OF CLIMATE CHANGE

6.1. GENERAL CONSIDERATIONS

In the sections below, we consider the economic costs associated with several of the climate change impacts described in Section 3. Indeed, while the description of physical impacts may be very instructive, for policy making the quantification of the damage costs is a necessary additional instrument to assess and compare impacts across different sectors.

Climate change causes several categories of costs. These include the costs related to mitigation (reduction of atmospheric greenhouse gas abundance) and the associated transition to a low carbon economy. In addition, there are adaptation costs, i.e. costs to counter unavoidable climate change impacts. In the present study we consider yet another category, i.e. the costs of inaction. Throughout the estimates presented below we will assess the market and non-market cost of sectoral climate change impacts, under the assumption of no adaptation.

Based on the findings in Section 3 (physical impacts), the international literature, and especially findings of recent major EU projects in the domain of economic cost assessment of climate change impacts (PESETA III and COACCH), we have selected the following topics for the assessment of the economic costs:

- Infrastructure damage loss owing to floods (coastal & inland) and drought, heat and cold
- Costs of heat-related mortality and morbidity
- Labour productivity loss related to heat and cold
- Drought and flooding losses in the agricultural and forestry sectors
- Drought- and temperature related losses in the energy sector
- Costs of biodiversity loss and ecosystems degradation
- International aspects (import- and export-related)

In the subsections below, statements are made regarding costs associated with certain (sectoral) climate change impacts which are expressed in euros, often using M€ (million euros) and B€ (billion euros) as monetary scales. In order to achieve a level of comparability, all amounts are converted to the 2019 price level, using the consumer price index (CPI) to do so. Stated otherwise, in all cost estimates we use the year 2019 as a base year, using the following expression,

$$C_{2019} = C_i(CPI_{2019}/CPI_i),$$

In which C_i is the cost and CPI_i the consumer price index (see Table 6-1) in year *i*. For instance, in case some monetary estimate is available for the year 2005, converting its value to the 2019 price level involves multiplying the figure pertaining to 2005 by a factor 108.78/83.97 ≡ 1.30.

Table 6-1. Consumer Price Index (based on the reference year 2013). Source: National Bank of Belgium.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
75.63	77.5	78.77	80.02	81.7	83.97	85.48	87.04	90.95	90.9

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
92.89	96.17	98.9	100	100.34	100.9	102.89	105.08	107.24	108.78

Moreover, whenever expressing a monetary estimate as a percentage or a fraction of the GDP (Gross Domestic Product), we use the GDP of the year 2019 as a basis, with a value of 473 B€. Table 6-2 gives an overview of the GDP share of a number of sectors, clearly showing the importance of the ‘services’ sector for the Belgian economy, totaling 330 B€ out of a total 473 B€ constituting the Belgian GDP.

Table 6-2. GDP per sector and in total for the Belgian economy for the year 2019, in M€. The rightmost column provides the share represented by each sector as a percentage of the total.

SECTOR		GDP (M€)	GDP%
Agriculture, forestry and fishing		2020.6	0.43
Industry (except construction)		67316	14.23
Construction		22715.3	4.80
Services	Wholesale & retail/transport/accommodation & food service activities	80541	17.02
	Information and communication	18175	3.84
	Financial and insurance activities	27702.7	5.86
	Real estate activities	39408.5	8.33
	Professional-scientific-technical & administrative-support activities	64999.6	13.74
	Other community and social and personal service activities	60670.4	12.82
	Human health and social work activities	29563.1	6.25
	Arts-entertainment-recreation/ household & extra-territorial orgs.	8862.4	1.87
Taxes less subsidies on products		51110.4	10.80
	Total economy	473085.1	100

In order to set the broader framework for the economic estimates conducted in the following sections, a few remarks are in order:

- The cost estimates we have made pertain to the *cost of inaction*, i.e. the damage costs that will arise if no adaptation measures are put in place.
- When considering costs related to impacts of climate change on humans (e.g., heat related mortality), we made an assumption of no physiological adaptation. While this may be debatable, insufficient scientific consensus is available on this topic for the moment, so that incorporation of this form of adaptation in our estimates is not warranted.
- Whenever relevant, we consider both adverse and beneficial impacts of climate change. In particular, warmer winters are expected to generate beneficial effects for health (decreased cold related mortality/morbidity), labour productivity (decreased illness-related absenteeism at work), and heating energy requirements (reduced residential heating demand). However, we account for positive and negative impacts separately, to allow policy makers to acknowledge and approach these impacts separately and appropriately.
- We often make very coarse assumptions. This is unavoidable given the large uncertainties both in the estimates of the physical damage (which is itself related to the uncertainty in the climate projections and in the impact functions) as in the monetary value assigned to a given damage (e.g., the value of a human life). Hence, the monetary estimates provided are to be approached with caution. At best, they constitute order-of-magnitude estimates. Nevertheless, we believe that our estimates – even if rather coarse – are useful to provide a science-based support the prioritization of adaptation options.
- In relation to this uncertainty, whenever possible we have attempted to compare economic costs estimates that were arrived at independently (e.g., considering bottom-up and top-down approaches), in order to derive confidence (or not!) from the comparison.
- We have tried as much as possible to stick to the agreed climate scenarios (RCP2.6/4.5/8.5) and time horizons (2030/2050/2100). However, this has turned out to be very difficult, given that the studies used as source material for the present study often use different scenarios and time horizons. ***In order to allow comparison between the different sectoral costs, we have always, i.e., for each sector, included costs for time horizon 2050 together with scenario RCP8.5, as a common projection standard.***

- Next to considering climate change impacts, whenever possible (but rather the exception given the lack of data) we have tried to also account future socio-demographic changes (population growth, enhanced share of elderly in the population, enhanced asset value in floodable areas, …). Yet, in order for the different sectoral impacts to be comparable, the reference cost estimates provided below are those that do not involve socio-demographic changes.

To end this introductory section on the economic cost estimates, we present some top-down assessments of monetary climate change impacts for Belgium, to provide a general sense of the overall magnitude of the costs we expect climate change to bring if no action is taken. We focus on end-of-the-century and 'high' climate scenarios, to somehow bracket the expected costs on the upper side.

Houghton (2015) puts forward a figure of 1-4% of GDP for the economic costs caused by climate change damage effects (considering RCP8.5) in developed countries towards the end of the century. Assuming that Belgium, on average, may be better off than many other developed countries, in particular those in Southern Europe, a range of 1-2% would seem appropriate. At the Belgian GDP of 473 B€ (2019) the economic cost would then roughly be in the range of 5-10 B€.

Kahn et al. (2019) estimate a GDP loss for Belgium of up to 2.2% of the GDP under RCP8.5 by the end of the century, which roughly corresponds to 10 B€ in 2019 monetary value.

Finally, it is instructive to aggregate economic cost estimates of past Belgian studies conducted at the regional level (Technum, 2012; ICEDD, 2014). This is a tough exercise, though, given the differences between those studies in the choice of time horizons, climate scenarios, and methodology.

- The Technum (2012) study states a figure of 3.5 B€/yr for the Flemish Region's climate related costs for 2050.
- ICEDD (2014) states a figure of 0.5 B€/yr for the Walloon region, but that applies to the year 2050 and not the end of the century. We simply extrapolate this mid-century value to the end of the century by doubling it towards 1 B€.
- In the absence of cost estimates for the Brussels Capital Region, we extrapolate the amounts from the Flemish and Walloon estimates, using the GDP of Brussels compared to that of the other regions (31% of the Flemish GDP and 79% of the Walloon GDP) as weights, roughly yielding a value of 0.9 B€/yr (and in the process totally disregarding the disproportionally urban character of our Capital Region compared to the other regions).

When summing these annual cost amounts, and allowing for inflation (around 10%) since the time these regional studies were conducted, we reach a total figure for Belgium (albeit extrapolated in a far from non-rigorous manner) of around 6 B€.

So, even though the estimates made above are very crude at best, they were also obtained in a completely independent way. Yet, the above preliminary estimates appear to converge to an order-of-magnitude estimate in the **range of 5-10 B€/year for a 'high' climate scenario, the lower value of this range pertaining to mid-century conditions and the higher value being representative for the end of the century**.

Finally, note that it was mentioned above that the amounts cited and derived here constitute an estimate for the expected upper limit on the economic costs (high scenario & end of the century). On the other hand, studies are rarely ever complete in their assessment and, even when they try to be, there might well be a number of cost estimates that are currently looming in the realm of the unknown, i.e., relating to impacts we are currently not even remotely aware of. Also, the above costs basically consider the 'regular' potential climate impacts, and not the more drastic or wholly unexpected impacts that could arise from exceeding certain thresholds that may trigger so-called tipping points.

6.2. HEALTH

In this section we consider the effect of a changing climate on the costs related to both heat and cold. Rather than just adding these to obtain a net effect, we treat them separately. Indeed, although the climate change related benefits from a decrease in cold-related mortality may balance the increasing trend in heat-related mortality, both require specific and different policy actions (Ščasný and Alberini, 2012). Stated otherwise, we should avoid considering the expected health benefits from reduced winter cold to serve as a 'compensation' for the adverse health effects of increasing summertime heat stress.

6.2.1. Heat-related mortality

According to several studies (e.g., Technum, 2012; Forzieri et al., 2017; Ciscar et al., 2018a), the economic cost of heat-related mortality ranks highest among the economic costs attributed to climate change. Obviously, this cost comes with a high uncertainty, particularly since it depends on a highly subjective monetary value assigned to a human life.

As mentioned in Section 3.1, heat-related mortality in Belgium currently amounts to approximately 70 excess death per year on average (Forzieri et al., 2017; considering the reference period 1980-2010). This average value has a strong interannual variability, fluctuating between 0 and a few hundred excess death per year, depending on the variability of the duration and intensity of heatwaves, and with a high value occurring during the summer of 2003 with an estimated 1200-2000 excess death.

The expected future number of annual excess death has been estimated by Forzieri et al. (2017) to reach up to 2800 at the end of the century under scenario RCP8.5. Another estimate, based on an extrapolation of a case study conducted in Antwerp (Sanchez Martinez et al., 2018; Section 3.1), yields a value of 1900 excess death for the same time horizon and climate scenario. The difference of approximately a factor 1.5 between both estimates can be explained by the fact that, while Forzieri et al. (2017) account for demographic projections (increased total population and larger share of elderly persons), Sanchez Martinez et al. (2018) do not. Similar differences of about a factor 1.5 between both types of estimates have been found by Watkiss et al. (2019).

For the time frame 2026-2045, estimates based on Sanchez Martinez (2018) yielded a figure of 707 excess heat related death (Section 3.1). To obtain a figure for mid-century (2050) conditions, we interpolate between this figure of 707 (which is taken to be representative for the year 2035) and the figure for the end of the century (1900 excess death, taken to be representative for conditions in 2090), yielding 962 excess heat related death in 2050.

Note that, in the remainder, we will use mortality *changes* compared to the current situation, in order to be able to estimate cost changes compared to today. Assuming the baseline value of 70 heat related death per year

- by the end of the century, the estimate based on Sanchez Martinez et al. (2018) amounts to 1830 per year (i.e., 1900 minus the 70 of the baseline) and 2730 death per year for the Forzieri et al. (2017) based estimate and
- towards the middle of the century we obtain 962 additional excess death,

each time considering scenario RCP8.5.

The cost of excess mortality is calculated by multiplying the number of heat-related excess death by the monetary value assigned to a human life, known as Value of a Statistical Life (VSL). This does not really represent an economic cost (i.e., it is a so-called non-market cost); rather, this should be seen as damage to the welfare of the population (Ciscar et al., 2018a).

The VSL is estimated by establishing the amount of money that people are willing to pay 'to reduce the risk of death by a defined probability or prolonged life by a given amount' (OECD, 2012). For instance, consider that from a survey it emerges that, on average, individuals are willing to pay 30 € to reduce the annual risk of dying by one part in 100,000. With such a risk reduction, one death out of 100,000 would be prevented. The total willingness-to-pay, i.e., summing those 30 € over 100,000 individuals, would correspond to an amount of 3,000,000 € to prevent one death, i.e., a VSL of 3,000,000. Hence, the VSL is not the value of a specific individual's life, but rather 'an aggregation of individual values for small changes in risk of death' (OECD, 2012).

Estimates for the VSL abound:

- EC (2019), which itself is based on figures from OECD (2012), cites a VSL for Belgium of 3.6 M€ (price level 2016), which converts to approximately 3.8 M€ in 2019.
- Estimates from other sources in EC (2019), considering various EU countries, are roughly in the range of 1-4 M€.
- Ciscar et al. (2018a) employ a VSL value of 1.14 M€ (2007 value) as an average for the EU, which amounts to 1.43 M€ in 2019 value.
- Most recently, Ščasný et al. (2020), based on a survey conducted in Spain and the UK, and results of which were converted to other EU countries using an income-adjusted procedure, obtained a VSL for Belgium in the range 2.63-3.00 M€ (2018 value), which converts to 2.67-3.04 M€ (2019 value).

In order for our study to be consistent with recent major European heat-health studies, in particular the PESETA III and COACCH projects, we will adopt the values established by (1) Ciscar et al. (2018a) (1.43 M€ found in the PESETA III project) and (2) Ščasný et al. (2020) (taking 2.85 M€ as the average of the 2.67-3.04 M€ range found in COACCH), which between them exhibit an uncertainty range of a factor two (1.43-2.85 M€).

Applying these VSL estimates of 1.43 M€ and 2.85 M€ to the mortality change projections made above (an increase by 1,830 resp. 2,730 annual excess death at the end of the century under RCP8.5, depending on whether demographic projections are included or not), we obtain a change in the annual heat-related mortality cost in the range of **2.6-5.2 B€/year** in the case when demographic changes are ignored (and 3.9-7.8 B€/year when such changes are accounted for). Considering the middle of the century, based on the estimated 962 additional heat-related excess death we obtain a figure of **1.38-2.74 B€/yr**.

One can of course argue that heat-related mortality mainly hits the elderly population or those already afflicted by serious underlying adverse health conditions, meaning that the number of lost life years is less than if the mortality occurred in the general population, i.e., comprising all age categories. Therefore, we approach this question from an independent angle, estimating the heat-related mortality cost based on the concept of the Value of a Life Year (VOLY), which requires an estimate of the annual number of lost life years caused by heat.

While information regarding the number of lost life years during heat waves for Belgium appears to be lacking, we may attempt to extract some information from an analysis of Keller (2015) (also see Section 3.1), who found that the 15,000 excess death occurring in France during the heatwave of 2003 corresponded to approximately 100,000 lost life years, i.e., one death corresponds on average to 6.67 years of life lost. (This value is fairly consistent with Bosello and Schechter (2013) and Sanchez Martinez et al. (2015), who used a value of 8 years.) Assuming that this ratio of 6.67 lost life years per unit mortality applies to Belgium, and using the range of 1,900-2,800 annual heat-related death as above, one finds an annual number of 12,700-18,800 lost life years, depending on whether or not demographic projections are accounted for.

These lost life years have to be multiplied by the Value Of a Lost Year (VOLY) to estimate the associated cost. As for the VSL, there is a large uncertainty on the VOLY. EC (2019) gives an overview of values obtained in recent studies: these display a considerable amount of scatter, ranging between approximately 15,000 and 270,000 €/yr. However, most values appear in the range 50,000-100,000 €/yr. For the Flemish Region, de Bruyn et al. (2019) have estimated a VOLY of approximately 75,000 €/yr (2019 price level), which is nicely in the middle of this range. Hence, we will use VOLY's with lower and upper limit values of 50,000 €/yr and 100,0000 €/yr, respectively.

Applying this VOLY range to the estimated number of lost life years, the heat-related mortality cost amounts to 0.63-1.27 B€/year in the case where no demographic projections are accounted for, and 0.94-1.88 B€/year when these projections are included. These estimates are about a factor four lower than the VSL-based estimates arrived at above. This disparity between the monetary outcomes obtained with the VSL- versus the VOLY-based method was also observed by Chiabai et al. (2018); it clearly illustrates the large uncertainty that comes with these cost estimates.

6.2.2. Heat-related morbidity

Little or no information regarding temperature related morbidity costs appear to be available for Belgium. Therefore, we develop a very crude calculation based on the estimated number of heat-related hospital admissions (approximately 2000 per day, see Section 3.1) together with hospitalization cost estimates for Belgium. This figure of 2000 excess heat-related hospital admissions, despite it has been established here on very loose arguments, is quite comparable with figures found in other studies. For instance, Kovats et al. (2004) noted almost 17,000 excess hospital admissions during the six-day heatwave of 29 July to 3 August 1995 in Greater London, i.e., nearly 3000 per day for an area counting around 7 million inhabitants (value for the mid-nineties according to the Encyclopedia Britannica[1]). This value of 3000/day, rather than the 2000/day estimated for Belgium, could be explained by the assumption of a higher average vulnerability of the urban population living in a major metropolitan area. For the 1995 heatwave in Chicago, Semenza et al. (1999) found an 11% excess of hospital admissions. Considering that Belgium counts 6.2 million hospital admissions per year (FPS Health, 2019), i.e., 17,000 per day, the figure of 11% excess admissions would entail 1870 extra daily admissions, which is again a close match with the estimate of 2000 daily excess admissions.

To estimate morbidity costs, we first assume that in the future (see Section 2), as a very rough estimate, summer periods will on average experience 30 heatwave days each year. Further, assuming the number of 2000 excess heat-related hospital admissions per day during heatwave episodes estimated in Section 3.1, we obtain a total number of admissions for heat-related illness of 60,000 each year. This figure has to be multiplied by an average hospitalisation cost, which is estimated next.

Using an example of a hospitalization cost calculation for Belgium presented in Swartenbroekx et al. (2012) (their Section 8.4), and converting this to a cost per day (rather than 3 days as in their example) and to the 2019 price level, we find the following average daily hospitalization costs:

- nursing: 135 €/day;
- emergency department costs: 29 €/day;
- emergency physician: 36 €/day;
- overhead: 153 €/day.

This adds up to a total daily hospitalization cost of 353 €, which is not too remote from values estimated for Belgium by the WHO[2], which amount (in 2019 value) to an average of 241 € (range 177-316 €) per hospital bed day, but which only represents the 'hotel' component of hospital costs (Adam et al., 2003), in particular excluding costs related to diagnostics, so that it underestimates the total hospitalisation cost.

Assuming a hospital stay of 4.5 days, which is the average for acute admissions (i.e., admissions with an initial emergency department admission) in Belgium (FPS Health, 2019), we arrive at a unit hospitalization cost of 1588 €. Considering the 60,000 annual admissions estimated above, this represents a **morbidity (hospital-only) cost** of approximately **95 M€/year**.

This figure is 1-2 orders of magnitude smaller than the VSL-based mortality cost estimates (see above), which is consistent with findings by England et al. (2018) who, for Glasgow, concluded that hospital-based morbidity costs are about 30 times smaller than VSL-based mortality costs.

We also estimated heat-related morbidity costs in an entirely different way, using a top-down

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[1] https://www.britannica.com/place/Greater-London

[2] https://www.who.int/choice/country/bel/cost/en/

approach, and by considering that the number of heat-related admissions (here estimated at 60,000 occurring in one summer) constitutes around 1% of the total annual admissions in general hospitals in Belgium (6.2 million in 2017, see FPS Health, 2019). Considering that the total annual turnover of Belgian general hospitals amounts to approximately 18.8 B€ (2019 value; FPS Health, 2019), and assuming that heat-related admissions carry an 'average' cost, the share of 1% represented by these heat-related admissions would correspond to approximately **188 M€/year** which, given the entirely independent way of estimating this figure, is not too remote from the above estimate of 95 M€/year.

Clearly, the estimates described above are, at best, very coarse. Nevertheless, it is very clear that, based on these results, the morbidity (hospital) costs are well below the cost estimates of heat related mortality. It appears very unlikely that the costs associated with heat-related hospital admissions would ever get anywhere near the mortality cost.

Of course, in the above we have not accounted for the costs of heat-related illness that is dealt with outside hospitals. Yet, it appears reasonable to assume that this cost would be smaller than the hospital costs. Heat-related illness does have other economic costs, however, related to labour productivity losses, which are described in Section 6.3.1.

6.2.3. Cold-related mortality

Exposure to cold can lead to (Huynen et al., 2001) cardiovascular stress (vasoconstriction, increased blood pressure and viscosity, thrombosis, …) and increased incidence of pulmonary infections; indirectly, influenza contributes to cold-related mortality. As is the case for heat, cold stress more strongly affects the elderly and those with underlying disease. Considering several recent winter periods, Bustos Sierra et al. (2019b) find a decreasing linear relation between excess mortality and minimum temperature, though the incidence of influenza and concentration levels of fine particulate matter also have an impact (but in the end these are also related to temperature seasonality).

Studies consistently point to a decrease, with global warming, in the number of cold-related deaths occurring during winter. However, no detailed information appears to be available regarding future projected changes in cold-related mortality for Belgium. Therefore, we attempt to extrapolate information gathered in a detailed study conducted by Ščasný et al. (2020) for the Netherlands, which has a climate and a demographic structure not too dissimilar from that in Belgium. In particular, the 'Excess Winter Deaths' index in Belgium and the Netherlands is similar (Liddell et al., 2016).

Ščasný et al. (2020) found that the decrease of temperature by 1°C below the optimal temperature of 17.6°C causes a daily excess mortality by 1.1%[1]. A similar value of daily mortality decrease of around 1% per °C temperature increase is also apparent from data presented in e.g. Gasparrini et al. (2015) for London (their Figure 1).

We took cold-related mortality figures presented in Ščasný et al. (2020) for the Netherlands (their Table 2.3), and converted these to match the Belgian situation, as follows:

- The climate scenarios referred to (G, G+, W, W+), which are used in the Netherlands alone, were matched to RCP scenarios by identifying the warming (temperature increase) associated with each scenario, using information contained in Section 2 (projected wintertime temperature increase in Belgium) as a basis to match the Dutch and the RCP scenarios.
- We applied a conversion factor to convert values obtained with the Ščasný et al. (2020) approach for the Netherlands to the Belgian situation. This was done by estimating the number of annual *heat* related death with the Ščasný et al. (2020) method for their scenario matching best the RCP8.5 scenario and a time horizon 2071-2100 which, for the Netherlands yields a value of 3314. Comparing this to the Belgian estimate of 1830 *additional* annual heat related

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[1] It is interesting to compare this to the 2.4% excess mortality found per °C above this threshold value by Ščasný et al. (2020), confirming the earlier observation in Section 3 that the slope of excess mortality increases more steeply for high temperatures than that it declines for low temperatures. Stated otherwise, the sensitivity of mortality to temperature is much higher on hot than cold days.

death (i.e. ,1900 minus 70 of the baseline, see above) for the same scenario and time horizon (Section 3.1), we obtain a factor of 0.55 to convert Dutch values to the Belgian situation. This conversion factor reflects not only differences in population density (17.3 million in the Netherlands, 11.5 million in Belgium – values for 2019 – which already explains a factor 0.66) but also differences in the methodology used.

To illustrate our approach, consider the case of time horizon 2031-2060 and scenario RCP4.5 which, according to Table 6-3, produces a winter warming of 1.5°C. This temperature values comes nearest to the 1.4°C warming associated with the 'G+ scenario of 2050' in Ščasný et al. (2020), which in their Table 2.3 shows a reduction by a factor 7 of the number of daily cold-related death occurring during 80% of the time or 292 days a year (this is the number of days the temperature is below the optimum value of 17.6°C), hence a reduction by a number of 2044 cold related death per year in the Netherlands. As a result, for Belgium – applying the conversion factor with value 0.55 – that would yield an annual reduction of the number of cold-related deaths by 1124.

Table 6-3. Estimated annual cold-related mortality changes (in number of death) for several time horizons and climate scenarios, calculated as explained in the main text.

time horizon	**scenario (and temperature increase in °C)**	**Corresponding Ščasný et al. (2020) scenario (see their Table 2.3)**	**annual mortality change**	
			cold	heat
2031-2060	RCP4.5 (1.5°C)	G+ / 2050	–1124	+602
	RCP8.5 (1.8°C)	W / 2050	–1230	+723
2071-2100	RCP4.5 (2.2°C)	W+ / 2050	–1485	+1045
	RCP8.5 (3.5°C)	average of W and W+ / 2085	–1816	+1830

The main outcome of this exercise is that, while initially the decrease in cold related death has a larger magnitude than the increase in heat related death, by the end of the century and under scenario RCP8.5 both figures arrive at a similar level.

It is instructive to compare estimates in Table 6-3 with a few independent estimates. First, we employ an Excess Winter Mortality (EWM) type of approach (Hajat, 2017). While this may be an overly simplified approach, it may at least help to get an idea of the order of magnitude that is involved. To apply this method, consider that, roughly speaking, in Belgium the daily number of deaths in winter (~320) exceeds summer values (~250) by 70. The temperature difference between January (2.5°C) and July (17.8°C) amounts to 15.3°C, hence the excess daily number of winter death can be (naively) associated with a seasonal temperature difference of 15.3°C, or 4.6 less daily cold related death per °C. Applying this figure over the period December-March (121 days), which is commonly used in EWM approaches, we arrive at a value of 557 less annual cold related death per °C winter warming. Multiplying this with a projected winter warming of 3.5°C (RCP8.5, 2071-2100) we obtain a reduction of 1950 annual cold related death, which compares fairly well with the estimated decrease of 1816 in Table 6-3.

In another study, Langford and Bentham (1995) estimated an annual reduction in the number of winter death for the UK by 9000 towards the year 2050, which for Belgium would correspond to about 1500 less winter death (considering that the UK counts approximately six times more inhabitants), which is not too remote from the estimates of a reduction by 1230 winter death in Table 6-3 that would correspond nearest to mid-century conditions.

Note though, that much uncertainty remains regarding the impact of cold on winter mortality. For instance, Staddon et al (2014) – in a paper appropriately entitled "Climate warming will not decrease winter mortality" – find that, while winters evidently are characterized by excess mortality, "winter cold severity no longer predicts the numbers [of death] affected". The expected decrease in wintertime mortality with climate change is also questioned by Kinney et al. (2015). For all we know, it might well be that the excess winter mortality is not (causally) related to cold stress, but rather (or partially) to other parameters such as the length of day or the number of sunshine hours.

To end this subsection, we make a monetary estimate of the reduction in cold related death, using the VSL (Value of Statistical Life) used above for heat related death, i.e., the range of 1.43-2.85 M€ per life lost. Considering the end of the century and RCP8.5, the resulting avoided average annual cold related mortality cost amounts to **2.6-5.2 B€.** Not too surprisingly, this is nearly identical to the increase of costs associated with the increase in annual heat related death. Obviously, this reflects the fact that, for the scenario and time horizon considered, the decrease in cold related deaths matches the increase in heat related deaths very closely.

For the middle of the century, we take the 1230 avoided excess death related to reduced winter cold from Table 6-3 as a basis to calculate avoided average annual cold related mortality costs of **1.76-3.51 B€.**

6.2.4. Cold-related morbidity

Given that for the case of heat related morbidity the costs were much lower than the mortality costs, we did not assess this topic.

6.3. LABOUR PRODUCTIVITY

6.3.1. Heat

A fairly large body of literature considering the impact of (extreme) heat on labour productivity loss has been established in the past years; see Day et al. (2019) for a recent overview including empirical estimates of the effect of heat on labour productivity and the economy-wide effects of the associated productivity losses. They state that 'the effect of heat stress on labour productivity is a key economic impact of climate change, which could affect national output and workers' income'.

According to ILO (2019), the strongest impacts of heat on labour productivity are found – not surprisingly – in tropical countries and in the sectors of construction and agriculture, which largely rely on outdoor work. Yet, other sectors, including in temperate countries, are also affected. For instance, Cachon et al. (2012) found that in automobile assembly plants in the US, a week with temperatures exceeding 32.2°C causes a 8% decline in productivity, on average. On a macro-economic level, Deryugina and Hsiang (2014) and Heal and Park (2016) estimated for the US that 20 additional hot days occurring in a year can reduce annual income by more than 1.2 %.

Section 3.2 provides estimates and examples of heat related labour productivity loss in Belgium, considering both indoor and outdoor workers. Below, we consider the economic cost that comes with labour productivity losses, based on a specific case study for the Antwerp area which, considering some assumptions, will be extrapolated to Belgium. The outcome of this exercise will then be compared with estimates from European studies.

Costa et al. (2016) and Costa and Floater (2016) assessed heat related labour productivity loss for the City of Antwerp. An important aspect of the study is that, unlike many other studies, they not only considered outdoor heat stress, they also estimated heat stress occurring in office buildings in order to allow estimates for the 'services' sector. As mentioned in Section 6.1, this sector constitutes the single largest sector in the Belgian economy.

The Costa et al. (2016) study was designed as follows:

- present and future time series of climate variables (temperature, humidity, wind speed, shortwave radiation) were downscaled from large-scale climate model output fields by means of the high-resolution urban climate model *UrbClim* (De Ridder et al., 2015b), considering the entire Antwerp area;
- additionally, indoor climate variables were estimated by means of a building energy model forced by *UrbClim* outdoor climate fields (Hooyberghs et al., 2017);
- these climate variables were converted to time series of the Wet Bulb Globe Temperature (WBGT, see Section 3.2), a thermal stress indicator that is commonly used (and has ISO standards) to estimate heat related labour productivity loss;
- based on WBGT time series, labour productivity losses were estimated per sector, accounting for the intensity of the work (light – moderate – heavy) and for the indoor versus outdoor character (agriculture and construction were considered as outdoor work, the remaining sectors as indoor);
- these sectoral productivity losses were then fed into an economic model (Costa and Floater, 2016) to estimate the economic production decline induced by labour productivity losses, considering both capital and labour and the elasticity of substitution between both;
- this whole chain of steps was conducted using RCP8.5 as scenario for future climate and considering the time horizons 2026-2045 and 2081-2100; yet, for each time horizon Costa et al. (2016) considered both a cool and a warm year, which allows to estimate a range of impacts.

The main outcome of Costa et al. (2016) was that for the Antwerp area, all sectors combined[1] suffered an economic productivity loss of up to 669 M€ per year (value for the warmest of the 20-year period

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[1] including all economic sectors: agriculture, forestry and fisheries, construction, industry and services

considered, towards the end of the century), which constitutes 2.1% of the Global Value Added (GVA) for this economic area. More details regarding the estimated economic production losses are shown in Table 6-4.

Table 6-4. Estimated economic production loss for Antwerp under RCP8.5 for different time horizons, each time considering a cool and a warm year. All values have been converted from Costa et al. (2016) monetary estimates (pertaining to the year 2005) to 2019 price levels. Antwerp's GVA (required for the estimates of the rightmost column) amounts to 41.3 M€ (in 2019 value).

		economic production loss (M€)	**% of Antwerp's GVA**
2026-2045	cool	0	0
	warm	335.5	0.81
2081-2100	cool	57.7	0.14
	warm	669.0	2.1

This outcome clearly shows the existence of large interannual climatic variability: a cool year in the far future may experience a lesser productivity loss than a warm year in the near future. Nevertheless, the increasing economic production loss trend is clear.

Based on these estimates for the Antwerp area, we make an estimate of heat related economic production loss for the whole of Belgium. This is done simply by transferring the percentage production losses from Antwerp to the Belgian GDP. Of course, this requires the rather strong assumption that the loss percentages for Antwerp can be applied to Belgium as a whole.

This is potentially problematic indeed, as the share (%) of the sectors constituting Antwerp's economy versus that in Belgium as a whole are not necessarily the same. In particular the different urban heating levels compared to e.g. Brussels, might make an impact. On the other hand, Antwerp does include a fair amount of urban heat increment, which makes is less relevant for extrapolation towards rural areas.

Considering that production losses generally are sector dependent, a simple transfer of the overall loss percentage (which is an aggregate value over all sectors) from Antwerp to Belgium is not straightforward. Yet, when considering the distribution of Antwerp's GDP over the different sectors these appear to be fairly similar to the Belgian values. Indeed, comparing sectoral GDP shares presented in Costa et al. (2016) for Antwerp with those applying to Belgium (see Section 6.1) yields:

- agriculture, forestry and fisheries: 0.3% in Antwerp, 0.43% in Belgium
- industry (manufacturing and other): 23.4% in Antwerp, 14.23% in Belgium
- construction: 4.2% in Antwerp, 4.8% in Belgium
- services: 72.1% in Antwerp, 69.7% in Belgium.

Hence, while differences are apparent, it is also clear that, e.g., the outdoor sectors combined (agriculture and construction) represent similar percentages of the GDP in Antwerp versus in Belgium. Moreover, the dominantly large share of the 'services' sector is apparent in both Antwerp and in Belgium as a whole. Therefore, we believe it is fair to extrapolate the economic production loss percentages from Antwerp to the whole country.

There is another aspect that needs to be addressed, though, and which is related to the difference between GVA (used by Costa et al., 2016) and GDP (used in our study). In recent years, figures provided by the National Bank of Belgium[1] show that the country's GVA is around 10% lower than the GDP. Therefore, when applying the percentages in the rightmost column of Table 6-4 to the GDP instead of the GVA, they first need to be reduced by a factor 0.9. For instance, the 2.1% value associated with a warm year at the end of the century (Table 6-4) would approximately become 1.9%.

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[1] stat.nbb.be (under 'national accounts' – 'detailed accounts' 'composition and identity of GDP')

When applying these adjusted percentage economic productivity losses to Belgium's GDP of 473 B€ (2019), we obtain the monetary values shown in Table 6-5.

Table 6-5. Projected economic productivity losses for Belgium in B€ (2019 price level). The percentages in the rightmost column were obtained from the percentages presented in Table 6-4, adjusted to account for differences between GVA and GDP (see main text). These percentages were then applied to Belgium's GDP of 473 B€ (2019) to yield the economic production loss in B€.

		economic production loss (M€)	**% of Belgium's GDP**
2026-2045	cool	0	0
	warm	3,450	0.73
2081-2100	cool	610	0.13
	warm	9,000	1.9

While the variability (between the 'cool' and 'warm' results) arising in these estimates is large, it is also clear that the impact of heat on labour productivity losses and the economy are potentially really large, with values between **0.61-9 B€/yr** in warm years (1 in 20) towards the end of the century. Interpolating from values in Table 6-5 we find values for mid-century (2050) conditions of **0.17-4.96 B€/yr**.

Based on these estimates for cool versus warm years, it is difficult to derive an estimate for the annual mean productivity loss. We will simply assume that the annual mean value is given as the average of the cool and warm year's production loss values. This is not necessarily correct (e.g., in case of skewed distributions), but in the absence of more detailed information regarding the probability distribution of the annual economic loss values we will assume this to be acceptable.

Given the large uncertainty on the above estimate, we make an attempt to produce an independent estimate based on results obtained in other (European) studies, considering both outdoor and indoor work and the associated labour productivity los.

Szewczyk et al. (2018) estimated labour productivity loss in European regions for outdoor workers. Considering Europe as a whole they found productivity loss values of around 1% under a 2°C warming scenario and 3.4% for a high warming scenario (RCP8.5, time horizon 2080) – each time involving large levels of uncertainty related to the ensemble variability of the climate simulations. They also found very large geographical differences, with markedly higher labour productivity losses in Southern European countries (up to 10-15%) compared to those in more Northern locations. For the 'Central Europe North' region, which includes Belgium, they found a productivity decrease of (on average) 0.5% for a 2°C warming scenario and 2% for a high warming scenario (RCP8.5, 2080s).

Szewczyk et al. (2018) also calculated the economic implications of these productivity losses, considering two sectors: construction and agriculture. They found a GDP decrease by approximately 0.03% under a 2°C warming scenario and 0.12% in the high warming scenario (RCP8.5, 2080s). These rather low numbers reflect the fact that the construction and agricultural sectors only constitute a small fraction of the economy in many European countries. For instance, in Belgium they represent slightly over 5% for the two sectors combined (see Section 6.1). When applied to Belgium and using the GDP of 473 B€ (2019), these percentage economic losses (0.03% and 0.12%, see above) correspond to monetary values of 142 M€ (2°C warming) and 568 M€ (RCP8.5, 2080). However, as mentioned above, these estimates only pertain to the construction and agricultural sectors, which constitute a modest share of the Belgian economy.

Gosling et al. (2018) provide estimates of labour productivity loss specifically for Belgium. More importantly, apart from estimates for outdoor work they include figures for *indoor* workers, which is very relevant given the high share of indoor workers in the Belgian service-dominated economy (see Section 6.1). We digitized productivity loss values from Gosling et al. (2018) for outdoor workers and indoor workers separately, and considering the near (2021-2050) and far (2071-2100) future. The results are shown in Table 6-6; with the 'outdoor' productivity loss percentages shown in the agriculture and construction sector, and the ‘indoor’ percentages in the service sector. For the industry sector we took an average of indoor and outdoor percentage loss values. Work in the industrial sector may be indeed be considered as intermediate. For instance, Kjellstrom et al. (2014) rank the labour intensity of the industry sector as ‘moderate’ in between that of agriculture (‘heavy’) and services (‘light’). Also, Costa et al. (2016) use ‘light/moderate’ and ‘moderate’ work intensity denominations for the ‘industry’ and ‘manufacturing’ subsectors.

From Table 6-6 it can be seen that the productivity loss estimates (percentages) exhibit large ranges, which largely reflects the variability exhibited by the ensemble of WBGT-based impact models Gosling et al. (2018) employed. (The uncertainty associated with climate model ensemble variability is not even included here.) Also, for indoor work, as expected, the percentage loss values are much smaller than for outdoor work.

Table 6-6. Belgian productivity loss estimates under RCP8.5 and considering a nearby and a far time horizon. Productivity loss percentages were digitized from Gosling et al. (2018), using the ‘outdoor’ values for the agriculture and construction sectors, and the ‘indoor’ values for the services sector. Percentage loss values for the industry were taken as an average of values for indoor and outdoor work. Sectoral GDP values were taken from Section 6.1.

	sectoral GDP (B€)	period	productivity loss (%)	GDP decrease (M€)
construction & agriculture	24.7	2021-2050	0-0.73	0-180
		2071-2100	0.1-4.0	25-990
industry	67.3	2021-2050	0.01-0.4	7-270
		2071-2100	0.16-2.78	110-1,870
services	329.9	2021-2050	0.02-0.07	66-230
		2071-2100	0.22-1.55	730-5,110
total		2021-2050		73-680
		2071-2100		865-7,970

The rightmost column in Table 6-6 gives the estimated productivity loss in M€, resulting from the application of the percentage productivity losses to the respective sectoral GDP values. The productivity loss in the services is by far the most important, with a value of up to 5.11 B€ at the end of the century. While the percentage loss figures for the service sector are much smaller than those for the outdoor sectors (agriculture and construction), the loss expressed in euros is much larger for the services sector given its much higher share in the Belgian economy.

More important perhaps is that the numbers in Table 6-6 are of a similar magnitude than those estimated above based on the Costa et al. (2016) results. Indeed, while the near-future productivity loss value appears quite a bit lower in Table 6-6 (based on Gosling et al., 2018) than in Table 6-5 (based on Costa et al., 2016), for the far future the upper part of the range is highly comparable, at 9 B€ for the latter versus about 8 B€ for the former.

Obviously, from the above it transcends that the uncertainty associated with these monetary estimates of heat related labour productivity losses are huge. At the same time, it emerges very clearly that, when the services sector is accounted for, the risk of economic production loss in Belgium because of heat stress is to be taken very seriously.

6.3.2. Cold

It is expected that the warmer winters that accompany climate change will reduce labour productivity loss, i.e., climate change is expected to have a beneficial effect in this regard. Unfortunately, to our best knowledge, not studies regarding its monetary impact is available for Belgium.

Therefore, we attempt to estimate this impact by following a simple approach using available data. To do so, we first estimate the expected change in the level (percentage) of absenteeism of workers across all sectors as a result of increasing winter temperature. Subsequently, we assign a monetary value per work day gained as a result of the winter warming.

In general, absenteeism at work because of illness is higher in winter than in summer. SD Worx[1] presents monthly data of absenteeism in recent years (Figure 6-1), showing a clear seasonal cycle. (Note that we only consider short duration (< 1 month) absenteeism, since long duration absenteeism does not exhibit a clear seasonal cycle, hence including it would not affect our estimate.)

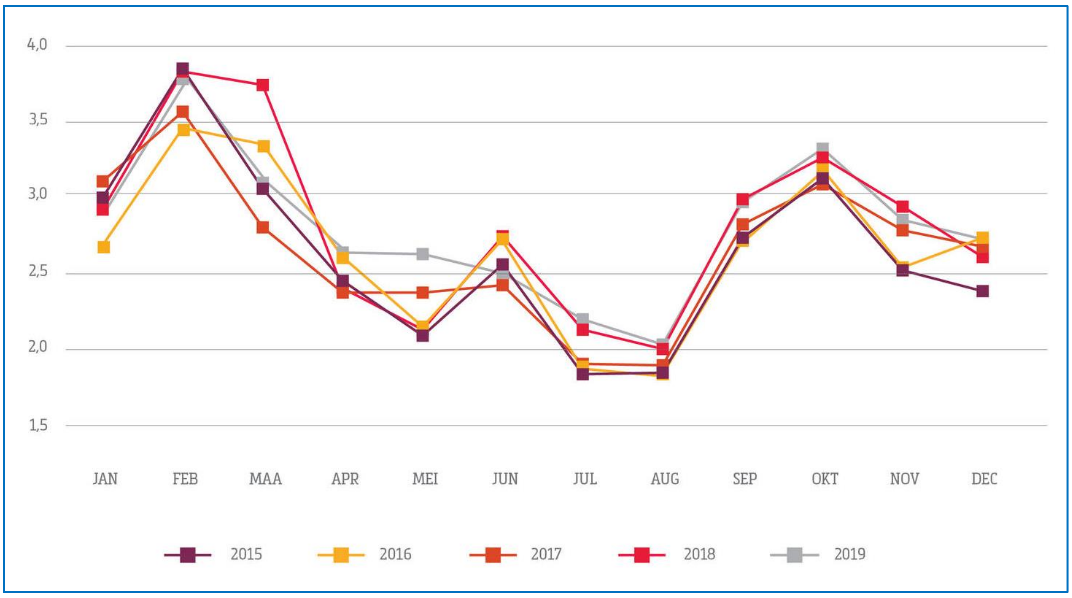

Figure 6-1. Absenteeism (short duration only) in the Belgian labour force in recent years. Source: SD Worx.

Roughly speaking, a visual inspection of Figure 6-1 reveals that absenteeism in the coldest months (December-March) is about 1%-point higher than that in the warmest months (May-August). This 'on sight' estimate obviously constitutes a very crude and not-so-commendable practice, but given the high level of uncertainty in all other aspects related to estimating productivity change, and given that the original data were not available as digital files, it appears fair enough to follow this approach. At least, it will allow an order-of-magnitude estimate of the productivity changes associated with winter warming.

In order to associate this absenteeism, change to a temperature change, we follow an Excess Winter Mortality (EWM)-like approach (Hajat, 2017), as done in Section 6.2 to estimate winter mortality, but applied to absenteeism instead. As then, we use the temperature difference between January (2.5°C) and July (17.8°C), and associate this 15.3°C differential with this 1%-point difference, yielding 0.065%-point per °C. However, cold related absenteeism pertains to the cold months December to March only, i.e., during 1/3rd of the year (i.e., the four cold months compared to the whole year), which finally yields an *annual* decrease of absenteeism by 0.022 %-point per °C winter warming. For a winter warming by 3.5°C, associated with RCP8.5 at the end of the century, this would yield a productivity gain of 0.077 %-points.

To find the cost (or rather the gain, since we consider a decrease of productivity loss, i.e., a productivity gain), we first estimate the number of working days gained by warmer winters. According to the National Bank of Belgium, the total number of hours worked in Belgium amounts to approximately 7.6

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[1] https://www.sdworx.be/nl-be/pers/2020/2020-02-20-februari-piekmaand-qua-ziekte-belgisch-ziekteverzuim-blijft-stijgen

billion per year (situation 2018)[1]. Assuming that a working day counts 7.6 hours (based on the 38-hours occurring in a working week), this yields a nice round figure of 1 billion days worked per year. The productivity gain of 0.077% derived above would thus result in 770,000 days won per year because of increasing winter temperatures, considering RCP8.5 at the end of the century. Following Cleemput et al. (2012) we assign a value of 301 € (adjusted from its original value of 257 € in 2010 to 2019 price level) per day, yielding a productivity gain of 232 M€/year.

Another approach is to simply apply the productivity gain of 0.077% directly to Belgium’s GDP of 473 B€ (2019). This is more consistent with the approach followed above for heat (at least in the Gossling et al. (2019) based method) and allows the best comparison with the heat related productivity loss estimates. Applying the productivity gain percentage to the country’s GDP yields an economic productivity gain of 364 M€/year.

To conclude, the productivity gain associated with warmer winter temperatures, under RCP8.5 at the end of the century, and in the absence of adaptation measures, is estimated to range **between 232 M€ and 364 M€** of avoided production loss costs. This appears to be quite a bit lower than the projected heat related productivity losses (see above), although all these productivity estimates (both heat and cold related) are fraught with a very high level of uncertainty. For mid-century (2050) conditions, given that the expected warming under RCP8.5 is roughly half that projected for the end of the century, and given that our simple approach is a linear one, we obtain the range of **116-182 M€/yr**.

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[1] http://stat.nbb.be/ under ‘population and labour market’ – ‘employment’ – ‘annual detailed data’

6.4. INFRASTRUCTURE – FLOODING

6.4.1. Introduction

Earlier in this study (Section 3), it was estimated that the total floodable area in Belgium under present conditions (and with a 1/100 probability of occurrence) is of the order of 333,000 ha, or about 11% of the total area of the country. Overall, some 350,000 persons can be potentially affected by a flood with a 1/100 chance of occurrence, which is about 3% of the Belgian population.

Figure 6-2 shows the maximum extent of areas that can be flooded in Flanders and Wallonia as a result of fluvial, pluvial and coastal inundations, under current conditions (i.e., not accounting for climate change). The differences between both regions that are obvious from the map can be attributed to different calculation methods, especially for the pluvial inundations.

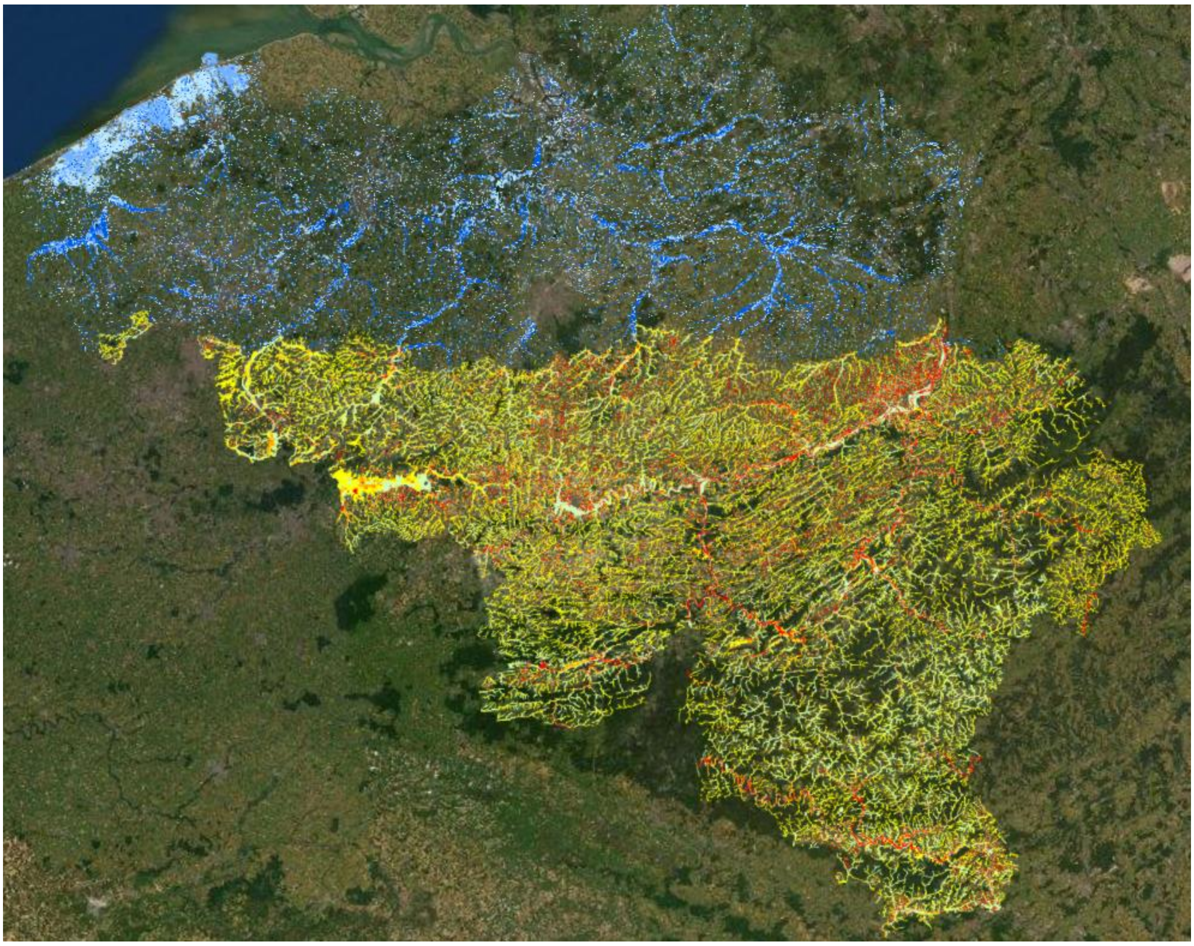

Figure 6-2. Maximum extent of floodable areas in Flanders and Wallonia under current climatic conditions.

The figures given above for the area inundated and number of persons affected do not explicitly take into account climate change. Climate change would make events causing the described effects more frequent, and the overall impact more severe.

For the Walloon Region for instance, it has been estimated that as a result of climate change the floodable area would increase by 50% and the number of people affected by 183%. The floodable area in Flanders (under a high impact scenario) would increase by 77% towards the year 2100, and the proportion of vulnerable institutions affected by 'dangerous' flooding by rivers and streams would more than double[1]. More information about the physical and health related impacts of flooding in

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[1] Flemish Climate Portal, https://klimaat.vmm.be/

Belgium and on the extent of flooding and the number of people potentially affected can be found in Section 3. In the present chapter, we seek to estimate the economic cost that results from damage caused by the different forms of inundation (pluvial, fluvial, and coastal) when taking into account climate change.

6.4.2. Historic data

Some historic data can set the stage. In Belgium, the average damages covered in case of significant inundations have varied in the past between 40 and 75 M€/yr. During the inundations of November 2010, for example, about 80.8 million euros in damages were paid by insurance companies. Costs caused by the inundation of the Meuse river in the Walloon region in 1995 exceeded 25 M€, and the flood of the Mehaigne (a small river in the Walloon region) in 2002 caused damages of about 3.5 M€ (ICEDD, 2014).

In Flanders, reported damages due to inundations amounted to about 432 M€ in the period 2011-2019, or about 48 M€/yr. These costs are not evenly distributed over time, of course, as can be seen from Figure 6-3.

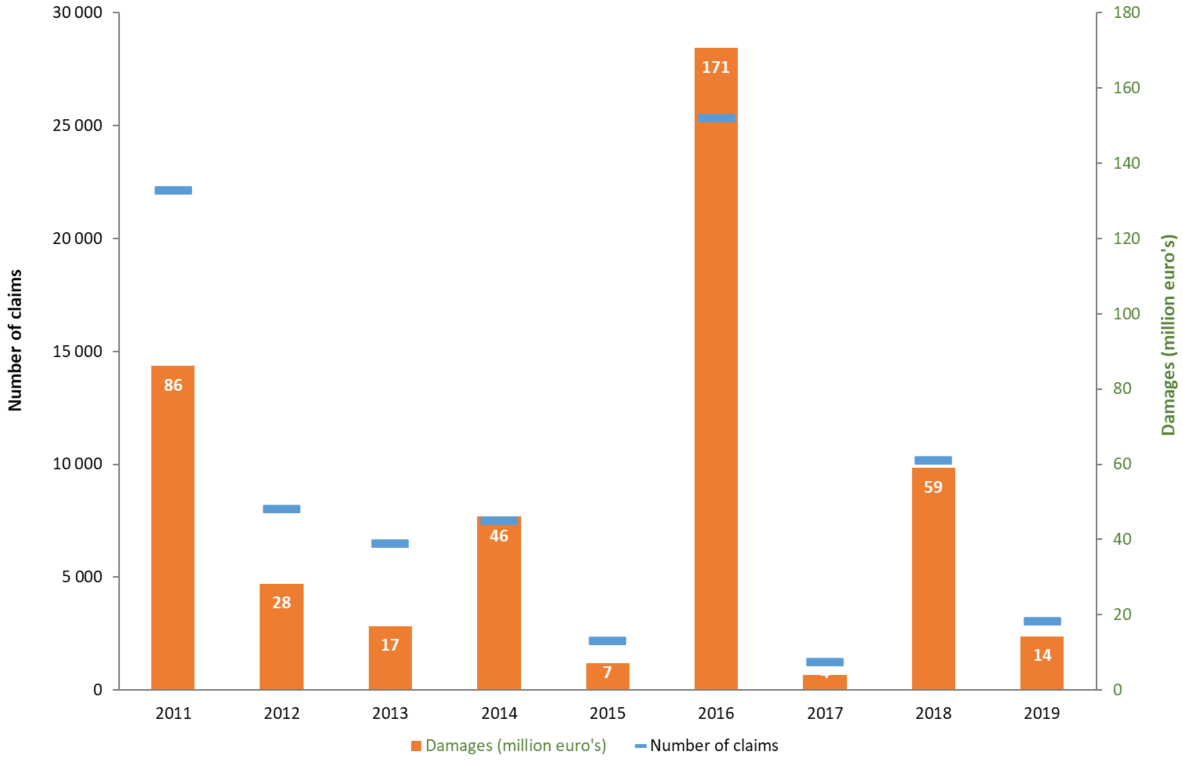

Figure 6-3. Annual damages (M€/yr) due to floods (bars) and number of insurance claims (lines) in Flanders for the period 2011-2019. Source: Assuralia.

6.4.3. Assets at risk

A first idea about the potential maximum damage caused by inundations resulting from climate change can be obtained by calculating the *expected maximum economic damage* (in €/m²). This parameter expresses the potential damage that would occur if an inundation would cause the total destruction of the asset (land, building, road, …) affected. It is thus a measure for the total economic value within the floodable area, without taking into account the probability of the flooding events. As such, this parameter represents the theoretical upper limit of the economic damage. As can be seen from the damage functions presented below (see Figure 6-5), a complete loss of all assets would only occur at water depths of 5 meter, which is not a realistic situation.

For Flanders, the expected maximum economic damage can be calculated using the maximum economic value (at 100% inundation) of the land use categories and assets incorporated in the LATIS-software (see more on this below). The maximum economic damage in LATIS is determined at a high level of detail, and does not only take into account land use classes but also the presence of individual receptors (e.g. buildings) and their category. As such, it requires complicated GIS-analyses and cannot be directly applied to the Brussels and Walloon regions.

If we want to use a uniform method for the Belgian territory, the damage functions and values for maximum economic damages compiled by Huizinga et al. (2018) are an option; they provide figures for maximum economic damage due to floods for almost 250 countries and regions. The figures for Belgium are given Table 6-7.

Table 6-7. Maximum damage values for different land use categories for Belgium, based on Huizinga et al. (2018)

impact category	**maximum damage value (€/m², 2010)**
residential (land-use based)	160
commercial (land-use based)	333
industrial (land-use based)	269
agriculture (using value added/ha)	0.20
infrastructure (based on GDP ratio)	25.7
transport (based on GDP ratio)	773

These figures assume that the building footprint represents on average 20% of the land use category ‘residential’ and 30% for the land use categories ‘commercial’ and ‘industrial’. Using those unit values and estimates of the land use distribution of the floodable area, a rough estimate for the theoretical upper limit of the total economic damage can be obtained.

Table 6-8 summarises the calculations and the results. Land use categories and their proportions are based on information from the PGRI (Wallonia) and Basin management plans (Flanders). For Brussels, it is assumed that the (additional) inundated area can be considered to be 100% residential. As the land use categories used in the documents available do not always correspond exactly to the categories used by Huizinga et al. (2018), we have indicated in the table which damage value factor we have used for each of the categories. Damages values are expressed in 2010 euros (as in Huizinga), but the totals have been converted to 2019 euros.

For nature, the value of ecosystem services has not been taken into account, as it is described in Section 6.9.

Table 6-8. Estimated maximum flooding related economic damage caused by climate change in Belgium.

Flanders				
Land use category	% land use in flood area[1]	area additionally flooded (ha)	damage factor (€/m²)	damage (m€)
Water	3%	3,900	0	0
Residential areas	6%	7,800	160	12,480
Arable land	30%	39,000	0.2	78
Grassland	43%	55,900	0.2	111.8

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[1] based on river basin management plan for the Scheldt – Flemish part

Industrial areas	2%	2,600	269	6,994
Infrastructure	1%	1,300	25.7	334.1
Nature	15%	19,500	0	0
Total Flanders	100%	130,000		19,997
Total Flanders (M€ 2019 value)				23,419
Wallonia				
Land use category	% land use in flood area[1]	area additionally flooded (ha)	damage factor (€/m²)	damage (m€)
Water	13%	16,116	0	0
Residential areas	4%	4,959	160	7,934
Arable land	6%	7,438	0.2	14.9
Grassland	45%	55,786	0.2	111.6
Industry, infra and commerce	7%	8,678	209.23	18,157
Other impermeable land use	2%	2,479	25.7	637.2
Forest	23%	28,513	0.2	57.0
Total Wallonia	100%	123,970		26,912
Total Wallonia (M€ 2019 value)				31,515
Brussels				
Land use category	% land use in flood area	area additionally flooded (ha)	damage factor (€/m²)	damage (million €)
Residential areas	100%	2.630	160	4,208
Total Brussels (M€ 2019 value)				4,927
Belgium				
Totals per region (M€ 2019 value)				
Flanders	23,419			
Wallonia	31,515			
Brussels	4,927			
Belgium	59,862			

The theoretical upper limit of the total economic damage by additional inundations caused by climate change is thus of the order of **60 B€**. As said before, this is not an annual cost (risk), but a measure for the *total value* of the assets present in the areas that can be inundated in an extreme scenario.

The figure for Flanders (23.4 B€) can be compared to the damages for Flanders reported by the MIRA-

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[1] based on PGRI for the Meuse

website[1]. According to this source, damages in the Flemish region due to inundations with a large probability are of the order of 100 M€, whereas damages due to inundations with an average and small probability are in the order of resp. 660 M€ and 2.4 B€. These figures refer to 2015; the corresponding costs in 2019 value would amount to total costs of respectively 108 M€, 711 M€ and 2.6 B€.

Note that the figures reported by MIRA do not only take into account the value of the land and assets present, but also the inundation depth. This means that in most cases the (calculated) damage incurred will only be a fraction of the maximum damage for the land use type involved, which explains part of the difference between both figures.

Another source is Prahl et al. (2018), who estimates the value of the assets affected in Belgium at 87 B€ at 5 m flood height and 270 B€ at 12 m flood height. The damages are theoretically for coastal flooding only (without coastal defences) but as the calculations use only the topography to determine whether an area is inundated or not, one can assume that this more or less represents the damage for the whole of Flanders, including fluvial flooding. Extrapolated to the whole of Belgium, the damages would turn out to be considerably higher than this, and much higher than the 60 B€ estimated above. This may at least partly be due to the assumption of no coastal flood defences being present.

6.4.4. Expected annual damage – international studies

A parameter that is more telling than the total value (in €) of the assets theoretically at risk is the expected annual damage (in €/yr). This concept takes into account the probability of floods with different degrees of severity and integrates the damage figures over the different probabilities.

Fluvial inundations

Alfieri et al. (2018) compared estimates of river flood risk in Europe from three recent case studies, assuming global warming scenarios of 1.5, 2, and 3 degrees Celsius compared to pre-industrial levels and based on RCP 8.5. Projections under this scenario typically exceed 3°C of warming before the end of the current century.

Projections with downscaled climate models were coupled with hydrological models. The inundation maps produced had resolutions between 100 m and 5 km, depending on the method and model used. In two of the three models, portions of river network with upstream area smaller than a given threshold (500 resp. 5000 km²) were excluded from the maps and thus did not contribute to the risk assessment. Economic damages were calculated for five relevant sectors (i.e., residential, commercial, industrial, infrastructure, and agriculture) by combining inundation depth with damage functions, GDP, and land use maps. Impact models were applied based on a stationary approach assuming present-day exposure and vulnerability. Table 6-9 summarizes the results for Belgium in terms of expected economic damage (in M€) for the baseline (period 1976-2005) and for specific warming levels of resp. 1.5°C, 2°C and 3°C.

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[1] https://www.milieurapport.be/milieuthemas/waterkwantiteit/afvoer-van-neerslag-overstromingen/overstromingsrisico

Table 6-9. Average, minimum and maximum expected economic damage (M€/yr) due to inundations in Belgium for three modelling frameworks and three levels of climate warming, according to Alfieri et al (2018).

	modelling framework	**baseline (1976-2005)**	**warming level 1.5°C**	**warming level 2°C**	**warming level 3°C**
average	JRC-EU	41.6	209.5	194.2	209.3
	ISIMIP	50.7	279.1	191.9	226.8
	JRC-GL	24.9	62.7	82.3	94.6
min	JRC-EU	14.7	27.6	66.9	37.7
	ISIMIP	0.0	0 .0	0.0	0.9
	JRC-GL	0.0	0.0	0.0	0.0
max	JRC-EU	95.5	346.5	451.5	371.0
	ISIMIP	414.3	2436.0	1434.2	1161.7
	JRC-GL	131.8	224.0	557.3	342.7

The quantitative comparison of results shows differences among the three assessments, which may depend on different climate models and hydrological models and on the different data used in each case study. JRC-EU appeared to produce the best quantitative estimates of past impacts as compared to the other two cases (at least at the European level), most likely due to the higher resolution and better quality of the underlying models and datasets. The authors also note that the coarser resolution inundation model of ISIMIP, coupled with flooded fraction maps, is prone to underestimating non-linear changes in the flood impacts.

On average, baseline damages for Belgium appear to be in the order of about 40 M€/yr, with estimates as low as zero and as high as 414 M€/yr. Note that the figure of 48 M€/yr given above, based on insurance claims (but limited to Flanders), falls within this range.

Damages at different future warming levels within the same modelling framework in the Alfieri study are generally of the same order of magnitude, and this holds for the average figures as well as for the maximum and minimum results. Average future damages across modelling frameworks and degrees of warming vary between about 63 M€/yr and about 280 M€/yr, with an average value of about 172 M€/yr. This represents an average increase of the costs compared to the (average) baseline situation with 323%. The absolute range in values goes from a minimum of zero (i.e., no change compared to the baseline) to a maximum of more than 2.4 B€/yr. It should be noted that all figures from the Alfieri et al. (2018) study concern only the impacts of fluvial flooding. Damages caused by pluvial and coastal flooding are not included.

The additional economic damages due to climate change can be obtained by subtracting the damages in the baseline scenario from the estimated damages in a future scenario. Using the average figures given above, flood damage due to fluvial flooding in Belgium that can be attributed to climate change would be of the order of 132 M€/yr (= 172 minus 40), with a range situated between 38 M€/yr and 228 M€/yr. In 2019 figures, this amounts to an average of about **134 million M€/yr** and a range of 38.5 to 231 M€/yr.

Technum (2012), based on Ciscar et al. (2009), mentions an annual cost due to river flooding of between 90 and 770 M€. For an 'average' climate scenario the annual cost would be 128 M€ or, in 2019 value, 153 M€/yr, which is very close to the Alfieri et al. (2018) estimate.

Lincke (2019) also puts the discounted change in expected annual damage (= risk) by river flooding that can be attributed to climate change (up to 2080) in a range between 3.98 and 11.95 B€/yr (RCP 6.0-SSP2). Those figures represent the cumulated annual damages over the 21th century, thus the annual damage would be situated in a range between about 40 and 120 M€/yr, which is of the same order of magnitude as the figures arrived at by Alfieri et al. (2018).

Dottori et al. (2020) estimate the additional economic annual damage (compared to the baseline) due to *fluvial flooding* at about 290 M€/yr, in the absence of any adaptation measures (2100, 2°C warming scenario).

Coastal flooding

Lincke et al. (2019) mention an annual cost of between 13 B€/yr (RCP2.6) and 141.5 B€/yr (RCP8.5) (note this is in *billion* euro per year) for the expected costs of *coastal* flooding in the year 2100, for the 'West Vlaanderen' NUTS2-unit (i.e., the Belgian coast) and an additional cost of between 25 B€ and 218 B€ for the 'Antwerpen' NUTS2 unit, probably representing the costs of flooding in the Schelde estuary.

Technum (2012) mentions a figure for the damage due to coastal inundations, in an 'average' climate scenario, of about 1.44 B€ per year, or about 1.72 B€/yr in 2019 monetary values.

Schinko et al. (2020) estimate annual expected sea-flood costs in 2050 and 2100 for a number of countries, including 4 European. Results for Belgium are not available, but we expressed the figures for Germany, France and the UK as a fraction of GDP, and calculated the average ratios obtained back to Euros using the Belgian GDP. This gives at least a rough estimate. The figures in billion 2019 euros are given in Table 6-10.

Table 6-10. Annual expected sea-flood cost (in 2019 B€) for Belgium in 2050 and 2100 without additional adaptation, based on data by Schinko et al. (2020).

2050		2100	
RCP 2.6	RCP 4.5	RCP 2.6	RCP 4.5
0.50 B€	0.65 B€	5.34 B€	22.52 B€

These figures are lower by at least an order of magnitude than those reported by Lincke et al. In any case, the results from both studies cannot be readily compared as Schinko et al. use a macro-economic model to estimate the damages, that takes into account indirect economic effects.

Vousdoukas et a. (2020) report additional annual damages for Belgium (without adaptation) in 2100 of about 2.4 B€/yr (moderate mitigation scenario, ~RCP4.5) and 3.9 B€/yr (high emissions scenario, ~RCP 8.5) due to *coastal floods*. In 2050, damages would be much lower, at about 200 M€/yr, for both a moderate mitigation and a high emissions scenario.

Multi-hazard

Forzieri et al. (2018) estimate the expected multi-hazard multi-sector annual damage for Belgium to be 68 M€/yr in the 2000's, 90 M€ in the 2020's, 159 M€/yr in the 2050's and 278 M€/yr in the 2080's (figures converted to 2019 value).

'*Multi sector'* refers to the fact that the study applies to critical infrastructure in the energy, transport, industry and social sectors. The latter includes the health and education subsectors. As such the damages do not include all possible damages (e.g. agriculture or housing are not included) but we can assume that a major part of the costs is covered.

'*Multi hazard'* refers to the fact that not only the damages due to river floods and coastal floods have been taken into account, but also heatwaves, cold waves, wildfires and wind storms. Forzieri et al. (2018) doesn't give figures for each of those hazards separately at country level; at a European level, they find that by the end of the century heat waves and droughts would become the dominant part of damages overall and the main driver behind the strong increase in total damages that is observed. This trend is stronger for the South of Europe than for the North, and Forzieri et al. (2018) state that 'river and coastal floods will remain the most critical hazard in many floodplains and coastal stretches of western, central and eastern Europe'. Nevertheless, by the end of the century heat and droughts become an important cause of climate-related damages in those countries too, so we choose not to use the 2080's figure in the context of this study.

As for the 2050's figure, we assume that, as far as Belgium is concerned, river and coastal floods are a major contributor to the climate related cost. It should be noted that, on the one hand, the 2050's figure of 159 M€/yr includes damages due to other hazards than flooding (which we suppose to be relatively small), but on the other hand does not cover all possible sectors (although we believe the main costs to be covered). As such, it can only be considered as an order of magnitude indication. The impact of climate change in 2050 can be obtained by subtracting the baseline damages (68 M€/yr) from the damages in 2050 (159 M€/y), yielding additional expected annual damages of 91 M€/yr.

6.4.5. *Expected annual damage – data from Belgium*

The annual expected flood damage can also be determined by a bottom-up approach using detailed local data. This approach starts by calculating hazard maps, which show information on flood extent, flood water depth and velocity (the latter only for pluvial floods and seaborne inundations) for different return periods. By superimposing the hazard maps on land use maps as well as maps containing information on the presence of specific vulnerable receptors (people, economic activities, polluting installations and protected areas), a semi-quantitative image of potential damage can be obtained, in terms of number of persons or in terms of specific receptors being potentially affected by the floods. Preparation of those maps are an obligation under the EU Floods Directive and as such are available for each of the three Belgian Regions. Figure 6-4 shows an example of such a map for the flood receptors along the Meuse river near Seraing (Walloon region).

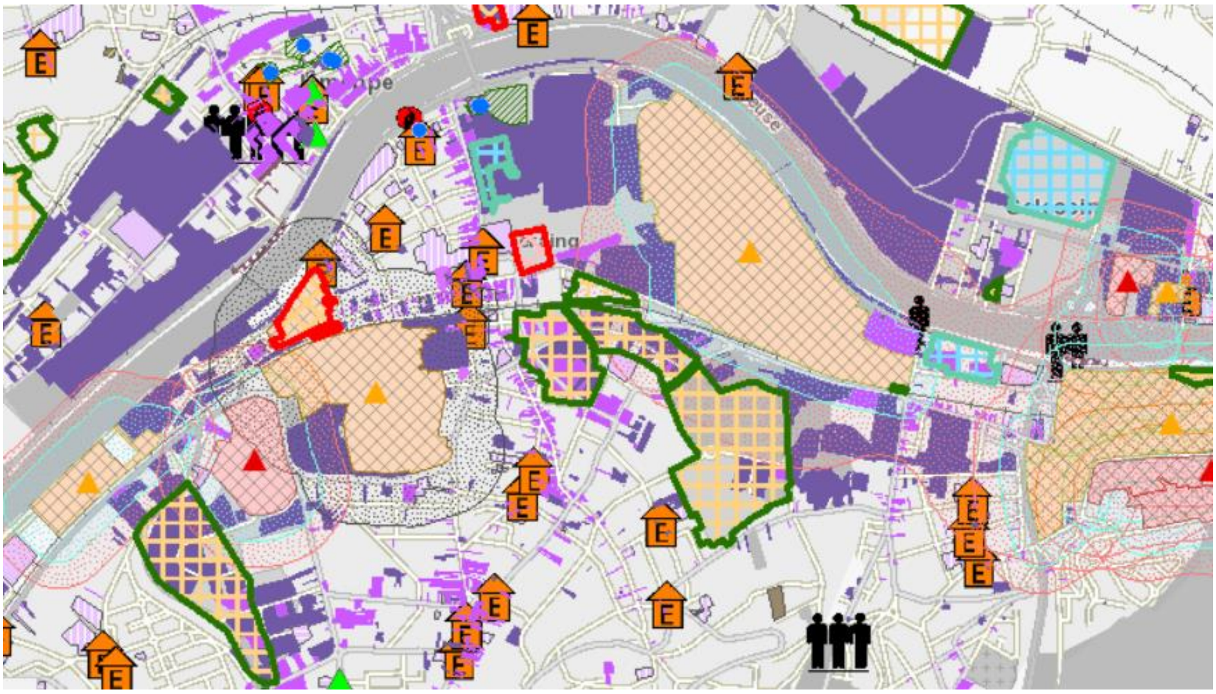

Figure 6-4. Risk map for the river Meuse near Seraing (source: geoapps.wallonie.be/inondations)

The maps have a high level of detail, allowing to assess precisely which vulnerable receptors are present at any given location, and hence where the focus of protection and adaptation should lie. A cumulative assessment of the number of vulnerable receptors at the level of the regions and, consequently, of Belgium has, however, not been published so far.

Moreover, those maps do not represent economic damages in monetary terms. To arrive at the latter kind of information, data regarding the affected land use has to be converted using so-called damage curves, which define the relation between damage and flooding depth for different types of land uses. Within Belgium such an exercise has been done for the Flemish region, using software specifically developed for this purpose (LATIS). Figure 6-5 shows the damage functions used in LATIS.

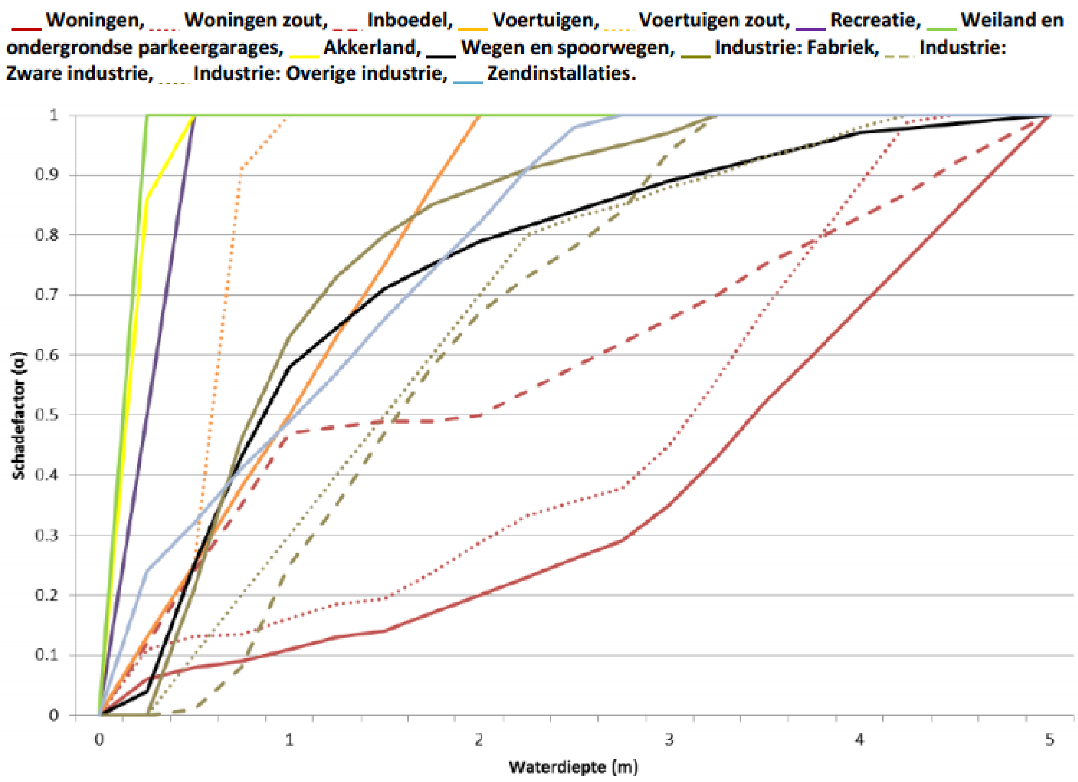

Figure 6-5. Damage functions used in LATIS

Using the LATIS software, maps containing the following information has been prepared for Flanders:

- the expected economic damage (€/m²) for high (1/10), medium (1/100) and low (1/1000) annual probability of occurrence: these map layers represent the damage that would occur at different probabilities, taking into account both the extent and the water depth corresponding to a given probability. For a given type of land use, as long as the water depth is less than the depth corresponding to a damage factor of 1, the estimated economic damage will be below the maximum.
- the aggregated economic risk (€/m²/yr) is the result of the combination of the different damage maps, weighted with their respective probabilities.

Maps showing the economic risks for the Belgian coast, with and without climate change, are shown in Figure 6-6 as an example.

The total economic *risk* (i.e. expected annual damages) for Flanders has been estimated to be of the order of 50 M€/yr (https://www.milieurapport.be). This figure has several limitations however, as it is representative for the *current* situation (i.e. does not take into account climate change) and does not include the impact of pluvial inundations, which are an important damage source. It is of the same order of magnitude as the average figure of 40 M€/yr we derived from Alfieri et al. (2018), although it should be noted that the Alfieri figure applies to the whole of Belgium, but does not include the cost of coastal inundations.

Recently (in 2020), new risk calculations for Flanders have been performed with a new version of the LATIS software, using inundation maps that do take into account both climate change and pluvial inundations, but those figures are not yet available.

Figure 6-6. Economic damage by coastal inundations with 1/1000 probability, without measures, for the current climate (top) and the projected climate in 2050 (bottom). Colours indicate the importance of the damage.

Willems et al. (2009) have estimated that the increase of the fluvial inundation risk (M€/yr) in a "high scenario" would by 2100 be of the order of 33% (not taking into account land use changes and economic development). Their conclusions were based however on calculations for a limited number of river basins and using models that were less sophisticated that those available today. Moreover, the 33%-figure does not apply to coastal or pluvial inundations. For those reasons, they are of limited use to estimate the 2100 risk based on the risk figure for the current situation given above.

An independent estimate of at least part of the future average annual costs can be derived from the results of the societal cost benefit analysis of three major flood protection infrastructure projects in Flanders: the Sigma Plan (Scheldt Estuary), the Coastal Protection Plan, and the Plan for the Protection of Ostend Harbour. In those studies, the benefits were expressed as 'avoided damages' over a period up to the year 2100. The resulting figures are given in Table 6-11.

Table 6-11. Estimated net constant value of avoided damage costs (until 2100) by three major flood protection projects in Flanders (in 2019 value).

	Avoided costs (B€)
Sigma Plan (Gauderis et al., 2005)	1.04
Coastal Protection Plan (De Nocker and Broeckx, 2011))	2.15
Ostend Harbour (De Nocker and Broeckx, 2013)	3.48
Total	**6.67**

The figures present net constant values, meaning that they are the sum of the depreciated values of all annual costs over the considered time period (i.e., until 2100). The annual costs take into account how the frequency and extent of flooding is influenced by climate change. The total cost takes into account the fact that future benefits do not have the same value as present ones.

Taking into account the future time span that the figures account for the extra average annual (avoided) damage would be of the order of about 75 M€. Note that those figures represent only part of the actual risk, as the selected projects, including (for the major part) the Sigma Plan, all deal with protection against the impact of sea level rise, but not with other inundation risks.

For the Walloon and Brussels regions no monetary assessments of damage or risk have been published either. The 'plan de gestion des risques d'inondation' (PGRI) for the Meuse river mentions a method for prioritising flood protection measures, using multi criteria analysis. One of the criteria in this MCA method is an 'efficiency ratio' that expresses the damages that the measure seeks to avoid in relation to the cost of the measure. However, while the cost is expressed in euros, the benefits (avoided damages) are expressed as 'points', a qualitative parameter that is said to be proportional to the value of the affected assets, although the exact relation is unclear.

The PGRI does describe a detailed method for calculating the cost of pluvial inundations (including mud flows) in agricultural regions. For the whole of the Walloon region, the corresponding cost is estimated to be about 580,000 €/yr, which no doubt is only a small fraction of the total average annual cost. ICEDD (2014), based on the results of the Amice-project (Sinaba et al., 2013) and using a (non-specified) extrapolation factor, estimated the extra cost of inundations in the Walloon region due to climate change at about 150 M€/year by the year 2100; expressed as 2019 value, the figure would be about 165 M€/year.

No method exists as yet for estimating the annual flood damages for Belgium as a whole, although much of the information and knowledge required to do so is available. A consistent cost figure for the whole of Belgium could for instance be obtained if the LATIS-model used for Flanders (or a comparable method, adapted to the specific characteristics of the different regions) would be applied to the Walloon and Brussels regions.

6.4.6. *Indirect effects*

Apart from causing damage and repair and maintenance costs, the effect of flooding on transport infrastructure also induces indirect effects, related e.g. to delays and productivity. (With respect to the latter, it should be realized that, on average, Belgian productivity losses due to congestion range from 0.011% to 0.023% of GDP if congestion increases by 1% (Baert and Reynaerts, 2018).)

In the Netherlands, it has been estimated that 2 mm of rainfall per hour results in an increase in delays in road transport with 10%; if the precipitation exceeds 10 mm/h, the probability of delays increases to 25%. It has been estimated that in the Netherlands each year up to 80 million transport hours are lost to rainfall, representing an economic damage of about 800 M€ (KvK, 2014). It is expected that those problems will be exacerbated with climate change as peak precipitation is projected to become more intense.

Sieg et al. (2019), in an assessment of economic costs related to flooding events in Central Europe, concluding that indirect costs (e.g., forced interruption of activities for periods longer than several days) may be as high as the estimated direct (damage) costs. In particular the ‘manufacturing’ sector exhibits nearly twice as high indirect costs compared to direct costs; the ‘construction’ and ‘financial and insurance services’ have comparable indirect and direct cost levels.

Cities are particularly sensitive to flooding, which may interrupt various urban services, in particular transport, thus generating indirect losses. Pregnolato et al. (2017) estimated the costs of road traffic disruptions for Newcastle (UK) caused by pluvial flooding events, considering time lost because of the flooding, as approximately 93,000 GBP for a 1-in-10 years event and 130,000 GBP for a 1-in-50 years event. By 2080, these costs could rise to 130,000 GBP and 220,000 GBP, respectively.

6.4.7. *Synthesis of the information and conclusions*

The studies presented on the previous pages report a lot of different figures, and it is not always easy to compare them. An overview is given in Table 6-12.

The range (hence the uncertainty in resulting costs is considerable. This can be explained by a lot of different factors: difference in modelling tools, base years and climate scenarios, among other. We think that a major factor also has to do with the differences in adaptation considered. In principle, all figures given are without adaptation, but it is not always clear whether this means without *additional* adaptation (i.e., taking into account the flood defences that already exist) and whether plans and policies that have not yet been fully executed but that have been decided (e.g. Integrated Coastal Protection Plan, Sigma Plan) have or have not been taken into account.

Notwithstanding those caveats, we come to the following conclusions, based on the figures presented in Table 6-12. All figures are additional to the baseline and expressed in 2019 value.

Fluvial floods

Figures for expected annual damage related to fluvial floods for 2050 are not explicitly available. If, however we assume that a 2°C increase in average global temperature is approximately reached by 2050 under RCP8.5, the annual risk in that year could be assumed to be situated somewhere between **134 M€/yr** (based on Alfieri et al., 2018) and **290 M€/yr** (Dottori et al., 2020). Alfieri et al. (2018) found no major or consistent differences between damages at 2°C and damages at 3°C (the latter temperature increase level is not expected to occur before 2100), which is plausible if higher temperatures do not cause a proportional increase in rainfall. In that sense, the relatively low damages that Lincke arrives at for 2100 (max. 120 M€/yr) may be explained. We thus consider that damages in 2100 due to fluvial inundations would be of the same order of magnitude as those in 2050.

Coastal Floods

For coastal floods, separate damage costs for 2050 and 2100 are available. What strikes is the big difference between the former and the latter figures. For 2050, there seems to be a reasonably good correspondence between the different studies, and based on Schinko et al. (2020) and Vousdoukas et aL (2020), we would estimate the expected annual damage to be situated between about **200 M€/yr** and **650 M€/yr** (both for RCP 4.5).

For 2100, all studies indicate a sharp increase in damages. This may be due to the fact that sea level rise (and its impacts) are not linear and existing coastal defences may be overwhelmed somewhere after the year 2050. Based on Lincke et al. (2019), Schinko et al. (2020) and Vousdoukas et al. (2020), coastal flood damages would in 2100 be of the order of 5,34 to 38 B€/yr for RCP 2.6, between 2.4 and 22.52 B€ for RCP 4.5 and between 3.9 and 395 B€ for RCP 8.5. We assume that the higher values in the ranges do not take into account adaptation measures that have already been decided (but not fully executed). In order to obtain valid figures for future damages in Belgium, those measures should be included though.

For that reason, it is preferable to opt for the lower figures in the ranges, which means that expected annual damages in 2100 as a result of coastal (and estuarine) flooding would be in the order of between **2.4 B€/yr** and **5.3 B€/yr**. Note though that there is no clear link between the level of those figures and the RCP used.

Total costs

If we simply add up the figures for fluvial and coastal floods we arrive at an estimated expected annual damage due to flooding in Belgium **between 343 M€/yr and 940 M€/yr** in 2050 and **between 2,540 M€/yr and 5,590 M€/yr** in 2100. Differences between the 2050 and 2100 figures are exclusively due to sea level rise, but are subject to major uncertainties. An important caveat is that none of the studies seems to explicitly account for pluvial inundations, which in Belgium may be an important damage factor. Also, as mentioned above, indirect effects from e.g. delays caused by infrastructural damage have not been accounted for.

Table 6-12. Overview of the expected annual flood damages for Belgium on the basis of different studies, all values pertaining to 2019.

source	additional expected annual damage	year	climate scenario	coastal/ fluvial	remarks
Alfieri et al. (2018)	134 M€/yr on average (range 38.5-231 M€/yr)	-	Warming levels of 1.5-2-3°C	fluvial	Results were obtained using three different modelling frameworks.
Technum (2012)	153 M€/yr (range 108-921 M€/yr)	-	'average' scenario	fluvial	Figures cited in Technum (2012) are originally from Ciscar et al. (2009).
Lincke et al. (2019)	40-120 M€/yr	2100	RCP 6.0	fluvial	Based on discounted costs over the 21th century.
Dottori et al. (2020)	290 M€/yr		2°C warming	fluvial	
ICEDD (2014)	165 M€/yr	2100		fluvial	For Wallonia only. Extrapolation based on Sinaba et al. (2012).
Brouwers et al. (2015)	50 M€/yr	-	Current situation	fluvial + coastal	Only Flanders
cost-benefit analyses of	75 M€/yr	2100		sea level rise	Limited to inundations caused by sea level rise (in Flanders, by

selected projects				(coast & Scheldt)	definition)
Lincke et al. (2019)	38,000 M€/yr 395,000 M€/yr	2100	RCP 2.6 RCP 8.5	coastal	Based on sum of ‘West-Vlaanderen’ and ‘Antwerpen’ NUTS2 units.
Technum (2012)	1720 M€/yr		‘average’ scenario	coastal	
Schinko et al. (2020)	500 M€/yr 650 M€/yr 5,340 M€/yr 22,520 M€/yr	2050 2050 2100 2100	RCP 2.6 RCP 4.5 RCP 2.6 RCP 4.5	coastal	Calculated on the basis of figures in Schincko et al. (2020) for other countries, using relative GDP figures.
Vousdoukas et al. (2020)-	200 M€/yr 2400 M€/yr 3900 M€/yr	2050 2100 2100	RCP 4.5 RCP 4.5 RCP 8.5	coastal	
Forzieri et al. (2018)	91 M€/yr	2050	A1B	multi-hazard	Figure is for multi-hazard and multi-sector risks. We assume that flooding (river + coastal) constitutes the major part of this in 2050 and that most damages are covered by the sectors considered.

6.5. INFRASTRUCTURE – DROUGHT AND HEAT

6.5.1. Drought

In Section 3 the impact of drought on inland waterways was described in general terms. Yet, the effect of drought-induced low-water events on navigability and traffic on waterways in Belgium has not been assessed. In the Netherlands, it has been estimated that the extra costs for inland navigation due to the effects of climate change would be of the order of 4% of current costs under a +2°C-scenario. Under a 'dry' scenario, extra costs could be as high as 18% (RIZA, 2004). Concerning the Meuse River, much higher changes in cost have been found – up to a factor 36 higher – as a consequence of extra waiting times at the locks (ICEDD, 2014).

The summer of 2018 was particularly dry. In Germany, this affected water levels of the Rhine River, leading to a limited navigability. The BASF plant in Ludwigshafen was affected by this, as during a considerable portion of the year it was nearly impossible to receive deliveries of raw materials via ship. As a result, BASF was forced to reduce plant capacity, which lowered earnings by around 250 M€ (BASF, 2019).

The Netherlands also experienced problems with inland shipping, the navigability being adversely affected by low water levels in, among others, the Rhine and Waal rivers (MIW, 2019). This put the cargo capacity under pressure to the extent that cargo prices fell 30% lower during the drought period. Also, it resulted in delayed delivery and non-delivery, affecting the economy. The total economic effects of the drought episode have been estimated at 140-345 M€, of which approximately half is estimated to consist of indirect ('knock-on') costs.

Another impact of drought concerns roads, which may experience subsidence and cracking because of soils settling (e.g., shrinking) in response to lower soil moisture conditions. During the summer of 2003, local authorities in Cambridgeshire (UK) estimated the cost associated with the impact of drought on local roads to approximately 40 million GBP, which compares to around 80 M€ (in 2019 value).

While the above monetary estimates are very informative, it is difficult to extrapolate them to the Belgian situation. Nevertheless, these figures suggest that, without adaptation (or without considering modal shifts from inland shipping to e.g. rail or road cargo traffic); and with recurring drought episodes as that occurring in 2018, we should expect costs from climate change impacts to inland waterways and roads running in the **tens to hundreds M€/yr**. The annual cost is hard to estimate, though, as it would require an estimate of the average return frequency of drought episodes as the one occurring in 2018.

6.5.2. Heat

In July 2015, a 6-day heatwave in Flanders, Belgium caused damages to 129 sections of regional roads, causing repair costs of almost 600,000 €[1]. Nemry and Demirel (2012) find that in Europe, heat impact to road infrastructure currently constitutes only around 2% of damage costs, cold- and flooding-related costs being much higher. While in the future it is expected that heat-related damage costs to roads will increase, more than likely this will still be a minor cost compared to costs caused by other hazards than heat.

While it would appear fair to say that the costs of heat related damage to infrastructure will, more than likely, be rather modest, indirect costs (productivity loss, service interruption) are expected to be much higher. In particular transport infrastructure but also e.g. the electricity network represents a great share of economic activity and contribute to the functioning of other sectors (Steininger et al., 2015).

With respect to heat impacts on infrastructure and subsequent service disruption, much can be

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[1] https://www.hln.be/nieuws/binnenland/hittegolf-129-gewestwegen-stuk-en-600-000-euro-schade~a268c622/

learned from a heatwave that occurred in 2009 in southern Australia, which has been extensively reported on in QUT (2010) and McEvoy et al. (2012). This heatwave took place in the period 27/1-8/2/2009, with a somewhat 'cooler' interruption in the middle, and with temperatures soaring well beyond 40°C. The heatwave affected the Territories of South Australia, Victoria, and Tasmania. Taken together these Territories count approximately 8.94 million inhabitants, and their combined GDP (converted to 2019 euros) amounts to 363 B€, hence this area is not too different from Belgium in size and economy. In fact, it represents around 77% of Belgium, both in terms of population and GDP.

Apart from its impact on excess mortality, this heatwave was observed to particularly affect critical infrastructure, such as the electricity power grid (transformator hubs incapacitated), railroad transportation (rail buckling, electric faults) and road cover damage ('flushing'). This led to costly service interruptions and response costs, which have been estimated at 800 M AUD (2010 value). Converted to euros (2019 value) and scaling the resulting amount with the respective population or GDP ratio (see the 77% factor mentioned above) the final cost reaches approximately 766 M€.

This was of course an exceptional event, and the situation in Australia (including the vulnerability of critical infrastructure) can hardly be taken to be representative for the Belgian situation. Yet, it can be argued that this heatwave is representative for summer conditions in Belgium towards the middle of the century.

Indeed, the Australian heatwave of 2009 was described (QUT, 2010) as having temperature values 12-15°C above seasonal averages. In Belgium, the climatological (1976-2005) seasonal average is 17.3°C (Table 1, Section 2). Conversely, summer temperature extrema in Belgium for the same climatological period amount to 26.3°C and 28.1°C for the maximum of daily mean temperatures occurring once every year and once every 5 years, respectively. Table 3 (Section 2) also shows that by 2050 under RCP8.5 there is a projected increase of these temperature extremes by 2.6°C and 2.9°C, respectively, hence they will evolve towards values of 28.9°C resp. 31.0°C. These values exceed the current climatological value by 11.6-13.7°C, which corresponds well to the 12-15°C range observed for the Australian heatwave of 2009. Based on this, we consider it appropriate to take the Australian heatwave of 2009 as a proxy for Belgian heatwaves in 2050 under RCP8.5, and we assign the value of 766 M€ as the cost of future heatwave events in terms of costs related to 'service interruptions and response costs' (QUT, 2010).

Converting this value to an annual cost is more difficult, as it requires information regarding the return frequency of heatwave events as the one described above. However, since our analysis is based on daily temperature extrema occurring between (1) once every year up and (2) once every five years, we will simply use this to establish a range, i.e., we will assume that the annual loss value ranges between **153 M€/yr and 766 M€/yr** (2050, RCP8.5).

6.5.3. Cold

It is expected that reduced winter cold will lead to reduced damage to (and maintenance costs for) roads. Indeed, wintertime cold currently constitutes a much larger problem than summertime heat, in particular in the Walloon Region, as subsequent cycles of freezing and thawing cause cracking of road asphalt surfaces (ICEDD, 2014). According to Nemry and Demirel (2012), the decreased damage associated with milder winters will, under RCP8.5, induce a maintenance *gain* to Belgian roads of **9.1 M€/yr** (2040-2070) to **18.6 M€/yr** (2070-2100).

Of course, it is expected that reduced winter cold, and the ensuing diminished damage to roads, will also lead to reduced service disruption and other indirect effects to the economy, constituting a gain rather than a cost. Unfortunately, no information was available to us to quantitatively estimate such impacts.

6.6. THE ENERGY SECTOR

This section presents a range of climate change induced costs for the energy sector. This sector is subject to great changes in the energy mix as nuclear power is going to be phased out by 2025, and as the share of renewables is growing rapidly (see Section 3.5), and total production is meant to decrease following the Paris Agreement and the European guidelines to a low carbon economy (see the Belgium PNEC[1] and the 2050 long-term strategy[2]). These mitigation efforts may go along or against adaptation strategies to counter the effects of climate change. In order to give a likely range of cost estimates for the impact of climate change (without additional adaptation), we have chosen to work with a 'non-mitigation' and a 'likely mitigation' scenario:

- the former is taken from Gusbin and Devogelaer (2017) and will be referred to as BAU (business as usual) scenario;
- the latter is the CORE scenario from Cornet et al. (2013), which is a balanced but ambitious scenario, and which is not extreme in its behavioural and technological shifts; it is therefore taken as a likely mitigation scenario.

For the sake of consistency with the global climate scenarios (RCP2.6 and RCP 8.5), we associate CORE with RCP2.6 and BAU with RCP8.5.

Energy price values were set as follows:

- when considering electricity production and distribution, we took the average day-ahead wholesale electricity price on the Belgian market over the period 2007-2018, which amounts to 47 €/MWh (CREG, 2019)
- when considering consumers, we used the household (196 €/MWh) and industry (109 €/MWh) prices (average 2009-2011 for Belgium; Eurostat, 2011[3]);
- concerning the gas price, we use a price of 60 €/MWh and 30 €/MWh for households and the industry, respectively (average 2009-2011 for Belgium, see Eurostat, 2011).

It should be noted that, due to the lack of data and due to the exploratory nature of this study, the methodologies used in this section do not take every aspect into account and should be take as rough estimates.

6.6.1. Climate impacts on electricity production and energy transport efficiency

Centralized production plants (thermal engine electricity power plants)

In the business as usual (BAU) scenario of Gusbin and Devogelaer (2017), a large fraction of electricity is still being produced from gas power plants up until 2050: 42.9 TWh (60%) in 2030 and 48.5 TWh (52% of the total 92.4 TWh electricity production) in 2050. In that scenario, 52% of electricity production from gas is subject to capacity losses from droughts and temperature related impacts in 2050, while no losses from nuclear energy production have to be accounted for as nuclear production is also phased out by 2025 in that scenario (as in the CORE scenario).

When the CORE scenario from a Low Carbon Economy for Belgium by 2050 (Cornet et al., 2013) is considered, then lower losses from droughts and temperature related impacts are to be accounted for in centralized electricity production plants as only 13 TWh is concerned for biomass.

In *Wallonia* and under a BAU-type scenario, climate change driven temperature related losses of electricity production thermal power plants have been estimated at 1.95% (2021-2050) and 7.5% (2071-2100) of total production, yielding cost figures of 17 M€/yr in 2050 and 65 M€/yr in 2100 (ICCED, 2014). The estimate is based on an energy produced of 25.49 TWh; a reduction of river flow by 20%

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[1] https://www.plannationalenergieclimat.be/admin/storage/nekp/pnec-version-finale.pdf

[2] https://climat.be/doc/national-lt-strategy-fr.pdf

[3] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_price_statistics&oldid=212804#Electricity_prices_for_household_consumers

(2021-2050) and 44% (2071-2100) (Föster & Lilliestam, 2010); an electricity price of 37 €/MWh (ICCED, 2014); an air temperature increase of 1.9°C and 4°C in 2050 and 2100, respectively; a transmission factor of 0.95 between air and water temperature.

Conducting a similar exercise for *Belgium*, and using a 2050 thermal engine electricity production of 48.5 TWh (BAU) and 13 TWh (CORE); an electricity price of 47 €/MWh; a reduced capacity of gas power plants of 1.95% to 7.50% for 2050 and 2100 (ICCED, 2014), the annual production losses for Belgium due to enhanced temperature is expected to amount to **12-44 M€/yr in 2050** and **46-171 M€/yr in 2100**, for the CORE and BAU scenarios respectively.

Electricity transport and distribution efficiency

If we consider a linear loss of 1% per °C of annual average temperature increase (Surminski et al., 2018), an electricity price of 47 €/MWh, an electricity consumption of 105 TWh/year (CORE) and 92.4 TWh/year (BAU), an average annual temperature increase of 0.38-2.1°C in 2050 and 0.6-3.3°C in 2100 (for RCP 2.6-RCP 8.5, respectively), then the economic losses due to the effect of temperature on electricity transport and distribution efficiency are **19-91 M€/yr in 2050** and **30-143 M€/yr in 2100.**

Decentralized production

The economic losses in *hydro power* due to water flow variability in Wallonia (95% of power capacity of Belgium) are estimated to amount to 41% by 2050 of its production from 2004 to 2012 (Sinaba et al., 2013; ICEDD, 2014). The Amice project estimates that, because of hydrological changes, river flow will decrease by 20% in 2050 and 44% in 2100. This reduced water flow can seem at odds with the increase in precipitation of 0.5 mm per year observed since 1833 (Brouwers et al., 2015) and the predicted increase in annual precipitation in the future (Fischer et al. 2014). But if precipitation has risen (and will rise in time), potential evaporation has risen even more, at 3.2 mm/yr since 1833 (Brouwers et al., 2015). In order to make cost predictions, we use the reduced water flow by 20% in 2050 and 44% in 2100 and an energy price of 47 €/MWh. Because production capacity has remained stable in the past 15 years, we make the assumption of a constant capacity in time of 261.18 GWh (see Section 3.5). Therefore, hydro production losses could reach **2 M€/yr in 2050** and **5 M€/yr in 2100.**

The overall Belgian *wind* fleet capacity factor (CF) has decreased from around 29% to 25% between the periods 2012-2015 to 2016-2019 (see Section 3.5). It is unclear how much of this is due to the change in wind patterns or rather the dilution of new wind turbine sites placed in less ideal locations. The MIRA Climate Report (Brouwers et al., 2015) shows that average wind speed has decreased by 10-15% since the 1960's. But wind farm production is hardly a function of average wind speed as it is proportionate to the third power of it. Therefore, lower average values and higher variability (with higher peaks) can lead to more energy produced. Due to those uncertainties, we will not attempt to make any prediction of economic losses.

Solar production from photovoltaic cells is also affected by climate variables, namely solar radiation itself, cloud cover, wind and temperature. Photovoltaic cells roughly lose 0.4-0.5% of production per °C of warming (Kaldellis et al., 2014) and cloud cover change may lead to a drop of incoming shortwave radiation by 3-5% in Belgium due to climate change (Jerez et al., 2015) by 2050. For an average air temperature warming of 0.38-2.1°C (RCP2.6-RCP8.5), the two combined effects lead to a drop of 3.2-6.1% in production. At 47 €/MWh, this translates into **19 M€/yr losses** for a production of 13 TWh/yr (CORE scenario) and **17 M€/yr** losses for a production of 6 TWh/yr (BAU scenario) in 2050**.**

6.6.2. Impact of higher air temperature on energy demand

Milder winters will reduce heating needs while warmer summers will increase cooling requirements in Belgium. Considering the heating degree days (HDD with threshold 15.5°C) and cooling degree days (CDD threshold at 22°C) and their rates of change, we see that the expected rate of change of 4-8 less HDD per year corresponds to eight times the expected increase rate of 0.5-1 CDD per year (EEA, 2019d). This range of HDD and CDD relates to the RCP2.6 and RCP8.5 scenarios.

The number of CDD and HDD is highly variable in time. Over a 14-year period (2005-2018) mean numbers are 4005 HDD and 23 CDD (Source: RMI). Thus, the number of HDD is reduced by 120-240 days in 2050 and by 280-560 days by 2100. During that time CDD increases by 15-30 days in 2050 and 35-70 days in 2100, reaching 93 days instead of 23. This four-fold increase is likely to trigger changes.

Reduced winter heating

For a cost estimate of gains (i.e., reduced heating energy consumption) due to a reduction in HDD in households, we use the total energy production of the CORE and BAU scenarios (316 and 407 TWh/yr, respectively) onto which we apply a constant consumption share of the residential sector of 20% and the fact that, today, 75% of the household energy bill is dedicated to heating (SPF Economie, 2019). We use household energy prices of 196 €/MWh and 60 €/MWh for electricity (CORE) and natural gas (BAU), respectively. We use the number of HDD and CDD and their evolution in time and find that the reduction of HDD in households leads to economic gains of **220-278 M€/yr** in 2050 and **512-650 M€/yr** in 2100 (the low end of these estimates corresponding to the BAU scenario and the high end to the CORE scenario).

Enhanced summer cooling

During heatwaves, monetary losses affect electricity producers first. Then costs are passed on to consumers, at least partly through electricity prices driven by increased demand. In France, the 2003 heatwave has seen a rise of 5-10% of electricity consumption due to an increased demand for cold production and ventilation (Létard et al., 2004). The increased demand in power supply was of the order of 250-300 MW per °C above 25°C leading to an excess demand of 4,000 MW at 40°C. It was also noted that the increase in demand would have been even higher in France, had the heatwave progressed past the 15th of August when the industry relaunched production after the summer break. The higher demand during summer months is also observed by Bartos et al. (2016) in a study considering the US, estimating an increase of 4.2%-15.0%.

In Germany, based on national electricity prices, river temperature, and water scarcity from 2002 to 2009, McDermott and Nilsen (2012) established that electricity prices rise about 1% for every degree of daily average river water temperature above 25 °C. River water temperature is considered to be at an average of 30°C during heatwave episodes, which could lead to a 5% increase in price during the expected up to 41.5 heatwave days a year by mid-century in Belgium (Wouters et al., 2017; also see Section 2).

Combining an increasing demand of 10% with increased prices by 5% during 6.4 to 41.5 heatwave days (RCP2.6 and RCP8.5, respectively), an electricity consumption of 105 to 92.4 TWh/yr (CORE and BAU scenarios), and electricity prices of 109 and 196 €/MWh for industry and households, heatwave days may lead to losses of **15 M€/yr** (CORE) and **88 M€/yr (**BAU) during Belgian summer months by 2050. This burden is to be shared among all consumers in the industry (e.g., frozen food producers), housing, transport (e.g., electrified and refrigerated) and tertiary sectors (e.g., super markets, buildings, data centres). Without specific data at hand, we make the assumption that the burden is shared equally between the industry and the household sector.

6.6.3. Climate change impact on trans-national electricity availability

Beyond the physics (e.g., temperature effects on transmission losses) of producing electricity, other costs may arise from organizational and human aspects and the market price, especially during unexpected extreme events. As an example, the main French electricity operator EDF estimates that the 2003 heatwave cost 300 M€ through technical- and human-related losses as well as in the costs related to importations from neighbouring countries (Létard et al., 2004).

Elia (2018) reports a number of extreme events that have hit the European network, though the associated costs are not given. Among these events are the storms of 25 January 1990 and 28 February 1990 that destroyed a considerable amount of high, medium and low voltage pillars in Belgium, despite the fact that high-voltage pillars are made to withstand 140 km/h winds. Another event is the snow storm of the 25-26 November 2004 that broke four 380 kV power lines, 18 150 kV lines, and 6 70 kV lines. Tornadoes and downburst have also been hitting electricity lines in recent years with winds as intense as 240 km/h: 21 July 2009 in Lint, 14 July 2010 in Archenne, 3 January 2014 in Ruien, and 23 June 2016 in Jodoigne.

6.6.4. Summary of climate change related costs in the energy sector

Most climate change impacts related to projected drought and temperature change are negative, except when it comes to winter heating where they are positive (i.e., reduced consumption costs), see Table 6-13.

The largest economic impacts are found for centralized thermal power plan efficiency loss, in electricity transport and distribution loss, and in the gain related to a reduced demand for heating. This applies to both BAU and CORE scenarios. The higher gains of the CORE scenario, which is related to lower winter heating requirements in the RCP8.5 scenario that we associated to the CORE scenario, is mainly due to a higher electricity price compared to the gas price. The net numbers reveal little positive or relatively high negative values. There is clearly a compensating effect of reduced winter heating over all other losses. Numbers should be interpreted with caution, especially when it comes to impacts occurring at the end of the century.

Table 6-13. Summary of costs associated with various aspects of energy production, transport and consumption.

	2050		**2100**	
	CORE / RCP2.6	BAU / RCP8.5	CORE / RCP2.6	BAU / RCP8.5
Centralized production (thermal engine)	12	44	46	171
Decentralized production – hydropower	2	2	5	5
Decentralized production – solar	19	17	-	-
Electricity transport and distribution efficiency	19	91	30	143
Energy demand – milder winters and reduced heating	–278	–220	–650	–512
Energy demand – heatwaves and enhanced cooling	15	88	-	-
TOTAL	–211	22	-	-

6.7. AGRICULTURE

We present the socio-economic impact of climate change induced effects on the agricultural sector in Belgium by 2050 assuming RCP 8.5. Projected impacts for the end of the century or under lower radiative forcing (e.g. RCP 4.5) are less frequently described in literature, and not considered here. Still, it is expected that towards 2100 the negative impacts of droughts and increased temperatures on agricultural production will outweigh the positive effects that of elevated atmospheric CO2 concentrations on agricultural production. The impacts under RCP 4.5 on the other hand are not always lower than those expected under more pessimistic scenarios since positive and negative effects have to be outbalanced and response are crop-specific (e.g., Boere et al., 2019).

In this section, we account in monetary terms for the combined impact of elevated atmospheric CO2 concentration, risen temperatures, and changes in precipitation patterns and atmospheric demand of the atmosphere (evapotranspiration) on mean agricultural production (hiding inter-annual variations with years with higher and lower production values than average). We consider the changes in productivity of major crops and livestock, account for climate change induced land loss and simulated price changes, and discuss how climate change impacts on product quality and interannual yield variation can change the overall return of the sector.

In line with the overall aims of this study, we do not consider adaptation measures (e.g., changes in sowing/planting dates, shifts in cultivar, crop or animal choice, land use changes, irrigation, technological development, food policy changes, market-driven (feedback) changes – apart from the assumed price changes – nor consumer behavioural changes), although it is expected that these will have a large impact on the productivity, trade, prices and consumption, hence on the agricultural sector at large (e.g., Ciscar, 2009).

Moreover, since agricultural markets are highly connected within Europe – and globally – via trade, impact on agricultural production outside Belgium will also have an impact on our domestic agricultural sector and food market. (Assessing these effects in an integrated way would require a modelling study (as for example by Boere et al., 2019; or Ciscar et al., 2018a), which is outside the scope of this study.)

6.7.1. Current situation of the Belgian agricultural sector

Whereas the share of agriculture in the Belgian economy continues its steady decline since the 80’s and is now less than 1% of the GDP (0,63% in 2018), export of agricultural products accounts for a proportionally large share of the overall Belgian export (5.3%). Moreover, the agro-food sector ranks second in the Belgian industry with a share of 14.6%. Still, the sector does not offer much employment opportunity: only a minority of the economically active population in Belgium is employed in the agricultural sector (about 70,000 people). In 2018, Belgium counted a little more than 36,000 agro-businesses, of which two-thirds was located in Flanders and Brussels. Walloon businesses are larger in size, however, and occupy more than 50% of the total area occupied by agriculture on the Belgian territory (Belgian Statistics, 2020).

Grassland, cereals and fodder crops (mainly including fodder maize and beets) are the major crops and together occupy 80% of the total cultivated area (Figure 6-7). Besides, also potato and industrial crops (including sugar beet and rapeseed) are regularly grown (15% of the total cultivated area). Perennial fruit trees and vegetables occupy a minority of the land (5%), even though in terms of production and created value, fruit and vegetables account for more than a quarter of the total. Effects on the latter minor group are not considered in this assessment because quantitative information on climate change induced impacts is scarcer than for the arable crops and difficult to generalize for diverse crops (Belgian Statistics, 2020). All actual information on production, cultivated area, productivity or total monetary value for different crops in the Belgian agricultural sector used in this assessment are available from Belgian Statistics (2020).

6.7.2. Socio-economic impact of climate change on crop production by 2050

Climate change-induced economic effects on crops are associated with the impact on crop productivity, quality and interannual production variability. In our temperate climate, the combined effect of elevated atmospheric CO_2 concentration and the associated climatic changes on mean crop yields is mainly positive (Ciscar, 2009; EEA, 2019b; Vanuytrecht et al., 2016). Also for grasslands, even though complex interactions between positive and invasive impacts of elevated CO_2 concentration, rising temperature and altered rainfall patterns exist, the overall effect on mean productivity in Europe's temperate climates is often predicted to be positive (Ghahramani et al., 2019; Morales et al., 2007). Yet, as climate change also tends to increase the occurrence of extreme events, which leads to lower inter-annual yield stability and years with low yields (Vanuytrecht et al., 2016), it induces changes in crop quality and stimulates proliferation of (new) pests and diseases (Olesen et al., 2011); the overall economic account shows mixed effects.

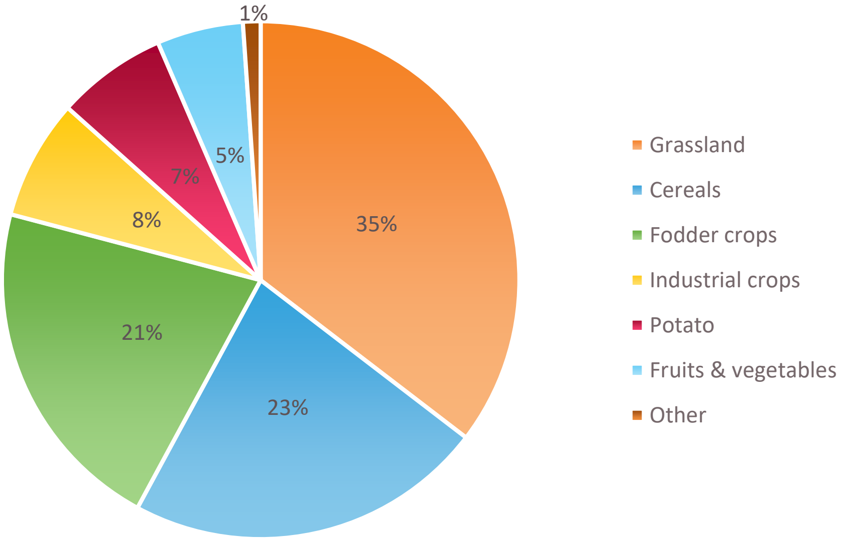

Figure 6-7. Share (%) of different crops in Belgium in terms of cultivated area. Source: Belgian Statistics (2020).

In our calculations, we considered mean productivity changes of arable crops found by Vanuytrecht (2016) by mid-century in the Flemish Region assuming a business-as-usual scenario and compared to the baseline period 1980-2010, i.e., mean yield increases for winter wheat, sugar beet and potato by 12%, 10% and 15%, respectively, and a mean yield decline for maize (grain and fodder) by 5%. We assumed that half of the productivity changes have already been realized by 2020. Mean yield rises of rapeseed and winter barley were assumed to be similar to those of winter wheat, and fodder beet yield rises were assumed to equal those of sugar beet. The assumed values fall with the estimated ranges for European regions by EEA (2019b), Boere et al. (2019) and Ciscar (2009).

Grassland is difficult to monetize since only a part is marketed. Therefore, we adopt product prices for mowed grassland from ICEDD (2014), i.e., 146 €/ton in 2019 value) and *shadow prices*[1] for pasture from Aghajanzadeh-Darzi et al. (2017, i.e., 18€/ton in 2019 value). For grassland productivity, we adopted impacts found by Graux et al. (2013) in an intensive pasture-based dairy system in the French Lorrain plateau (300 m.a.s.l., 830 mm annual precipitation and an average daily temperature of 10°C, comparable to the Belgian climate), i.e., an increase in annual grassland production by on average 18% by mid-century as compared to the baseline period 1970-1999[2]. As for the crops, we assumed that half

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[1] According to Wikipedia, a shadow price is 'a monetary value assigned to currently unknowable or difficult-to-calculate costs in the absence of correct market prices. It is based on the willingness to pay principle – the most accurate measure of the value of a good or service is what people are willing to give up in order to get it'.

[2] including increases in winter and spring production (on soils with good water holding capacity) and a decrease of up to 10% in summer production

of the productivity changes had already been realized by 2020. For comparison, Ciscar et al. (2018a) estimated an 11% increase in grassland production for the whole EU.

Considering a weighted average of current production values (Belgian Statistics, 2020) and assuming only projected direct productivity changes (denoted 'scenario I'), Belgium's mean annual crop production (including grassland) would rise by 3.9% towards 2050 as compared to the period 2015-2018, assuming RCP 8.5. As a consequence, and by only considering the productivity changes and crop-specific production values, the total value of crop production would rise by 3.8% (≡ 82 M€) to 2.2 B€ (Figure 6-9). The average land return (i.e. the average production value per unit area) would rise by 5% to 3112 €/ha for cropland and by 8.6% to 744€/ha for grassland (see Figure 6-8 and Table 6-14 for more details). This positive impact is largely due to the beneficial effect of elevated atmospheric CO_2 concentrations. Yet, crops can only benefit if they can take up enough nitrogen (Vanuytrecht et al., 2011), so fertilization should be precisely tailored to the crop demand.

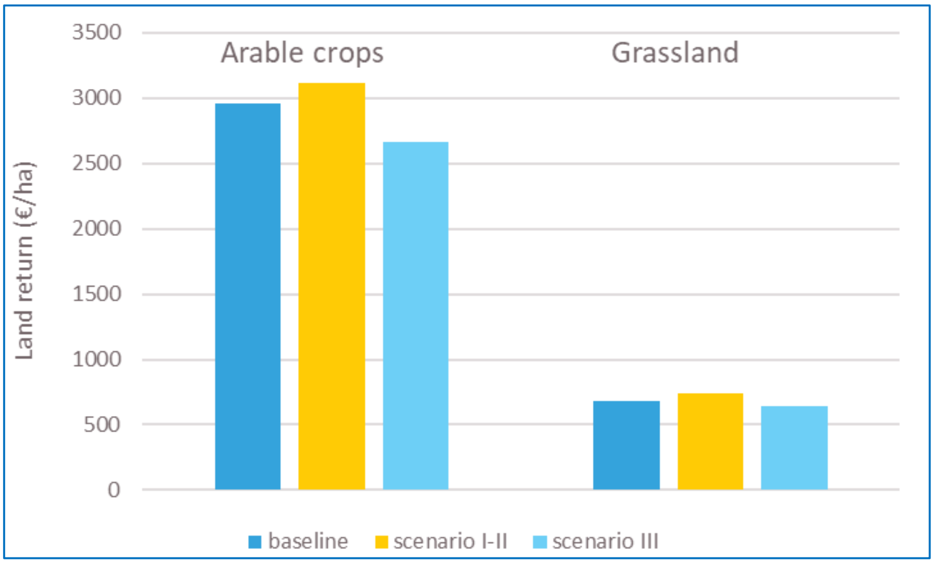

Figure 6-8. Land return of the cultivated area in the current period (2019 "baseline") and in 2050 (assuming RCP 8.5) for different scenarios. Scenario I (and II) assumes only crop productivity changes, no price changes (and for scenario II land loss); scenario III assumes crop productivity and price changes for crop products. (All values are converted to 2019 value.)

Climate change increases the share of land that is prone to flooding and soil erosion (by sea level rise along the coastline or riverbeds, or by extreme precipitation). This can lead to years with low yield or even yield failures, but part of the land can also be permanently lost even with planned protection measures to minimize land loss. Given that less than 1% of the agricultural land in our country remains fallow (Belgian Statistics, 2020) and urbanization pressure is high in Belgium, there is not much room to move to other land. Hence, in scenario II we also calculated the climate change impact on crop production if the total cropped area would shrink by 5% (equally distributed over grass- and cropland although it is likely that market processes will affect the current share of different crops), a number that is in line with the simulated drop in utilized agricultural area by Ciscar et al. (2018a). We explicitly do not account for land loss due to urbanization here, which may increase the land loss further, especially in the Flemish Region[1]. Assuming 5% land loss, crop production would decrease by −1.2% as compared to current levels, and the total value of cultivated crops would drop by −1.4% or 29.2 M€ (see Figure 6-9 and Table 6-14 for more details).

Climatic changes do not only lead to quantitative changes in crop yields. Temperature rise, elevated CO_2 concentrations, droughts and water excess also affect crop quality. Both positive and negative impacts are observed on protein concentration, starch or sugar content, tuber sizes and digestibility,

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[1] See for example https://ruimtemodel.vlaanderen/c/VITO%20RuimteModel/

to name some (e.g., Bisbis et al., 2018; Kawasaki and Uchida, 2016; Vanuytrecht, 2020). It is impossible to identify and quantify all possible and crop-specific impacts or the relation between product quality and price. Still, the value mentioned above may be overly optimistic if quality-induced product values decline.

In scenario III, we adopted the simulated decline in EU agricultural producer prices for cereals due to the general increase in EU domestic production according to Ciscar et al. (2018a; i.e. −20% by 2050 relative to the period 1981-2010). Relative to 2019, we assumed a price decline of 10% for all crops (including mowed grass) except for the shadow price of pasture which was kept constant (see Table 6-14 for details). In this more pessimistic scenario, the total crop production value would drop by 11% or 234.8 M€ to 1.91 B€ (Figure 6-9). Farmers would see their average land return drop by 10.2% to 2661 €/ha for cropland and by 6% or 644 €/ha for grassland (Figure 6-8 and Table 6-14 give more details). This is slightly more than the decrease in agricultural income projected for the EU as a whole (Ciscar et al., 2018a).

New emerging pests and diseases under new climatic conditions (influenced by the interaction between warmer, temporarily wetter climate at higher CO_2 concentration) may lead to yield losses or require higher investments in pesticides and curing treatments. This cost has not been taken into account. Also, we did not consider irrigated crops, as only 1.8% of the agricultural area in Belgium is currently irrigable and about half of that is effectively irrigated[1]. Irrigation can alleviate drought stress, but then the cost of additional water supply in drier years would have to be accounted for. Equipping more agricultural land with irrigation infrastructure is an adaptation option – that depends on infrastructural investments and water availability that has to be shared with other sectors – but this has not been taken into account in this study.

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[1] Eurostat data 2016

Table 6-14. Climate change induced impacts on crop production by 2050 (RCP 8.5) relative to the baseline year 2019

	Baseline 2019 [i]					**2050**							
							Scenario I [ii]			Scenario II [ii]		Scenario III [ii]	
Crop	**Cropped area** [iii] **(10^3 ha)**	**Production** [iv] **(10^4 ton)**	**Productivity** [v] **(ton/ha)**	**Value** [vi] **(10^6 €)**	**Land return** [vii] **(€/ha)**	**Relative yield change** [viii] **(% vs. 2019)**	**Production (10^4 ton)**	**Value without price change** [ix] **(10^6 €)**	**Land return without price change** [ix] **(€/ha)**	**Production (10^4 ton)**	**Value without price change** [ix] **(10^6 €)**	**Value with price change** [ix] **(10^6 €)**	**Land return with price change** [ix] **(€/ha)**
Cereals [x]	304.5	271.6	8.9	412.7	1355	4.3	282.5	429.3	1410	268.4	407.9	367.1	1205
Winter wheat	181.8	161.7	8.9	245.7	1352	6.0	171.4	260.5	1433	162.8	247.4	222.7	1225
Winter barley	39.0	35.3	9.1	53.7	1376	6.0	37.4	56.9	1459	35.6	54.1	48.6	1247
Grain maize	54.0	55.6	10.3	84.5	1566	-3.0	54.0	82.0	1519	51.3	77.9	70.1	1299
Fodder crops [x]	287.2	734.1		638.8	2224	-2.6	715.1	622.2	2167	679.3	591.1	532.0	1852
Fodder maize	179.8	695.8	38.7	605.5	3369	-3.0	675.0	587.3	3268	641.2	558.0	502.2	2794
Fodder beet	3.8	37.0	78.2	32.2	6804	5.0	38.8	33.8	7145	36.9	32.1	28.9	6109
Potato	93.3	363.2	38.9	571.2	6120	8.0	392.3	616.8	6609	372.7	586.0	527.4	5651
Industrial crops [x]	101.7	865.8		219.3	2156	5.0	909.0	230.2	2264	863.6	218.7	196.9	1936
Sugar beet	62.7	490.3	78.2	143.0	2283	5.0	514.8	150.3	2381	489.0	142.8	128.5	2050
Rapeseed	7.5	3.4	4.5	9.0	1198	5.0	3.5	9.4	1257	3.4	9.0	8.1	1076
Mowed grassland [x]	200.6	167.1	8.3	244.4	1218	9.0	182.2	266.0	926	173.1	252.7	227.4	1133
Pasture [x]	372.1	308.9	8.3	56.8	153	9.0	336.7	60.6	163	319.8	57.6	57.6	155
TOTAL	1360.0	2710.7		2143.2	2204	4.1	2817.7	2225.2	2256	2676.9	2114.0	1908.3	1989

[i] All values according to Belgian Statistics (2020) and monetary values converted to 2019 by applying the consumption price index (CPI) unless otherwise mentioned

[ii] Scenario I: assuming no price change nor land loss; Scenario II: assuming land loss (-5%) but no price change; Scenario III: assuming land loss (-5%) and price change (-10%) according to Ciscar et al. (2018a)

[iii] Data of 2018; for rapeseed based on total production and productivity according to Lamont et al. (2005)

[iv] Mean data of 2015-2018, except for grassland for which the most recent data are from 2013

[v] Calculated as ratio of production over cropped area if those data were available and confirmed to be in line with values in Belgian Statistics (2020); for fodder beet, the biomass productivity

was assumed equal to that of sugar beet; for rapeseed, values were adopted from Lamont et al. (2005); for grassland, more recent value for 2013 adopted from Belgian Statistics (2020)

[vi] Values based on 2015-2018 values (Belgian Statistics, 2020) and converted to 2019 values by applying CPI and calculated for crop-specific cereal/fodder crop values based on the relative production of specific cereal/fodder crops with reference to the total cereal/fodder crop production; for sugar beet, assuming 29.2 €/ton gross return (based on 2014 returns reported by Bergen et al. (2015), converted to 2019 values by applying CPI); for rapeseed, assuming 266.3 €/ton gross return for rapeseed (based on 2004 returns reported by Lamont et al. (2005), converted to 2019 values by applying CPI); for mowed grassland, assuming 146.2 €/ton gross return for forage (based on 2013 returns reported by ICEDD (2014), converted to 2019 values by applying CPI); for pasture, assuming the shadow price of 18.4 €/ton (based on 1995 shadow prices reported by Aghajanzadeh-Darzi et al. (2017), converted to 2019 values by applying CPI)

[vii] Land return is calculated as the average production value per unit area. The TOTAL value is a weighted average. Values based on 2015-2018 values (Belgian Statistics, 2020) and converted to 2019 values by applying the consumption price index

[viii] For winter wheat, maize, sugar beet and potato, changes were estimated based on findings of Vanuytrecht et al. (2016) for 2050 relative to 2019; for winter barley, changes for winter wheat were assumed; for fodder beet, changes for sugar beet were assumed; for rapeseed, changes were estimated based on findings from the COACCH study (Boere et al., 2019) for 2050 relative to 2019; for grassland, changes were estimated based on findings of Graux et al. (2013) for 2050 relative to 2019

[ix] According to 2019 values and prices

[x] Cereals = winter wheat, winter barley, grain maize and others; fodder crops = fodder maize, fodder beet and others; industrial crops = sugar beet, rapeseed and others; total grassland distinguished in mowed grassland and permanent pasture

Table 6-15. Climate change induced impacts on livestock products by 2050 (RCP 8.5) relative to the baseline year 2019.

	Baseline 2019 [i]		**2050**			
				Scenario I [ii]		Scenario III [ii]
Animal product	**Production** [iii] **(10^4 ton)**	**Value** [iv] **(M€)**	**Relative productivity change** [v] **(% vs. 2018)**	**Production (10^4 ton)**	**Value without price change** [vi] **(M€)**	**Value with price change** [vi] **(M€)**
Milk	67.3	1243.0	-1	66.6	1230.6	1184.4
Eggs	*na*	142.7	0	*na*	142.7	137.4
Poultry	47.0	724.1	0	47.0	724.1	662.6
Pork	107.3	1427.4	-1	106.2	1413.1	1293.0
Beef	27.7	1114.3	-1	27.5	1103.1	1009.4
TOTAL	249.3	4651.5		247.3	4448.3	4286.7

[i] All values according to Belgian Statistics (2020) and monetary values converted to 2019 by applying CPI unless otherwise mentioned

[ii] Scenario I: assuming no price changes; Scenario III: assuming price changes (-3.75% for dairy products; -8.5% for meat products as adapted from Ciscar et al. (2018a))

[iii] Data of 2018

[iv] Values based on 2015-2018 values (Belgian Statistics, 2020) and converted to 2019 values by applying CPI

[v] For animal products, changes were adapted from Gobin et al. (2008) for 2050 relative to 2019

[vi] According to 2019 values and prices

6.7.3. *Socio-economic impact of climate change on livestock production by 2050*

The climate change impact on livestock is complex and diverse. The economic impact is associated with the animals' welfare and health, their reproduction and production capacity (in terms of quantity and quality of meat and dairy products). These are influenced directly by (reduced) cold and (increased) heat and drought stress experienced by the animals, and indirectly by the (higher yet potentially variable) availability and (lower) quality of feed, by water shortage, and by emerging pests and diseases (e.g., Craine et al., 2010; Ghahramani et al., 2019; Graux et al., 2013; Lacetera, 2019; Nardone et al., 2010; Phelan et al., 2016; Rojas-Downing et al., 2017; Summer et al., 2019; Wolfenson and Roth, 2019; Wreford and Topp, 2020). Climate change impacts on livestock are often neglected in economic assessments (ICEDD, 2014) or effects are assumed to be only indirect through the effect of feed prices and trade on dairy and meet products (Boere et al., 2019; Ciscar et al., 2018a).

Effects of integrated climate change impacts on the livestock system are rarely quantified, or they are predicted to be small. Gobin et al. (2008) simulated direct impacts of heat stress (high temperature in combination with high humidity) on animal production in the Flemish Region towards the end of the century. Impacts are species-specific and dependent on whether maximum or mean temperatures are considered, but remain below 5% production losses. Rescaled to expected production changes by 2050, effects remain slightly below 1% for cattle and pigs, and are negligible for poultry. In our calculations, we assumed a decrease of 1% in the total production of cow and pig products, but no change for poultry (scenario I). The total animal production value would drop by 0.8% or 37.8 M€ to 4.6 B€ (see Figure 6-9 and Table 6-15 for more details). We did not assume that land loss would affect livestock production. In scenario III, we adapted the simulated decline in EU agricultural producer prices for cow milk and beef meat production as livestock benefits from cheaper feed prices by Ciscar et al. (2018a) relative to the period 1981-2010, for dairy products and for meat, respectively. By 2050, we thus, we considered a price decline of -4.8% for dairy products and -8.5% for meat relative to the year 2019. This makes the total animal production value to drop by 7.8% or 364.8 M€ to 4.3 billion € (see Figure 6-9 and Table 6-15 for more details).

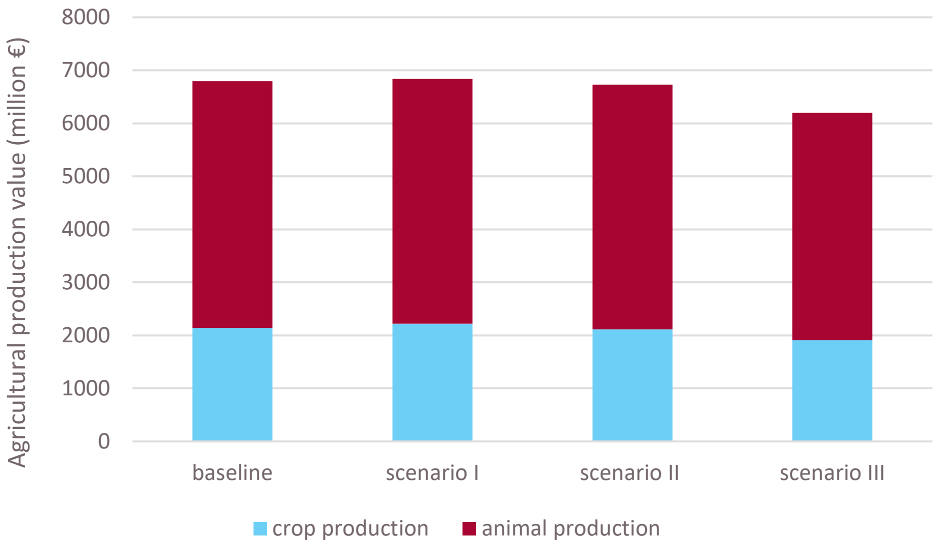

Figure 6-9 Total agricultural production value in the current period (2019 "baseline") and in 2050 (assuming RCP 8.5) for different scenarios. Scenario I and II assume crop and livestock productivity changes, no price changes (and for scenario II land loss); scenario III assumes productivity changes and price changes for crop and animal products. All values are converted to 2019 values by applying the consumption price index

6.7.4. *Overall economic impact of climate change on the agricultural sector by 2050*

To assess the overall impact on the agricultural sector, the agro-economic account was made considering the total production of the agricultural sector (i.e., crop production, animal production and derived services and side activities), intermediate expenditures, depreciation, wages and taxes to be paid, as well as subsidies and insurance pay-outs (Belgian Statistics, 2020).

We assumed that the proportion of intermediate expenditures (as for example additional heat-related costs may balance reduced cold-related costs), depreciation and taxes relative to the total production of the agricultural sector would remain the same in scenario I and II. Wages were assumed to remain at the absolute level in 2019 (in scenario I), or 95% of that level when considering 5% land loss hence less labour in scenario II (for details see Table 6-16). In scenario III, intermediate expenditures and depreciation were assumed equal to the absolute values in scenario II, while for the taxes the same relative proportion was assumed.

Subsidies and especially insurance pay-outs, however, may increase in response to the decreased gross income and increased variability of agricultural production induced by climate change, due to more extreme weather including heavy rainfall events, late frosts, hail storms or more frequent and prolonged drought spells.

Even though the mean productivity may increase, farmers will face years with difficult conditions and see their production and income fall. By 2050, in years with unfavourable weather conditions, crop yields could drop well below historic minimum levels (–35%), especially for potato and maize (Vanuytrecht et al., 2016). For poultry, cattle and pig production, production losses up to about 2%, 5% and 4%, respectively, are likely (Gobin et al., 2008).

While markets may respond to this reduced availability by increasing food prices, the presence of products on global markets may counteract this effect. If subsidies and insurance pay-outs do not rise, the total agrarian income would rise by less than 1% or 6.6 M€ without assuming price changes (scenario I), or shrink by as much as 36.9% (378.4 M€) when EU agricultural producer prices would drop in response to crop productivity rises (scenario III). Without increases in subsidies, insurance pay-outs or damage compensations, this cost would have to be borne by the farmer. In order to balance out the agrarian income loss for farmers, mean annual subsidies, compensations paid by governments and/or insurance pay-outs by private insurance companies would have to rise from 8% of the total production value of the agricultural sector to 15%, or by 378.4 M€, while the mean annual tax income would decrease from 3.4 to 3.1 million €. In comparison, the Flemish government paid out almost 100 million euro in 2018 to compensate for agricultural drought damage, while for a total of 150 million euros damage claims were filed[1]. Although the government allocated twice 27.5 million euros for compensation to farmers in 2019 and 2020, the drought conditions in the year 2019 have not been recognized as agricultural disaster, and no compensations have been paid out. As from 2020, the disaster fund no longer compensates crop damage. Instead of reimbursing part of farmers' revenue losses, in a new subsidized weather insurance system the government will pay part of the farmers' insurance premium on the private market.

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[1] https://veeteelt.nl/nieuws/vlaanderen-bijna-100-miljoen-uitgekeerd-voor-droogteschade-2018 and https://www.vilt.be/geld-beschikbaar-voor-uitkering-droogteschade-uit-2018

Table 6-16. Climate change induced impacts on the total agrarian income by 2050 (RCP 8.5) relative to the baseline year 2019

	Baseline 2019	**Projection 2050**		
		Scenario I [i]	Scenario II [i]	Scenario III [i]
Agro-economic account [ii]	**Value (M€)**	**Value without price change [iii] (M€)**	**Value without price change [iii] (M€)**	**Value with price change [iii] (M€)**
Total agricultural production [iv]	6794.7	6838.9	6562.3	6195.1
Services & side activities [v]	67.9	68.4	65.6	62.0
Total production agricultural sector [vi]	6862.6	6907.3	6627.9	6257.0
Intermediate expenditure [vii]	5147.0	5180.5	4970.9	4970.9
Depreciation [viii]	686.3	690.7	662.8	662.8
Net added value [ix]	1029.4	1036.1	994.2	623.3
Wages [x]	549.0	549.0	521.6	521.6
Taxes [xi]	3.4	3.5	3.3	3.1
Subsidies and insurance pay-outs [xi]	549.0	549.0	549.0	549.0
Agrarian income [xi]	1026.0	1036.2	1018.3	647.6

[i] Scenario I: assuming no price change nor land loss; Scenario II: assuming land loss but no price change; Scenario III: assuming land loss and price change

[ii] Agro-economic account calculated according to Belgian Statistics (2020)

[iii] According to 2019 prices and values

[iv] Sum of crop and livestock product values

[v] Assumed to be 1% of the total agricultural production value according to Belgian Statistics (2020)

[vi] Sum of total agricultural production and service & side activities values

[vii] Assumed to be 75% of the total production value in the agricultural sector according to Belgian Statistics (2020) without considering value changes due to price change

[viii] Assumed to be 10% of the total production value in the agricultural sector according to Belgian Statistics (2020) without considering value changes due to price change

[ix] Total production of the agricultural sector minus intermediate expenditure and depreciation

[x] Assumed to be 8% of the total production value in the agricultural sector according to Belgian Statistics (2020) without considering value changes due to price change

[xi] Assumed to be 0.5% of the total production value in the agricultural sector according to Belgian Statistics (2020)

[xii] 8% of the total production value in the agricultural sector in 2019 according to Belgian Statistics (2020)

[xiii] Net added value minus wages and taxes, plus subsidies and insurance pay-outs

6.8. FORESTRY

6.8.1. Economic losses due to droughts

Direct economic loss: change in growth rates and stand optimum

The impact of climate related vulnerabilities on the forest sector for beech (*Fagus sylvatica*), spruce (*Picea abies*) and oak (*Quercus robur*) was assessed by ICEDD (2014) for Wallonia, based on trophic regimes, water cycles and ecological regimes. The scenario involves a 'no change' policy: no stand mix adaptation, no legal change. The cost is estimated on the basis that the stands will need to be harvested before their optimal maturity. Pest outbreaks, fire risk and other secondary threads were not included in the model.

The estimate is based on the Land Expectation Value (LEV) computed by Hanewinkel et al. (2013), where the economic shortfall has been calculated as the difference between the harvest at the optimum age and the early harvest due to climate change impact on growth rate in 2030 (low hypothesis), 2040 (mean hypothesis) and 2050 (high hypothesis) for a high emission scenario (A1F1)[1], which means that stand types outside their suitability area in the future will be harvested or will disappear in 2030, 2040 or 2050.

Table 6-17: Beech, spruce, and oak: estimated economic shortfall in Wallonia (ICEDD, 2014) in 2030 (low hypothesis), 2040 (mean hypothesis) and 2050 (high hypothesis) for the A1F1 scenario.

Espèce	Calcul	Hypothèse basse	Hypothèse moyenne	Hypothèse haute
hêtre	Peuplements en exclusion, tolérance et nouvelle exclusion	8 045 327	14 473 259	21 431 433
epicéa	Peuplements en exclusion, tolérance et nouvelle exclusion	50 043 730	89 250 563	144 691 543
chene	Peuplements en exclusion et tolérance - chene pédonculé et indéterminé	3 442 471	6 883 194	10 739 482
Total		**61 531 528**	**110 607 016**	**176 862 458**

ICEDD results show an economic shortfall of 119.9 M€ loss by 2050 (2019 value) for beech, spruce and oak stands in Wallonia based on the mean hypothesis. Additionally to the hypotheses made by ICEDD (2014) in this estimate, further assumptions were made:

- We assume that the standing volume of beech, spruce and oak remained in the same proportions between Flanders and Wallonia since the study performed by Baveye & Massinon (2008). For Flanders, the inventory dates back to 1997-1997 (Afdeling Bos & Groen, 2001). This assumption is plausible given the inertia between planting a tree and harvest and its optimal LEV.
- Prices to calculate the economic shortfall by ICEDD were not adapted, except for spruce stands, as the market remained quite constant for the senescence (biological ageing) chosen, but not for spruce stands (OEWB, 2019), which is linked to bark beetle[2] outburst. Since the related costs to bark beetle are assessed in this study, we estimated a price of 27.5 €/m³ (2019 value) (FNEF, 2020) to avoid counting this impact twice.
- Due to the comparatively small volume in Brussels, the shortfall in this region has been

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[1] We recommend reading ICEDD (2014) for further insights on their methodology and hypothesis taken.

[2] We focus on bark beetle as it mainly attacks spruce, hence it has a large economic impact.

neglected.

- We assumed the LEV and price were the same in Flanders than the ones used in the ICEDD study.

The estimate for beech, oak and spruce economic shortfall due to direct impact of climate change on yields performed by ICEDD has been adapted to cover Flanders. The mean hypothesis (2050, A1F1 scenario) was chosen in this estimate, using the volume ratio between the two regions (see hypothesis above). For spruce stands, an estimate of 55 €/m³ was made for 2013 (based on mean price evolution presented in OEWB (2019)). This price was updated to 27.5 €/m³ due to the bark beetle outburst impact (see following section), resulting in a loss of 76.7 M€/year for period 2040 – 2070.

Indirect cost: Pest outbreaks and pullulations

Due to mild winters and heatwaves, bark beetle (*Ips typographus*) have pullulated during the years 2018 and 2019 in a row. Bark beetle on spruce stands has caused the authorities to force contaminated stands to be cut and taken out of the forest, to avoid further spreading: 600,000 m³ spruce stand were concerned in 2018, over a million m³ in 2019, and about the same amount in 2020, causing a drop in Spruce abundance (Mikolajczak, 2020b; RTL INFO, 2019). Furthermore, a study conducted in Europe by Marini et al. (2017) shows a strong link between the rate of timber loss on spruce stands due to bark beetle and the volume of storm-felled forests in the previous year, because of the windfall, creating a cascading effect on price drop.

Bark beetle usually pullulate during one to three subsequent years (Mikolajczak, 2020b), but given the mild winters and heatwaves increase, the current situation might become the norm. Bark beetle breeding cycle is 6 weeks, which is why it is of upmost important to log infested spruce in a 3-week time, forcing forest managers to pay constant attention to their Spruce stands. The value of infested Spruce dropped between 10 €/ha and a negative price of -10 €/ha as a result of short deadlines (due to the breeding cycle) and a saturation of the spruce market (Mikolajczak, 2020b). We assumed the price to be an average of 5 €/h, given that all the infested stands are not taken away in time.

For the estimation of the associated costs we made the following assumptions:

- The loss of yield due to shift in suitability area for the spruce stand was not included.
- No cascading effect between bark beetle and storm were taken into account.
- No mitigation has been taken into account: no change in forest management practices, nor standing spruce volume decrease.
- The current drought situation of 2018 and 2019 is considered to become the norm by 2050, which is why the loss estimate is considered to be ‘for 2020 and beyond’. While droughts will become more severe in the future, bark beetle outburst usually follows a 2-3-year cycle before decreasing again. Those two opposing tendencies are cancelled out in the current estimate.
- Negative impacts of other pullulations on other stands were not included.

Since bark beetle outbursts already strongly affect standing Spruce market prices, the indirect loss of bark beetle on the market could be estimated comparing the years 2017 and 2019. This cascading effect on healthy spruce stands is taken into account in our calculation as an indirect impact. Bark beetle impact on spruce prices are estimated as following:

- An average price for the lost volumes has been taken for 90 cm diameter price per m³, based on OEWB (2019) and FNEF (2020): 52.2 €/m³ for healthy spruce in 2017, dropping to 27.5 €/m³ in 2019, while infested spruce are sold at 3 €/m³ (assuming forest managers respond in time to the infection).
- Volumes of infested spruce are estimated to be 600,000 m³ in 2018, and 1,000,000 m³ in 2019 (Mikolajczak, 2020b) in Wallonia. The total spruce harvest volume in Wallonia in 2019 is 2,645,559 m³ (OEWB, 2019), with a harvest rate of 148%. The infested spruce volume and total spruce harvest have been estimated based on the spruce volume in 1997-1999 (Afdeling Bos & Groen, 2001), applying the same ratio of harvested spruce volume (m³) divided by the standing volume.

The total loss due to *Ips Typographus* is estimated around 66 M€/year from 2020 onwards. The calculation leads to a loss of 16 €/m³ loss for healthy spruce, and 50 €/m³ loss for infested spruce.

Indirect cost: Forest fire risk

A recent study from UGent shows that fire risk is the highest during dry months of March/April and the hot summers in July and August mostly due to the rainfall patterns; Belgium's forest fires amount to about 66% of declared fires (Depicker et al., 2020).

The Fire Weather Index (FWI) has been designed for North American forests (standard pine fuel type), and includes the following parameters: 24-h accumulated precipitation, wind speed, air temperature and relative humidity, and soil water content (Fargeon et al., 2020).

Based on the data provided by the PESETA III project (EEA, 2017) (see Section 3), the median FWI of Belgium could be estimated to be in the range of 10-15 for the present climate (1981-2010), with a projected 30% to 40% of FWI increase by 2071-2100 for scenario A1B. This number even goes higher than 40% for the Belgian Ardennes.

A method of calculation of fire costs increase might consist of using the current burned area and extrapolate the area lost to fire based on the FWI increase. However, since fire size was small during the previous years in Belgium, financial claims linked to forest fires were so low that they are not representative as a basis for extrapolation using the FWI, according to Amifor, an insurance company specialized in forest fire cover (M. Terlinden, personal communication, 26 May 2020). Furthermore, Fox et al., (2018) showed in a study conducted in the South-East of France that a clear correlation between burned area and FWI evolution exists, it is strongly nonlinear, so that projections of future fire burned area are difficult to make.

Current literature lacks sufficient information on the topic to base our analysis on solid scientific grounds. Therefore, in order to estimate the forest fire costs for Belgium in the future, we will base our burned area estimate on the current area estimate of the UK, a nearby country showing the best corresponding values among neighbouring countries of fire risk today as what Belgium might expect in the future. Indeed, the South of the UK is within in a 15 < FWI < 20 zone, which is expected to be the case for the Ardennes in the future (with forest cover of > 60%). France was not chosen because the majority of its fires are declared in the Mediterranean basin, where FWI values are much higher at more than 125 at the peak of the summer (notice that FWI > 50 is considered 'extreme'), hence the Mediterranean impacting (biasing) strongly the resulting French burned area statistics (Fox et al., 2018).

The hypothesis mentioned above is to be taken with precaution, given the uncertainty regarding the assumptions made, since the FWI does not take into account the relief, stand type, forest management practices for mitigating fire spread, afforestation rate nor firefighter reactivity (Fox et al., 2018). The latter factor plays a crucial role into limiting the damage: for instance, in the South of France fire spreads at a speed between 4 to 8 km/h under violent wind (Barroux, 2017). Choosing to past burned area statistics of the United Kingdom is thus a strong hypothesis wrapped in uncertainty.

Average burned area per year since 2000 was found on the EFFIS Database (n.d.): Belgium has lost 141 ha/year to fire on average since 2010, and the UK 3930 ha/year (with a rising trend). We assumed that 58% of the burned area concerned forest area, which is the EU average in 2018 (JRC, 2019). No fire related damage to houses or infrastructure was taken into account.

The burned area estimate (*BA_BE_future*) for Belgium for the 2071-2100 period under scenario A1B, is made as follows:

- *BA_UK_today*: Burned area for the United Kingdom, average since 2010, according to the JRC's European Forest Fire Information System (EFFIS) database
- *AREA_ratio*: the ratio between Belgium's and the UK's forest area (with percentage forest cover of 12.9% in 2010). This ratio is equal to 0.225.
- *BU_forest*: the percentage of burned area that concern forest and woodland, estimated at 58% (JRC, 2019).

Based on this information we calculate Belgium's future burned area by 2071-2100 (RCP8.5) as

$$BA\_BE\_future = BA\_UK\_today \times AREA\_ratio \times BU\_forest = 1{,}026 \text{ ha/year},$$

which is an increase by a factor six compared to current burned area estimates.

The estimate of the monetary value of this burned area takes into account the following factors:

- The value of the type of stand growing on the terrain: (Baveye & Massinon, 2008) estimated an average value of standing trees in Wallonia and Flanders of around 10,125 €/ha (2019 price).
- The cost of replanting: including transportation costs and brush cutting, replanting cost are estimated to amount to 6,000 €/ha (M. Terlinden, personal communication, 26 May 2020).

Hence, the estimated fire related logging losses and costs by 2071-2100 (RCP8.5) are expected to amount to (10,125 €/ha + 6,000 €/ha) × (1,026 ha/year – 141 ha/year) = 14.28 M€/year. This number is to be taken with caution given the uncertainty regarding the burned area estimate. For the year 2050, we roughly estimate the losses to be the half that expected for the 2071-2100 period, hence 7.14 M€/year.

Another cost is related to firefighting, which represents a cost to the community. France, which is heavily affected by fires in the Mediterranean basin, spends about half a billion euro every year on fire prevention (about a third of this budget) and firefighting, heavily relying on planes (Chatry et al., 2010). In Belgium, no planes or helicopters are deployed in case of wildfires, although agreements with the Netherlands and other neighbouring countries were signed in case of major events (Depicker et al., 2020). No firefighting (investment) costs were estimated in this study.

Finally, forest land value is affected by forest fires, which affects the volume of tree stands. The land value depends among other on the soil quality, its accessibility, and the relief. Baveye & Massinon (2008) estimated the price (2008 value) of land value at 8,184 €/ha. Current prices vary between 4,000 €/ha and 7,000 €/ha (M. Terlinden, personal communication, 26 May 2020).

As a result of drought, pest outbreaks and other risks, forest land is not considered as a safe investment anymore (Mikolajczak, 2020a). Because of the duration of tree growth (with harvests between 40 and 110 years after initial plantation, depending on the stand type) the risk of revenue losses in logging also has an impact on the land value, unlike agricultural lands. The forest land market is still stable, but might lower in the coming years for spruce, especially at low altitude (Mikolajczak, 2020a).

6.8.2. Damage due to storm and heavy precipitation

An extract from the calamity fund was used in order to assess the damage on forests (damage category E) from 1993 to 2016, after which the calamity fund was regionalised. The data provide costs for storm, flood and extreme weather events and the amount requested by claimants as well as the amounts paid by the calamity fund.

The extract shows that two events had a major impact on the claimed amounts in the forest category:

- the storm of 18-19 January 2007, with wind speeds around 120 km/h (see Section 2): 15.5 M€;
- the heavy winds on 14 July 2010, with wind speeds up to 137 km/h in Elsenborn (Meteo Belgique, 2010): 6.7 M€.

Those two events amount to 91% of total refunded claims over 1993-2016 period (total of 24.2 M€ in 2019 value).

Considering Figure 15 in Section 2.9 on extreme wind speeds recorded in Belgium since 1990 it emerges that, although the frequency of heavy wind is not expected to increase, the maximum wind speed might increase by up to 30% in winter towards the end of the century (Brouwers et al., 2015). This raises concern since the wind force increases quadratically with wind speed while gust wind speed increases linearly (Usbeck et al., 2010).

The assessment of shortfall in forest due to extreme wind was based on ICEDD (2014). They performed calculations for spruce stands, which are prone to storm. Costs were estimated based on prices of different tree sizes for spruce and considering that higher trees are more vulnerable to storms, considering the A1B scenario for the 2040-2070 period. The calculation was made using data from Panferov et al. (2009). The type of ground used was Cambiols (shallow), which was considered representative for Walloon soils.

Costs were estimated for different tree sizes for spruce. Spruce standing volume beyond the optimal suitability were not included, as they are assumed to be exploited by 2050. This assumption avoids overlap between the different cost estimates. The cost estimate was made assuming that all felled trees are sold at a firewood price of 25 €/m³.

Yet, the cost estimate made in 2013 is no longer accurate due to pullulation: an average price for the lost volumes has been taken for 90 cm diameter price per m³, based on OEWB (2019) and FNEF (2020): 55 €/m³ for healthy spruce in 2013, dropping to 27.5 €/m³ in 2019. A firewood price of 15 €/m³ was used.

The wood volume for Flanders was calculated using the volume ratio of spruce standing volume between Flanders and Wallonia since the study performed by (Baveye and Massinon, 2008). For Flanders, the inventory dates back to the period 1997-1997 (Afdeling Bos en Groen, 2001). The ratio shows that the standing volume of spruce in Flanders amounts to about 1% of that in Wallonia, which will therefore have little impact on the results.

Moreover, we did not take into account the impact on the market of sudden increases of volume supply, and we did not take into account the cascading effect of pest outbreaks and pullulations that occur due to windfalls when they are not harvested in time.

The distribution of costs between the collectivity (i.e., amount paid by the calamity fund) is on average 67% of the requested amount, assuming the amount assessment made by the claimant is correct and that all the forest managers actually file a claim.

With a shortfall of 12.5 €/m³ of spruce stands, the storms and violent wind impact due to climate change is estimated to be 2.2 M€/year (A1B scenario, 2040-2070), which is distributed between claimants (33% or 0.7 M€) and the collectivity (67% or 1.5 M€).

6.8.3. Financial impacts on forests apart from logging revenues

The eco-systemic services given by forests are not always easy to quantify. Should forests be so damaged that they couldn't fill their role, the economic impact aside logging would be huge: in a study on France, Chevassus-au-Louis et al. (2009) tried to provide a financial estimate of all the services forest are providing 'for free': those were 9 times the gross revenue provided by harvesting the wood. The services (recreation, harvest, hunt, water quality and carbon sink) were estimated at 1158 €/ha each year, while logging profit were estimated between 90 and 191 €/ha per year. It is reasonable to assume that for Belgium similar figures would apply. No estimate on those functions were included in the present study, because of the hardship to evaluate the function losses, since forests regenerate; addressing this further would require an estimation of regeneration time based on studies that consider succession.

6.8.4. Conclusions and impact on forest land value

Table 6-18 summarizes the different costs mentioned and estimated in this study, in €/yr. Given the uncertainty and the different hypothesis taken for the estimates, one should be caution while summing them up. Numbers shown are considered as to be conservative estimates for the scenario chosen.

Further study in the different fields are needed. Lack in literature on climate change impacts on forest hinder forest owners in their choice of (mix of) climate-resistant stand types to plant, having in mind to harvest the benefits in half a century or more.

Table 6-18. Summary of costs of climate change on forests in Belgium. All costs are borne by forest owners, except the 2.2 M€ spruce loss due to windfall, which is borne for 1/3 by forest owners, the remaining 2/3 being borne by the collectivity (calamity fund).

	costs (M€/yr)
yield loss due to tree stand optimum change[1] (A1F1, 2050)	76.7
direct loss due to *Ips Typographus* (beyond 2020)	47.8
cascading effect - market price loss for Spruce (beyond 2020)	16.2
burned forest area costs (estimated for 2050)	4.5
replantation costs (estimated for 2050)	2.7
spruce loss due to windfall (A1B scenario, 2040-2070)	2.2
total cost in M€/year	150.1

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[1] for beech, spruce and oak

6.9. ECOSYSTEM SERVICES

6.9.1. Impact on species: migration and phenological changes

Direct impacts on plants and animals such as migration and change in phenology are very hard to quantify in economic terms. There is a lack of knowledge regarding the role of particular species of particular habitats in providing life supporting functions. We will probably never know how important the existence of certain species will be for the stability of the ecosystem under future climate conditions until it is too late.

Biodiversity also plays a key role in the delivery of ecosystem services: nature's contributions to human wellbeing. Biodiversity is a factor controlling the ecosystem processes underpinning ecosystem services. In many contexts higher biodiversity is associated with increased ecosystem functioning and increased delivery of ecosystem services. More biodiverse ecosystems are also believed to be more resilient to pest and environmental change, and therefore better able to assure the future delivery of ecosystem services. Through these ecosystem services we can partly value biodiversity and the impact of climate change on the delivery of these services.

6.9.2. Invasive species

Invasive species can bring enormous damage and control costs. They not only threaten native species directly but can also have a negative impact on the structure and functioning of ecosystems. Annual damage and control costs associated with a set of economically relevant invasive species were conservatively estimated at 23.4 B€/year for Europe (the majority of it damage costs). It is an underestimate of the real costs as it is an extrapolation of existing documented costs and based on a subset of invasive species. Information on economic impacts was found for only 52 of 125 invasive alien species considered for their ecological and ecosystem service related impacts in the study (Kettunen et al., 2008).

6.9.3. Carbon sequestration

Land use, land use change and forestry constitute a net sink of CO_2-equivalents for the times series of the national emissions report, but this is in constant decline since 1990 till 2012 after which it has stabilized (NIR, 2020).

Organic carbon in the soil plays an important role in regulating the nutrient cycle of plants. Changes in biomass production and degradation caused by climate change can have an influence on plants and the functioning of ecosystems. On a global scale, carbon uptake by terrestrial ecosystems is still increasing because of a longer growing season caused by higher temperatures and because of higher atmospheric CO_2 concentrations. But a further temperature rise might turn these sinks into sources of CO_2 because of the quicker degradation of hummus than biomass production. Furthermore, increasing drought will lead to more CO_2 emissions because of the deterioration of forests and peatland, which are both important sinks, and considering the enhanced forest fire risk. For sandy soils this means also higher risk on nutrient leaching (van der Aa et al, 2015).

Carbon sequestration can be monetarized by considering the avoided CO_2 emission reduction cost. Here, we use the damage costs calculated in De Nocker et al. (2010), which amount to 220€ per ton carbon.

For the period 1990-2000, Van Wesemael et al. (2007) estimated an annual carbon storage in ecosystem soils in Belgium at 0.78 MtC/yr. Taking this as a reference, and using the above-mentioned unit cost of 220 €/tC, we find a value of 172 M€/yr in monetary benefits that can be assigned to carbon uptake by the soil.

For the period 2012-2050, including the impacts of both climate change (considering SRES scenario A1F1, which we will take here as close enough to RCP8.5) and land management, Van Wesemael et al. (2007) obtained a strongly decreased value of 0.14 MtC/yr. They attribute this decline in carbon sequestration mainly to the slowing down of the growth rates of the forests. Since this value of 0.14

MtC/yr is an average over the entire period 2012-2050, it appears plausible – given the previously descending trend – to assume that towards the end of this period the annual carbon uptake goes to zero or even becomes negative (i.e., ecosystems acting as a source rather than a sink of CO_2).

There is ample corroborating evidence for such a declining carbon uptake trend. Indeed, while it is well established that the current increasing trend of atmospheric CO_2 concentration is causing an increasing land carbon uptake, there are now indications that these trends of increasing sinks may be slowing down, and that future climate change impacts will decrease this uptake compared to the case with constant climate. Moreover, it is expected that nutrient shortage will limit the effect of rising atmospheric CO_2 on future land carbon sinks (IPCC, 2013). In fact, there are indications that ecosystems may undergo a transition from a CO_2 fertilisation period to a period dominated by nutrient constraints and larger climate change impacts; in particular, heatwaves and drought are leading to negative impacts on carbon sinks (Fernández-Martínez et al., 2019). Considering the recurrent heatwave and drought episodes that have occurred in Belgium in recent years, it is not unlikely that in the future the capacity of ecosystems in Belgium to store carbon may become compromised.

Hence, assuming that carbon uptake in ecosystems may reduce to zero (or become negative) would imply that the avoided CO_2 emission reduction cost of 172 M€/yr for the period 1990-2000 (see above) would be lost, or even that it would turn into a negative value. In the absence of more detailed information, we maintain this figure of **172 M€/yr**, representing the monetary loss associated with the reduced functioning of carbon storage in ecosystem soils, by 2050 and under climate scenario RCP8.5 (as a proxy for A1F1, see above).

6.9.4. Air quality, recreational and health benefits

The ECOPLAN project (Vrebos et al., 2017) has quantified the monetary impacts of climate change for a number of ecosystem services, including air quality (particle) filtering, and recreational and health benefits. We use the results from ECOPLAN for the Flemish Region to derive an average value (in €/ha) for each ecosystem service for non-urban areas. This is then combined with data regarding climate change-related land use change (Table 6-19) in Belgium presented in Carraro et al. (2009) – and which was also used in ICEDD (2014) – to estimate overall ecosystem services benefit losses, considering scenarios A1F1 and A2, which on average are fairly close to RCP8.5, at least in terms of projected CO_2 emission trends (see Hayhoe et al., 2017; Their figure 4.1).

Table 6-19. Climate-related changes in surface area (in units of 1000 ha) occupied by forest, cropland and grassland, for Belgium. The column labelled 'average contains the average land cover values of the A1F1 and A2 scenarios, and 'difference' refers to the difference between the 'average' value with the value of 2005.

	2005	2050			
		A1F1	A2	average	difference
forest	667	526	545	535	–132
crop	859	1111	729	920	61
grass	519	653	355	504	–15
				TOTAL	–86

From Table 6-19 it can be seen that the loss of the three land covers (forest, cropland and grassland) amounts to 86,000 ha, considering the average of the A1F1 and A2 scenarios. In order to estimate the monetary loss of the ecosystem benefits considered in this subsection, i.e., air filtering, recreational and health benefits, we multiply the unit ecosystem value (in €/ha/yr) of Table 6-20 with the lost amount of forest, cropland and grassland combined, i.e., the 86,000 ha decrease given in Table 6-19.

Table 6-20. Ecosystem service valuation in 2050, based on detailed monetary ecosystem service values obtained for the Flemish Region (Vrebos et al., 2017). The ecosystem service value per ha per year is obtained by dividing the total ecosystem benefit value by the number of ha (counting non-urban areas only). The ecosystem service loss value is obtained by multiplying the value per ha and per year by the 86,000 lost ha calculated in Table 6-19.

	total value in the Flemish Region (M€/yr)	ecosystem service value in €/ha/yr	ecosystem service loss for Belgium (M€/yr)
air quality (fine particles)	910	786	67.6
recreational benefits	370	320	27.5
health effects (contact with nature)	1648	1424	122.5

It should be noted that the approach described above is grossly crude and fraught with considerable uncertainty. For instance, in case we had taken the land loss values of either the A2 scenario or the A1F1 scenario (see Table 6-19), instead of their average, results would have been wildly different. In case of the A1F1 scenario we would even have ended up with a gain rather than a loss in the estimated future ecosystem service value. Taking the average of both scenarios at least appeases such fluctuations to some extent.

As a conclusion, we take the monetary loss of the air filtering, recreational and health benefits of ecosystems in Belgium in 2050 to reach **up to 217.6 M€**, which is the sum of the individual impacts of the three effects provided in Table 6-20, and with the caveat that this figure is highly uncertain.

6.9.5. Pollination

A direct link between biodiversity loss and economic activity is the ecosystem service provided by pollination. If the number of pollinators decreases, there will be a decrease in crop production. In Johnson et al. (2020) a proportional change in effective hectares (reached by pollinators) was multiplied by the pollination yield dependency ratio, which is a measure of how dependent a crop yield is on pollinators (Johnson et al., 2020). For Belgium a decrease of 0.005% of GDP under the RCP8.5 scenario was estimated, or **23.7 M€/yr**.

6.9.6. Freshwater ecosystems

Freshwater ecosystems (lakes, rivers, wetlands) constitute an important natural resource that delivers important ecosystem services. The decrease in summer precipitation in combination with higher summer temperatures – hence a higher level of evaporation – is expected to induce drought (Section 2) and put these resources under pressure.

Among other things, it induces a decrease in river flow and may alter the structure of the river basin (ADAPT, 2008; Boukhris et al., 2006); in Flanders, the lowest river flows can drop by more than 50% during dry summers (Willems et al., 2009).

Groundwater reserves could decrease by approximately 8-15%, which will have a negative impact on drinking water reserves (d'Ieteren et al., 2003). If drinking water supply has to be limited due to a water shortage (e.g. by 10% for 10 days), the associated unit cost per m³ would become be higher (3 €/m³). With large and long-term usage restrictions, the costs per m³ rise sharply, given that high-quality uses become limited. For example, in the situation of a 25% restriction for 20 days the unit drinking water cost could rise to more than 100 €/m³. The social cost to Flanders of a scenario with such restrictions amounts to more than 1 B€ (Ingle et al., 2013).

As little information is available for Belgium, we follow the approach of Carraro et al. (2009), which was also adopted in ICEDD (2014). Carraro et al. (2009) made an extensive economic valuation of ecosystem services provided by freshwater ecosystems, including the following types of services: provisioning (water supply), regulating (flood control, water quality), amenity (biodiversity) and recreational (fishing, swimming, walking…). For Belgium, they estimated that the benefit of these services combined amounts to 3.477 B€/yr (converted from USD (2003) to € (2019)).

Moreover, from their analysis Carraro et al. (2009) found that, under SRES scenarios A1F1 and A2, climate change is expected to decrease the freshwater ecosystem value by 20% in 2050. (Recall that, as before, A1F1 and A2 are considered a reasonable proxy for RCP8.5.) Applying this percentage to the annual monetary benefit estimate provided above, the loss of freshwater ecosystem benefits amounts to **695 M€/yr**.

Taking all the ecosystem benefit loss values derived above together, the total ecosystem services benefit lost amounts up to **1,108 M€/yr**.

6.10. INSURANCE

Since 1980 there has been a steep increase in costs around the globe of weather-related disasters (Houghton, 2015; Deloitte, 2019), a sizeable portion of which leads to insurance claims. Part of the observed upward trend in disaster losses is related to climatic factors such as storms, flooding and drought. Another part is related to socio-economic aspects, including population growth and settlement in vulnerable (e.g., floodable) areas. In Belgium, with regard to socio-economic aspects, continued urbanization is a particular concern, as urban impermeable surfaces tend to amplify pluvial and fluvial flooding, as well as heat stress.

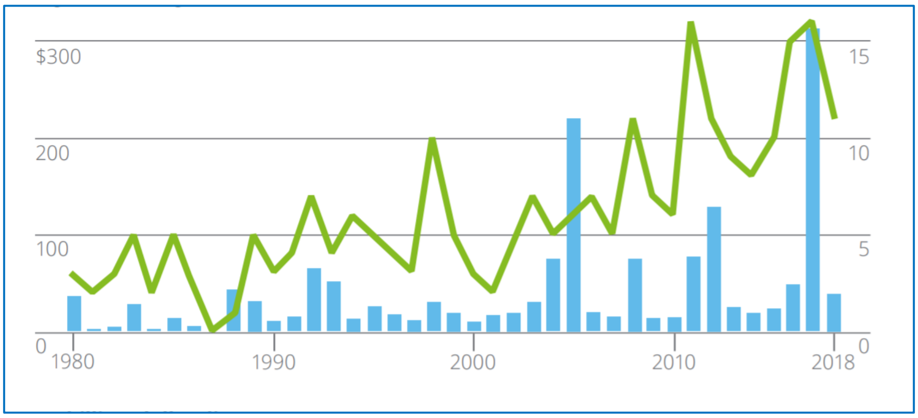

Figure 6-10. Global weather-related losses for events with costs exceeding a billion USD, blue = cost in billions (left scale), green is number of events (right scale). Source: Deloitte (2019).

A considerable share of the sectoral damage costs mentioned in the preceding sections (on health, agriculture, infrastructure, …) directly affects the insurance sector. Among these, heat related morbidity may affect **hospitalization** insurance costs. Estimates of additional hospital costs presented previously are in the range 95-188 M€/yr, a portion of which may end up as insurance coverage.

Damage following **drought in the agricultural sector** is increasingly covered by private insurance. In the Flemish Region drought risk has been recently transferred from the calamity fund to private insurance, though the government still provides premium subsidies. In Wallonia, a private insurance scheme is promoted that helps farmers get higher compensation by the Walloon calamity fund, as indemnities are reduced when farmers do not take insurance. Drought related damage costs in the agricultural sector have been on the rise in recent years, with claims amounting to 150 M€ for the dry summer of 2018 in Flanders alone. In France, costs associated with extreme drought are expected to nearly triple over the period 2014-2039 (Dantec and Roux, 2019). This figure could rise substantially later in the century, considering that drought projections after 2070 show very large increases in the severity and duration of drought episodes.

Private property insurance (fire insurance, car omnium) includes ‘broad weather risk’ such as flooding, storms (winter storms and thunderstorms) and hail damage. It should be noted that natural hazards constitute 20-25% of common household insurance premiums (W. Robyns / Assuralia, *personal communication*).

As to **extreme wind speed**, observations from past decades do not show a clear trend in Belgium (see Section 2). Also, projections for the daily average wind speed in Europe do not show a clear trend towards the future (see, e.g. Dantec and Roux, 2019). This also appears to be the case for Belgium, though it is expected that during the most intense storms wind speed may increase by up to 30% (Brouwers et al., 2015). Likewise, Christodoulou and Demirel (2018) present projections of higher wind gust speeds for the middle and end of the century for areas bordering the North Sea.

Damage caused by storms and flooding constitutes a large cost in insured claims. Table 6-21 shows amounts claimed to Belgian insurance companies for storm and flooding events of recent years, amounting to 220 M€/yr on average over the period 2011-2019.

Table 6-21. Cost of insurance claims (in M€) related to storms and floods in recent years. Source: data from Assuralia.

	2011	2012	2013	2014	2015	2016	2017	2018	2019
storm	94	64	75	505	109	146	71	188	296
flooding	86	28	17	46	7	171	4	59	14
total	180	92	92	551	116	317	75	247	310

In the UK, according to ABI (2004), the future cost of weather-related insurance claims (storm, inland flooding) is expected to double by 2050 as compared to 2004, disregarding any socio-economic changes such as the location and value of assets. Assuming that such a doubling of insurance claim amounts applies to Belgium would yield future (2050) **flooding-/storm-related damage claims of 220 M€/yr** in addition to the current 220 M€/yr.

Although it is included in the 'storms' category, **hail** is worth mentioning separately, given that it constitutes a large damage cost for Belgian insurers in recent years. Indeed, in Table 6-21, the year 2014 stands out very distinctly with respect to the claimed amount (more than 500 M€) because of the major hail damage (dented cars, damage to greenhouses in the horticultural sector, …) that occurred that year and associated claims. Comparably, the extreme hail storms of June 2016 in South-East Holland caused 100,000 claims for damage to houses, cars and greenhouses, for a total amount of approximately 500 M€ (Van Ginkel et al., 2018).

There is a large uncertainty involved in future projections of the frequency and intensity of hail storms. Yet, climate projections for Belgium conducted within CORDEX.be (Termonia et al., 2018) for the end of the century under IPCC scenario RCP8.5, while indicating a reduced total number of hailstorms, also find an increased hailstone size. In the Netherlands, the Dutch 'warm' climate scenarios (comparable to RCP8.5) are expected to lead to a doubling of extreme hail events in 2050 compared to the period 1981-2010 (KNMI, 2015). In any case, the intensity (and hailstone size) of summertime thunderstorms is expected to increase, because atmospheric moisture, which fuels convective storms by releasing latent heat of condensation, is more abundantly present in a warmer atmosphere.

Botzen et al. (2010) and Botzen and Bouwer (2016) estimated damage caused by hail during thunderstorms. They used the Dutch climate scenarios 'G' and 'W', which approximately correspond to IPCC scenarios RCP4.5 and RCP8.5 respectively (KNMI, 2015). In their estimate, by 2050 hail damage claims for motor vehicles will increase by 13%-33%, claims for damage to crops by 25%-48%, and for damage to greenhouses by 116%-219%.

According to the National Bank of Belgium (NBB, 2019), an increase in insurance claims causes a growing concern with respect to affordability and insurability. Indeed, after extreme hydro-meteorological events, insurers tend to critically reassess their risks in case claims turned out to be higher than estimated. This reassessment could result in decreased affordability and availability of insurance (Cremades et al., 2018), increasing the burden on households and companies. For instance, in the UK, household insurance costs are anticipated to rise fourfold by 2080 as a result of climate change (City of London, 2010).

Lamond and Penning-Rowsell (2014) state that, in general, rapidly rising premiums can cause unaffordability of insurance and lower demand for coverage, which can even lead to a collapse of specific insurance markets. Likewise, Tesselaar et al. (2020) conclude that the rise in insurance premiums causes problems with the affordability of flood coverage, resulting in a declining demand for flood insurance. This subsequently increases the financial vulnerability of households to flooding, in particular given that insurance can become unaffordable for lower income groups.

Increasing insurance premiums also may raise a question of equity and the distribution of wealth. For instance, in the UK, 25% of households choose not to insure their contents, this number rising to 50%

for low-income groups due to the price (GLA, 2002). At the same time, weather related damage costs 'tend to be met disproportionately by those who cannot afford insurance, re-location or adaptation investments' (Barker, 2008).

However, the findings above regarding insurance affordability mainly stem from studies conducted at the European level or in the UK. In Belgium it is likely that affordability will be less of an issue, because to some extent insurance coverage against natural disasters is mandatory. In particular it is compulsory as a part of property insurance. Conversely, inclusion of weather-related damage in car insurance is voluntary, and generally insurance takers need to subscribe to an omnium or a 'reduced omnium' to have these risks included. It is interesting to realise that, sometimes, leasing companies do not have omnium insurance cover for their car park, considering that the large number of cars (often several thousand) naturally helps to spread the risk. However, there is a case known of a leasing company that saw its annual benefits reduced to naught after the hailstorm of 2014, when this calamity affected a major portion of their car park. Also, insurance of greenhouses against hail damage is voluntary, so affordability because of climate change could become an issue in this segment of the insurance market.

According to the National Bank of Belgium (NBB, 2019), apart from affecting affordability, climate-related risk is increasingly seen as a potential threat to the financial stability of the insurance sector. Insurance companies exhibit vulnerability to such risks both in terms of assets (depreciation of investments) and liabilities (increasing claim levels). According to Houghton (2015), recent events have even shown that 'weather-related losses can stress insurers to the point of bankruptcy', using hurricane Katrina of 2005, with insurance claims amounting to 40 billion USD, as an example.

To take a more local example, consider a recent account by Van Ginkel et al. (2018), who refer to the 2016 hailstorm in the Netherlands to argue that '…at one point the insured damage can become too high and then it cannot be insured anymore under the standard conditions'. They add that '…according to insurance experts, the occurrence of another similar hailstorm that year would have made the risk uninsurable in the sense that premiums would have risen considerably'.

Of course, several mechanisms are in place in Belgium as elsewhere in Europe, to ensure the resilience of insurance companies against large and sudden shocks in damage claims. For one, the reimbursement of claims is generally limited to certain amounts. In addition, insurance companies – especially the larger ones – spread risk across different categories, i.e., they have some buffering capacity with respect to strong interannual fluctuations in the amounts claimed. Moreover, insurance companies are re-insured, as a matter of obligation. All this, including the required level of re-insurance, is regulated by the National Bank of Belgium, which follows European legislation (Solvency II Directive 2009/138/EC) to ensure the solvability of insurance providers, up to withstanding financial shocks associated with a one-in-200-year event.

In fact, it should be kept in mind that a distribution of costs between insured (through franchises), (re-) insurers (through guarantees up to certain limits in exchange for the premiums that make it possible to build up reserves) and government (through promised amounts on top of the obligations of the (re-) insurers) can be determined or adjusted as desired. This obviously has an impact on what companies and citizens pay as premiums or as taxes.

Even if extreme events were to become more frequent or intense with climate change, the insurance sector uses evolving insight, re-negotiating premiums on an annual basis, hence adapting the system in a flexible way. So, in general terms, the insurance industry is flexible and can cope with evolving risk because its annual re-evaluation of premiums in principle allows to quickly adapt to changing (climatic) conditions. Also, a strict solvency regulation including re-insurance coverage aim to make the sector robust.

However, to what extent can this model be stretched under (drastically) changing climatic conditions?

At a recent policy dialogue event in Brussels, the sustainability of this model has been questioned, and it has been argued that 'changing annual premiums is no longer the way forward'[1]. Also, Deloitte

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[1] Zurich Insurance Group, at *Adapting to change: Time for climate-resilience a new EU adaptation strategy*,

(2019) states that '…the inherent uncertainty of a changing climate, combined with the diversity and rising frequency of perils, may render the historical loss data that catastrophe models rely upon less useful for future loss projections'. Recently, Tesselaar et al. (2020) have argued that the impact of climate change and remote natural catastrophes, through their impact on re-insurance companies, could adversely affect the 'local' (European) insurance market and premiums.

In all this, the largest risk for the insurance sector may reside in the inherent unsteadiness and variability (and unpredictability) of extreme weather. The variability observed in recent years, as shown in Table 6-21, illustrates very well the large year-to-year fluctuations in reported claim amounts.

To end this section, we would like to additionally mention a particular and increasingly relevant point of concern, that '… it is more than likely that there will be an increase in claims in the future as a result of companies failing to adequately manage the risk of climate change on their business and to disclose these risks to investors' (Deloitte, 2019). In this respect, it might well be worth for the insurance sector in the future to align with the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD, 2017).

European Policy Centre, Brussels, 5 March 2020.

6.11. TRANSBOUNDARY IMPACTS

6.11.1. Agricultural and labour productivity losses outside Europe

Many countries, especially developing countries, are expected to be confronted with much larger climate change related losses in labour productivity and agricultural yields than is the case in Europe, with losses by up to several ten percent. However, it should be realized that, even though the impact in temperate countries like Belgium may be modest compared to many other countries, the export to and import from such countries is expected to decline with global warming, which may also affect foreign trade hence our economy.

Knittel et al. (2020), for Germany, estimated climate change related import reductions from outside Europe by up to 2.46% (RCP8.5, 2050), which may affect Germany's GDP by up to 0.46%. Transferred to the Belgian GDP (2019 value), this would yield around 2.2 B€ of GDP decrease – which is to be added to productivity loss costs incurred directly in Belgium itself.

Szewczyk et al. (2018) find an effect of 27.5 B€/yr of transboundary effects for the EU-28 in 2007 value. Compared to the GDP of the EU-28 (13,087 B€ in 2008)[1], this represents 0.21% which, applied to Belgium's GDP of 473 B€, yields 993 M€/yr. This is quite a bit lower than the estimate above but still at the same order of magnitude, and an indication of the uncertainty involved in the estimate of transboundary economic impacts.

As a final range of the costs associated with transboundary impacts we retain **0.99-2.2 B€/yr**.

6.11.2. Migration

It is expected that in developing countries, climate change may trigger massive migration streams. Following Houghton (2015), under a business-as-usual scenario the total number of displaced persons may reach 3 million per year before 2050. Two thirds would be related to sea level rise and one third to agricultural yield loss because of drought. More recently, research has been published regarding the occurrence of deadly heat[2] in certain parts of the world, which may also trigger mass migration (Xu et al., 2020), not only as a result of people seeking refuge from dangerous environmental conditions, but possibly also as a result of declining labour productivity levels associated with such extreme heating levels, and the ensuing impoverishment of nations, eventually driving people to move.

Missirian and Schlenkerl (2017) found a relationship between climate change and fluctuations in asylum applications in the EU, and they estimated that under RCP4.5, towards the end of the century asylum applications are projected to increase by 28 % due to climate impacts, or an average of 98,000 additional asylum applications per year.

The cost of resettling a displaced person has been estimated at approximately 1500 to 7500 €[3] (Myers and Kent, 1995), which on average – and considering the above mentioned 3 million annual refugees, would yield a total (global) cost of around 13.5 B€/yr. Of course, it is difficult to estimate the fraction of these displaced persons reaching Belgium and the associated cost, although it would appear that Western Europe might be a receiver of a large share of environmental refugees if we consider historic trends, see Abel et al. (2019).

Also, the final cost estimate should account for other aspects, such as the possibility (or not) to integrate environmental refugees in the Belgian labour market hence contribute to the country's GDP, especially in so-called bottle neck professions. More important, though, is the consideration of human suffering that comes with displacement.

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[1] https://ec.europa.eu/eurostat/statistics-explained/index.php/National_accounts_and_GDP see under 'GDP at current market prices' (ideally we would have used the 2007 value but the series only went back as far as 2008)

[2] A combination of high temperature and humidity levels that limit the physiological capability of the human body to cool, possibly leading to dangerous and even lethal overheating of the body.

[3] Taking the original 1000-5000 USD (1995 value) range and applying a factor 1.68 to convert USD from 1995 value to 2019 value, and an exchange rate (in 2019) of 0.89 € per USD.

6.12. SYNTHESIS OF SECTORAL COSTS AND GAINS

Table 6-22 provides a synoptic overview of the costs and gains that have been assessed throughout Section 6. Note that insurance has not been included, as the costs for this sector are already contained in the infrastructure (mainly flooding) impacts.

Table 6-22. Overview of the economic costs and gains per sector under scenario RCP8.5, considering the middle and the end of the century. A blank cell means that either we expect no impact, or that information to assess the impact was not available or that the assessment was out of scope in the present study.

	Sectoral costs/gains in M€/yr			
	2050		**2100**	
	costs	**gains**	**costs**	**gains**
Health	2058 ± 682	2635 ± 875	3900 ± 1300	3900 ± 1300
Labour productivity	2565 ± 2395	149 ± 33	4805 ± 4195	298 ± 66
Infrastructure (flooding)	641 ± 299	-	4112 ± 1478	-
Infrastructure (drought/heat)	460 ± 306	9.1	-	-
Energy	242	220	-	-
Agriculture	606	45	-	-
Forestry	150	-	-	-
Ecosystem services	1108	-	-	-
Transboundary	1596 ± 604	-	-	-
TOTAL	9427 ± 4285	3058 ± 908	-	-

A few comments are in order:

- Costs included under *Health* only include heat/cold-related mortality, as morbidity was not estimated for the middle of the century. Also, the mortality costs shown here are those based on the VSL, which yields higher values than figures based on the VOLY concept.
- The large range found for *Labour productivity* loss arises from the fact that the lower and higher end of the range correspond to the coolest resp. warmest year occurring in a 20-year period, so these values are about two standard deviations away from the mean. Another caveat is that the gains were not calculated in the same way as the costs, which limits the comparability of both aspects.
- The large difference between time horizons 2050 and 2100 in the *Infrastructure (flooding)* category arises from the sole effect of projected sea level rise increase.
- The cost figures in the *Agricultural* sector take the year 2019 as and not a typical climatological period such as 1981-2010. Also, very coarse assumptions were made regarding macro-level impacts (overall land loss and price setting).
- Damage arising from reduced *Ecosystem service* functioning are fraught with a very large uncertainty. In particular, the single highest cost within this sector – related to freshwater resources – was adopted from a single study from the grey literature, the figures of which were hard to verify.

The data presented above, or at least their mean values per sector, are presented in the form of a diagram in the Conclusions.

7. SOCIAL ASPECTS

7.1. INTRODUCTION

Climate change impacts do not affect all citizens in the same way. Extreme events like flooding from heavy rainfall or urban heat often cause worse impacts on certain vulnerable groups. These groups include people living in areas with low environmental qualities (green space and air quality), people with low socio-economic status, and people with physical conditions that present greater difficulties in preparing for, and in recovering from, climate change impacts. The reasons for these difficulties can lie in the lack of economic resources or, in particular, physical conditions like poor health, or living alone, or suffering from other social disadvantages like being a tenant or not understanding the national language.

Urban centres often include significant socially vulnerable populations whose demographic and socio-economic characteristics, coupled with the qualities of the environment they live in, can have a significant effect on the susceptibility of the local community to harm from climate hazards.

The EU strategy on adaptation to climate change explicitly recognizes that “climate change impacts are expected to widen social differences across the EU and encourages that special attention needs to be given to ‘social groups and regions which are most exposed and already disadvantaged (e.g. through poor health, low income, inadequate housing, or lack of mobility)”.

7.2. CHARACTERISTICS OF SOCIAL VULNERABILITY

The spatial dimension of social vulnerability has been explored by Lindley et. al. (2011), who introduced the concept of socio-spatial vulnerability. This framework was developed for a research project funded by the Joseph Rowntree Foundation in the United Kingdom. It is based on the concept of “risk triangle”, where climate disadvantage (understood as the degree to which an external event has the potential to convert into losses in human well-being) is realized when vulnerability of communities coincides spatially with the hazard-exposure (e.g. occurrence of flooding or heatwaves in a given location).

The concept of vulnerability is disaggregated into sensitivity (personal factors driving vulnerability, such as age and health), enhanced exposure (environmental factors, such as characteristics of housing or presence of green space that can either mitigate or exacerbate climate impacts locally), and adaptive capacity (social factors, such as income level, ability to speak the official language, length of residence in the area). Adaptive capacity in turn is split into the ability to prepare for, respond to, and recover after extreme weather events.

This framework brings together characteristics defining individual and social elements of vulnerability with spatial characteristics that define exposure, and enabling features of the environment that promote preparedness, response capacity, and ability to recover, as summarized in Figure 7-1.

Based on this concept, indexes of social vulnerability have been developed, using different indicators. There is quite some agreement in literature about which indicators are important to describe social vulnerability.

Tapsell et al. (2002) proposed a social vulnerability index based on indicators pertaining to unemployment, overcrowding, non-car ownership, non-home ownership, long-term sickness, single parents and elderly people.

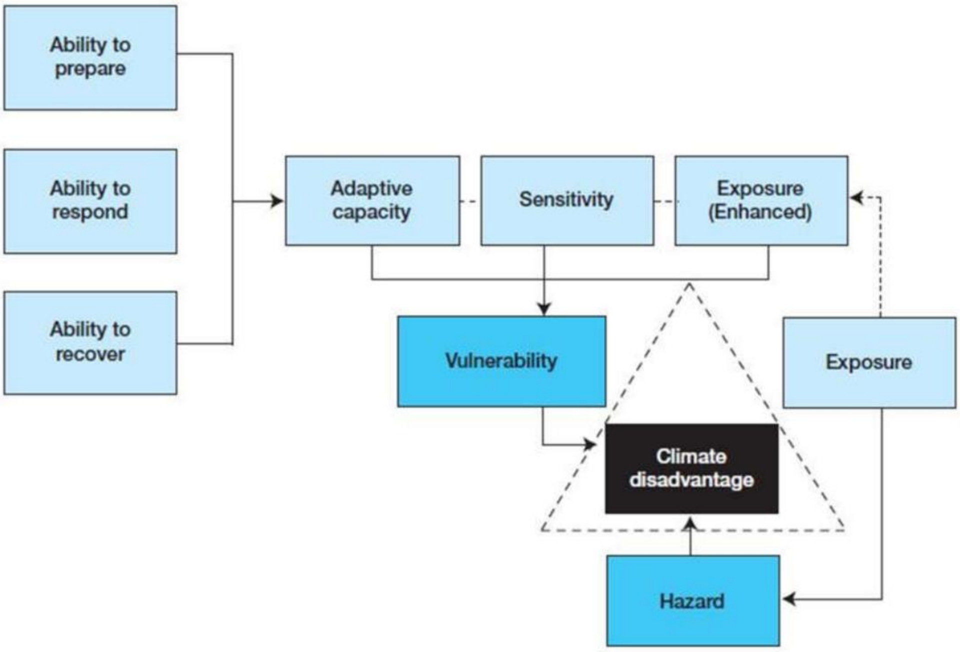

Figure 7-1. Conceptual framework for assessing socio-spatial vulnerability and climate disadvantage (Lindley, 2011).

In the Urban Climate Adapt Viewer[1], the following socio-economic characteristics related to social vulnerability are available:

- Percentage of people 75 years old or older in the population
- Percentage of lone-pensioner households
- Percentage of unemployed people in working age population
- Percentage of working-age population with higher education
- Percentage of lone-parent households
- Percentage of people born in another country in the population

Table 7-1 shows the indicators of social vulnerability used in the pan-European assessment of exposure to air pollution, noise and extreme temperatures.

In 'Mapping flood disadvantage in Scotland 2015' Kazmierczak et al. (2015) used 34 different indicators in the domains age, health, income, information use, insurance, local knowledge, tenure, mobility, social networks, physical access, crime, access to health services, housing characteristics and physical environment.

Kazmierczak (2015) gives a list of 33 initial indicators for the Helsinki Metropolitan Area, that was subsequently reduced to 23 on the basis of a correlation analysis. The final list contained 19 indicators that were relevant to social vulnerability to flooding, and 15 that related to social vulnerability to high temperatures. Information on social vulnerability were combined with hazard maps to yield maps of the spatial distribution of flood disadvantage.

The LATIS-software used for the determination of the cost of inundations in Flanders does not only calculate economic damage, but also considers social, ecological and cultural impact through the calculation of dedicated impact scores. The social impact is based on a social vulnerability index which takes into account:

- the number of beneficiaries of increased social benefits
- the number of people unable to work
- the number of non-Europeans and people from Eastern Europe

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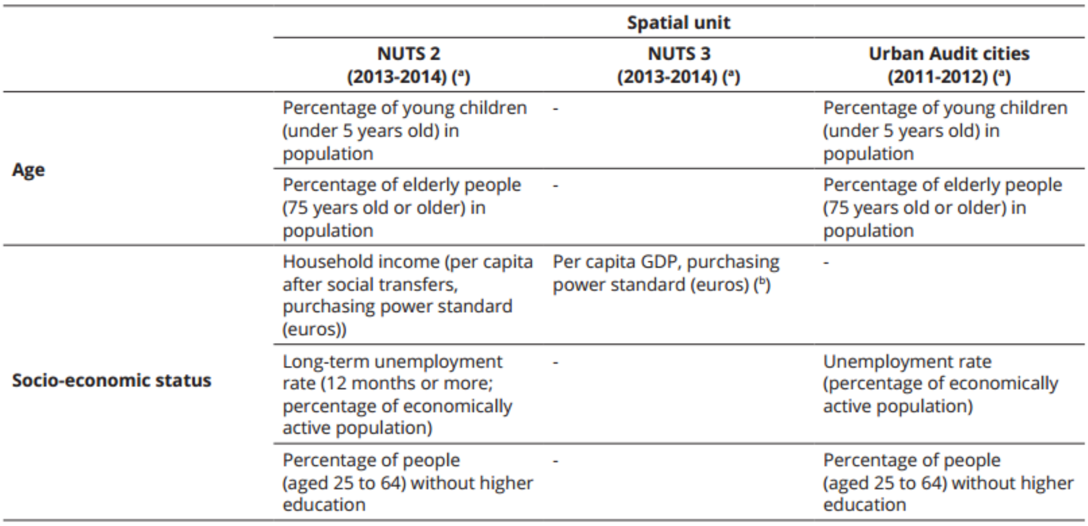
[1] https://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation/Urban-Adaptation-viewer-datasets

- the number of people older than 75
- the number of one-parent families

Table 7-1. Indicators of social vulnerability used in the pan-European assessment of exposure to air pollution, noise and extreme temperatures



	Spatial unit		
	NUTS 2 (2013-2014) (a)	**NUTS 3 (2013-2014) (a)**	**Urban Audit cities (2011-2012) (a)**
Age	Percentage of young children (under 5 years old) in population	-	Percentage of young children (under 5 years old) in population
	Percentage of elderly people (75 years old or older) in population	-	Percentage of elderly people (75 years old or older) in population
Socio-economic status	Household income (per capita after social transfers, purchasing power standard (euros))	Per capita GDP, purchasing power standard (euros) (b)	-
	Long-term unemployment rate (12 months or more; percentage of economically active population)	-	Unemployment rate (percentage of economically active population)
	Percentage of people (aged 25 to 64) without higher education	-	Percentage of people (aged 25 to 64) without higher education

Poor social networks are identified as a factor increasing vulnerability, as isolated people are less likely to receive information and help (EEA, 2018). Social isolation increases the risk of death as a result of extreme weather events. Generally, people living on their own tend to be more vulnerable during heatwaves; 92 % of the 2003 heatwave victims in France lived alone (Poumadère et al., 2005). The lack of social networks is particularly frequent among older people, people in poor health or with disabilities, people reliant on social services for home care, people living alone, ethnic minorities, people who are homeless, people who are substance abusers, …. Also, areas with a high turnover of population in a residential area may have reduced social network connections.

The above list suggests that vulnerability extends beyond material deprivation and covers a range of interacting factors.

Note that the concept of social vulnerability is not entirely independent of the hazard considered; the factors that determine social vulnerability to floods may differ from those that determine social vulnerability to heat.

7.3. RELATION BETWEEN SOCIO-ECONOMIC VULNERABILITY AND PHYSICAL PARAMETERS

Next to socio-economic and demographic parameters, the physical characteristics of the urban neighbourhood can affect the extent to which people are impacted by a flood or heat wave event or experience other forms of climate impacts. Increased surface sealing by roofs, roads, car parks, walkways, and paved-over gardens reduces the ability of drainage systems to remove runoff created during intense rainfall events. A high proportion of sealed surfaces also raises temperatures in the area. The type of housing also plays a role; houses with the lowest floor at or below ground level are more exposed to flooding than dwellings located on higher floors, whilst single-aspect, difficult to ventilate flats on top floors or in high rise buildings may be prone to overheating. Unfavourable physical characteristics of dwellings and neighbourhoods often are strongly correlated with the high socio-economic vulnerability of the inhabitants.

Exposure to high and low temperatures within cities or regions are largely driven by the quality of their living environment. The UHI effect causes the temperatures in cities to be higher than in surrounding rural areas; at the level of individual buildings or households, people's exposure to extreme temperatures is influenced by their ability to maintain comfortable temperatures in their homes. This, in turn, depends on the type and quality of housing and the ability of people to afford artificial cooling or heating.

In many European countries, including Belgium, more vulnerable communities tend to live in dense, urban environments and, therefore, may be exposed to higher temperatures. In locations such as Rennes, France, and Birmingham, United Kingdom, city centres are characterised by high proportions of the elderly, people in poor health and those living alone. They also have the highest intensity of UHIs (Buscail et al., 2012; Tomlinson et al., 2011).

In Belgium, a lot of socio-economic data are available, but most of them only at the level of the municipalities. One of the exceptions is the city of Ghent, which makes socio-economic data publicly available on its website, many of them down to the level of detail of the statistical sectors. This makes it in principle possible to analyse the spatial distribution of socio-economic characteristics and to link those to the known distribution of certain hazards, such as heat or flooding.

Most information is thus available to devise a socio-economic vulnerability index for Ghent and to asses, in combination with knowledge of exposure and hazards, the spatial distribution of the “climate (dis)advantage” in the city. To our knowledge this exercise has not been systematically executed, and is out of the scope of the present study. Some examples of the data and their possible interpretation are nonetheless given below.

Inspiration can be found in the study by Kazmierczak (2015) for the Helsinki Metropolitan Area. Combining data on social vulnerability with data on flood hazard, she was able to prepare a detailed map of the (pluvial) flood disadvantage of the area (see Figure 7-2).

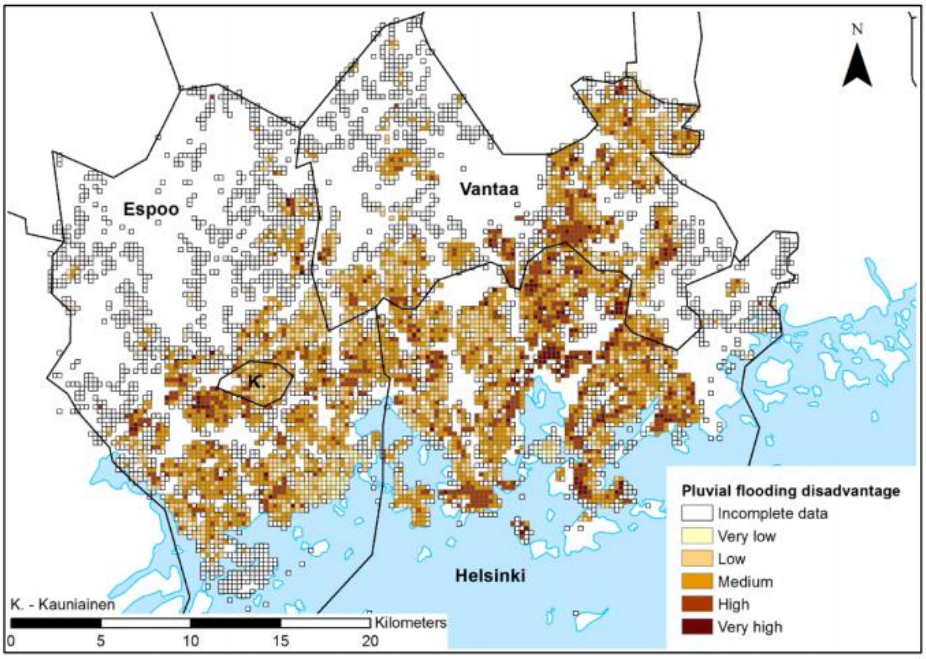
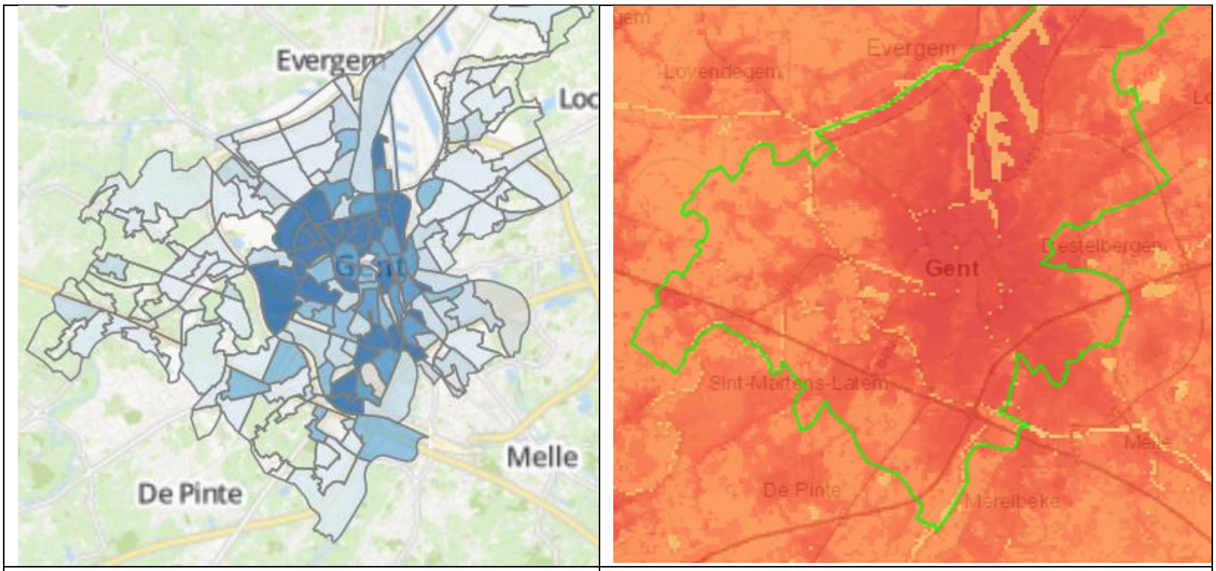


Figure 7-2. Pluvial flood disadvantage in the Helsinki Metropolitan Area.

Figure 7-3 shows two maps of the city of Ghent. The one on the left shows, for the different statistical sectors within the city, the number of people (per 1000) that receive a basic income, a parameter that we use as an indicator for social deprivation (many other suitable indicators are available in the database). The map on the right shows the number of heatwave degree days in 2100, a measure for summer heat. The correlations between both maps are striking: poverty (dark blue colours) is concentrated in many of the inner-city sectors, that are also characterised by intense summer heat. In contrast, the greener and cooler sectors in the western and southern parts of the city have clearly less people living on basic income, and hence less poverty. This shows that many of the neighbourhoods that will be hit hardest by climate change (and possibly feel the burden already now) are among the poorest in the city.



Number of people in the city of Ghent receiving a basic income per 1000 inhabitants (source: https://gent.buurtmonitor.be/)	Number of heatwave degree days in Ghent in 2100 (source: www.klimaatportaal.be)

Figure 7-3. Social indicators for Ghent compared to future heat.

Table 7-2 shows some physical and socio-economic characteristics for the different neighbourhoods of Ghent. Again, the database contains other parameters that are interesting in view of the development of a social vulnerability index. Figure 7-4 Shows the relation between the physical characteristics (built-up area in this case) and a socio-economic parameter (in this case, people living on a basic income), based on the figures of *Table 7-2*.

Table 7-2. Some physical and socio-economic characteristics of the neighbourhoods of the city of Ghent

Neighbourhood	% built-up area	# people/1000 living on a basic income	Median value of net income (€)	People declaring sufficient nearby green space (%)
Binnenstad	43.9	25.3	17069	68.5
Bloemekenswijk	27.4	28.1	14842	61.5
Brugse Poort-Rooigem	27.1	38.5	15303	73.4
Dampoort	37.4	19.6	16460	58.5
Drongen	5.5	2.5	22137	83.1
Elisabethbegijnhof-Papegaai	47.0	30.3	16608	50.7
Gentbrugge	9.5	9.7	20767	90.6
Kanaaldorpen en -zone	8.5	2.8	20987	78.0
Ledeberg	27.9	29.3	16695	49.3
Macharius-Heirnis	32.6	26.0	17236	79.3
Mariakerke	12.3	6.1	21429	91.7
Moscou-Vogelhoek	26.2	10.7	19308	67.7
Muide-Meulestede-Afrikalaan	23.8	32.8	14512	54.8
Nieuw Gent-UZ	17.4	46.7	14662	73.4
Oostakker	13.0	3.5	21282	65.5
Oud Gentbrugge	31.4	16.7	19618	81.0
Rabot-Blaisantvest	30.8	42.0	13120	50.8
Sint-Amandsberg	16.7	8.3	19815	84.7
Sint-Denijs-Westrem	9.2	7.2	21540	89.1
Sluizeken-Tolhuis-Ham	41.1	36.2	13734	58.6
Stationsbuurt Noord	28.8	23.7	20923	78.7
Stationsbuurt Zuid	21.0	21.7	22156	79.2
Watersportbaan-Ekkergem	12.3	32.9	16745	86.0
Wondelgem	18.1	8.7	19811	71.8
Zwijnaarde	7.2	5.3	20885	73.8

Figure 7-4 shows a clear correlation between the built-up area (that we can consider an approximate indicator for the urban heat island effect) and the relative number of people receiving a basic income, which is a poverty indicator. The fact that the correlation is not perfect can be explained by, among other things, physical and social heterogeneity within neighbourhoods (the correlation would probably be stronger if data from statistical sectors rather than from neighbourhoods were used), as well as by the fact that many rich(er) people also tend to live in or near the historic (and densely built) city centre.

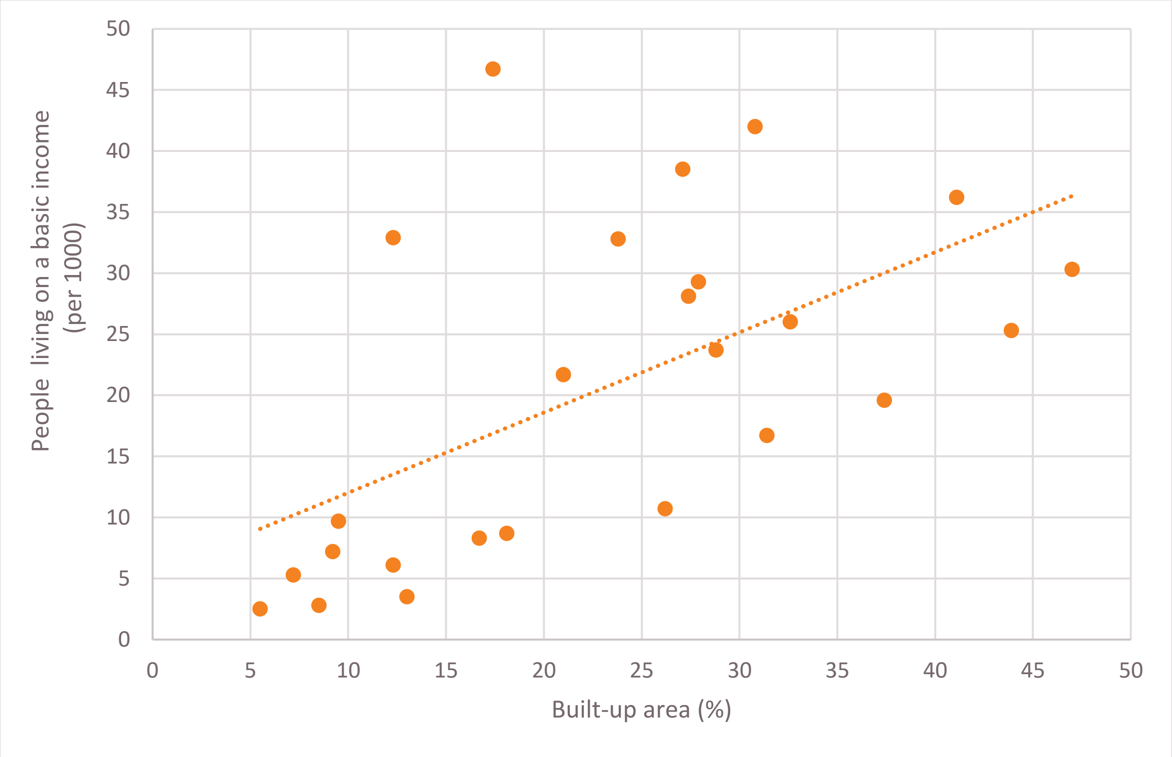


Figure 7-4. Relation between % built-up area and people per 1000 inhabitants living on a basic income, for the different neighbourhoods in Ghent.

In any case, the data seem to corroborate the information from Figure 7-3, and are in line with the findings of international studies. Since the physical and social structure of many cities in Belgium are comparable to the situation in Ghent, one can expect that the relations between socio-spatial vulnerability and climate impacts will be applicable on a wider scale within Belgium.

An interesting parameter at the level of Belgium as a whole, available from Eurostat, is the share of population living in a dwelling not comfortably cool during summertime. Figures are available per income quintile and for different degrees of urbanisation, and were obtained in a Europe-wide survey, carried out in 2012. In all countries of the EU (except Lithuania), households with an income in the bottom 20 % were less able to keep their homes cool during summer than the rest of the population.

Table 7-3 shows the figures for Belgium. From this table it is obvious that a) for all income groups, a higher proportion of houses is uncomfortably warm in summer in the cities than in the countryside and b) significantly more people from the bottom 20% of incomes live in houses that are too hot in summer than is the case for the upper 20%, especially those living in towns, suburbs and cities.

Table 7-3. Share of population living in a dwelling not comfortably cool during summertime by income quintile and degree of urbanisation in Belgium (Eurostat, 2019 – figures for 2012).

	1st quintile	**5th quintile**
Cities	26.3%	16.2%
Towns and suburbs	15.0%	7.6%
Rural areas	8.3%	5.5%

7.4. CLIMATE CHANGE IMPACTS ON THE FUTURE COST OF LIVING

Distributional variations of the effect of climate change on people by income and deprivation level have been investigated in the project ‘Climate Change Impacts on the Future Cost of Living’ (Watkiss et al., 2016). The aim of the study was to explore how climate change could affect the future costs of living in the UK at the household level. The results are presented for the near-term (2020s) and mid-century (2050s). Many of the findings of the study are expected to be relevant to the situation in Belgium. The study considered a broad range of impacts from climate change on households, including:

- Direct expenditures, e.g. changing temperatures and the impact on household energy-use;
- Indirect cost pathways, e.g. additional costs from the effects of flooding;
- International effects, e.g. climate change affecting global agriculture and thus UK food prices;
- Policy costs, e.g. from mitigation (greenhouse gas emission reduction) policy;
- Non-market costs, which affect people's quality of life and well-being (economic welfare).

One of the largest current household expenditure items in the UK is food (11% of average household expenditure), which is related to agricultural production: a highly climate sensitive sector. Based on the international literature review, and noting the indicative nature of the analysis, the results indicate minor effects in the short-term, but larger, although still modest effects on family budgets towards the middle of the century. The food bill for an average family in the UK could rise by 9% by 2050 due to climate change, assuming all other things being equal. Importantly, such an increase would have much greater impacts on low income households, because they spend a larger proportion of average household expenditure on food.

Climate change will also affect **energy demand**, which is also a major household expenditure item (at around 5% of average household expenditure in the UK). The potential benefits of reduced winter heating indicate a minor to modest saving by the 2050s. There would be disproportionately larger benefits for low income households from these changes, as they spend a higher proportion of their incomes on fuel (10%). With higher summer-time temperatures, there will also be an increase in cooling demand, i.e. a potential cost. In the UK, the increase in cooling demand is projected to be much lower than the reduction in winter heating demand (in energy terms), although cooling is more expensive than heating. While the reduction in heating bills (benefits) will largely happen automatically (autonomously), the additional cooling impacts will vary by household, with additional direct expenditures for high income households (due to higher projected purchase and use of air conditioning). On the other hand, low income households will experience higher economic welfare costs from the associated discomfort and health related impacts.

There are also **policy costs** associated with the UK's mitigation commitments that affect the energy sector and thus household energy costs. Climate change mitigation policies can potentially increase electricity and energy costs, but policies to encourage improvements in energy efficiency could lower household energy costs. Previous assessments in the UK have concluded that when these energy savings are included, the typical household energy bill will actually decrease overall (up to 2020) as a result of policies. However, low income households tend to be lower adopters of energy efficiency measures and benefit less from energy efficiency policies.

In terms of the effects of climate change on more general housing costs (e.g. insurance, maintenance, repair), the dominant effect is from the increase in flooding. When expressed as an average cost across the population, this only represents a minor increase in household costs, but in practice, floods could lead to large costs for a smaller number of affected households. This issue is particularly important if the frequency of flooding increases such as to affect property prices.

The other potentially important impact for households relates to the **costs of water**, which in the UK is around 2% of average household expenditure. However, the regulated nature of the UK's water sector means that any impacts of climate change on household costs are indirect and are expected to be low. Still, as the lowest income decile of households in the UK spends 2.9% of their budget on water supply services compared to 1.2% for the highest decile, the pass through of higher costs would impact more strongly on low income households.

Direct health costs are not a large direct expenditure item, but there are effects on household (economic) welfare resulting from the potential impacts of climate change on health. The key benefits (reduced economic welfare costs) are from warmer winters and the reduction in cold related mortality and morbidity – the main negative impacts (increased economic welfare costs) are from the increased mortality and morbidity from higher temperatures and heat extremes. Health effects also have strong distributional impacts on low income households, as heat and cold-related mortality/morbidity is primarily an issue for the elderly, those with existing health conditions, those with budget constraints that restrict their use of energy and those with access to low levels of social care.

A large number of **other direct and especially indirect costs** have been identified in the UK but were not included in the analysis. Some of these omissions are large (e.g. non-residential building and indirect costs of flooding has been estimated to lead to costs that are 5 – 6 times greater than from residential flooding alone), but it is difficult to assess how these will pass through to household costs, i.e. in terms of increased prices for goods and services, or wider employment and economic prospects.

Furthermore, there are a large number of **additional economic welfare costs** that will arise from climate change. These do not directly affect household expenditure, but have potentially very large costs (when expressed in monetary terms using non-market valuation), such as the impacts on biodiversity and ecosystem services.

The results are summarised below, indicating the impact on various components of a household budget in the UK, and highlighting where there are potentially larger impacts and distributional effects. A common finding is that low income households will face proportionately greater impacts, e.g. in relation to higher food prices and flood risks, though they will also benefit most from reduced heating demand. For some low-income households, even the modest changes expected in future decades could have important impacts on household budgets, especially under higher warming scenarios.

Note that the table mentions “lower insurance cover” as a distributional issue for low income households in case of floods. In Belgium, this should not be an issue, as insurance against flooding is compulsory. It is also not certain whether the statement that ‘there is a higher flood risk for deprived areas’ is true for Belgium.

Table 7-4. Potential direct impacts of climate change on household costs (2050) in the UK, for impacts considered in the study by Watkiss et al. (2016).

Expenditure item	Impact on average household cost*	Relative impact on individual households**	Distributional issues for low income households***
Food	-Modest to Substantial cost	-Average	-Yes (high), as spend higher % of expenditure on food
Energy	+Minor to modest benefit (heating) -Minor cost (cooling)	+/- Average	Yes (high) (+/-) for low income households
Water	-Negligible	-Average	-Yes (low) as higher % of expenditure
Housing costs-flooding	-Minor cost	-Very high	-Yes (very high), as higher flood risk for deprived areas and lower insurance cover
Housing cost - subsidence	-Negligible	-Very high	-Yes (medium) as potentially lower insurance cover

*The ranking of the average impact on household costs (negligible, minor, modest and major) is relative to the budgets that households must spend for a minimum acceptable living standard. Note this is relative to current household expenditures, not values in 2050.

**This considers the potential household costs on individual affected households (e.g. a household that is flooded) rather than for the average UK household (as above). The ranking considers the size of effects relative to average costs, and whether these are similar to the average or higher.

***This considers whether there are distributional effects on low income households, with a low, medium, high or very high ranking to reflect the size of the effect.

7.5. EFFECTS OF CLIMATE POLICIES

7.5.1. Distributional effects

As seen above, direct climate change impacts such as urban heat or floods can have a social component, in the sense that not all social groups are affected by it to the same degree. However, *policies* intended to combat climate change are not always socially neutral either. Policies can lead to a change in income, either direct (e.g. as result of taxes or subsidies) or indirect (e.g. when closure of activities in sectors with a high climate impact lead to loss of employment). Capital values can also be influenced by policy measures. Examples are changes in land values (as a result of changes in zoning regulations, for instance), changes in value of a house as a result of insufficient insulation, or changes in the value of financial assets if they are backed up by physical assets that lose value (e.g. fossil fuels). Moreover, the capital reserves of a household will limit the capacity of a household to react to those losses in value by investing in e.g. job training, insulation or an electric car.

The cost of specific climate policies will be borne to a higher degree by low-income households relative to high-income households (regressive policies), when the former stand to lose more (or gain less) compared to their income than the latter. This means that vulnerable social groups can be affected by climate change in more than one way: the impact may be direct, as a result of the physical impacts, but also indirect, as a result of the policies implemented to combat climate change. Note that income is but one discriminating factor; aspects such as gender, nationality, ethnicity and educational level (which are often correlated to some degree) can also play a role.

Zachman et al (2018) found that key climate policy tools such as carbon taxes for different fuels, certain mandatory standards, subsidies and regulatory tools, can be regressive. For instance, carbon pricing on electricity or heating has a regressive distributional impact, due to low-income households spending higher shares of their income on those expenses, and because of inelastic demand and credit constraints (e.g. because of a limited financial ability to replace old electric appliances with efficient ones). Subsidies on low-carbon technology are another example, as subsidies for e.g. building insulation, rooftop solar or electric vehicles tend to mainly go to higher income households. Lower income households often do not have the means to make the necessary upfront investment. For instance, it has been shown that in Flanders 58% of the total amount of fiscal subsidies for the installation of rooftop solar went to households in the highest tax bracket (> 40.000 €/y). The fact that green power certificates for rooftop solar were advanced by the electricity distributing companies and recuperated via the tariffs probably has had a regressive effect as well, as less well-off households tend to spend a higher proportion of their budget on energy.

In essence, as stated by Zachman et al. (2018), many low-carbon subsidies are regressive because they reduce the price of goods that are primarily bought by higher-income households.

Such undesirable distributional effects (real or perceived as such) may limit public acceptability of certain climate policy measures and therefore should be carefully considered when designing effective policy packages. In order to be successful, all societal groups should participate in efforts to combat climate change; to make this possible, social acceptance of measures is of prime importance, and no group of sectors should be made to feel that they have to shoulder an undue burden caused by the implementation of climate policies.

In this context, it is interesting to observe that low income households generally contribute less to greenhouse gas emissions than do higher income households. Zsuzsa Lévay et al. (2019) studied what they call the social distribution of greenhouse gas emissions for Belgium. They estimated the emissions for different income groups based on information on consumption patterns on one hand and emission coefficients (emissions per euro consumed) for different goods and services on the other. The emission coefficients took into account both direct and indirect emissions, meaning that the production chain upstream from the consumption was taken into account, including for products manufactured abroad.

On average, about 70% of emissions by Belgian households turned out to be indirect. Total per capita emissions were 9.4 ton CO_{2eq} on average. When looking at per capita consumption for different income groups, they found that households within the group with the highest consumption spending emitted almost four times as much greenhouse gases per capita as households within the group with the lowest consumption spending, and this despite the fact that the emission intensity (in CO_{2eq} per euro spent by a given household) was higher for the latter group than for the former. This is due to the fact that low-income households spend a (much) higher proportion of their budget on food and housing, both categories with a rather high emission coefficient for greenhouse gases.

7.5.2. Impacts on employment

Climate change is expected to lead to economic damage and hence to (relative) loss of employment opportunities, and would affect the less well-off parts of society more than the richer parts. So, there is no dispute about the need for action on climate change, despite the potentially regressive effects of certain policy choices, as detailed above. Overall, the potential economic and employment impacts of the necessary transformation and transition initiated by climate change (with a ‘deep decarbonisation‘ ambition in the EU) are expected to be positive, as these transformations will require significant additional investment in all sectors of the economy (Eurofound, 2019a) and will liberate funds now used for importing fossil energy carriers. Obviously, figures for GDP and employment do not tell the whole story, and might hide inequalities.

The new draft law recently (May 2020) presented by the Spanish government, which aims to cut the country’s carbon emissions to net zero by 2050 is forecasted to generate more than €200,000 million of investments in the next decade, create up to 350,000 new jobs, and boost the country’s economic growth by 1.8% by 2030, compared with business as usual[1].

A study by the European commission[2] has estimated the EU-wide employment impacts of **long-term** climate change scenarios using macroeconomic models. In terms of total employment in 2050, a 1.5°C scenario (implying net zero emissions in the EU by 2050, or a 94% reduction in emissions) points to potential gains of 0.6% to 0.9%, or about 1.5 to 2 million jobs, compared to the expected baseline evolution. Job gains are expected in construction, agriculture, forestry and renewable energy sectors, but could be partly offset by a contraction in sectors such as fossil fuel-related mining and quarrying. In absolute terms, agriculture, forestry and construction combined could add up to 2.4 million jobs to their baseline levels. The power sector could gain up to 250,000 jobs. In relative terms, some of the biggest expected winners are power generation and agriculture, with almost 25% of job gains in electricity supply. The biggest job-losing sectors in relative terms are fossil fuel extractive industries, which could experience a loss of up to 60% of their jobs. This obviously is not relevant for the Belgian situation. Even at a European level the impact on employment in the mining and extraction sector would be limited though, as the share of total jobs in the EU in 2015 was only 0.5%.

Employment gains in agriculture and forestry are explained by a higher biomass demand, while gains in the power sector are driven by increased electrification of the economy, and by the fact that renewable energy deployment has a higher labour intensity (related to installation, management, and maintenance) compared to power generation from fossil fuels. The positive employment developments in construction result from a predicted investment hike driven by the increased demand for energy-efficient structures. Results are more mixed in the manufacturing industries. These sectors, particularly the energy intensive sectors, will face significant changes in their production processes in the future due to the transition towards a low-carbon economy. This evolution is significant for the Belgian situation, where e.g. the petrochemical sector is an important employer (both direct and indirect). If successful, this transition should not be negative for employment. Particularly the circular economy is often associated with job increases in the value chain, and this could well be the case in Belgium.

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[1] https://www.climatechangenews.com/2020/05/18/spain-unveils-climate-law-cut-emissions-net-zero-2050/

[2] In-depth analysis in support of the Communication “A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy” (2018)

The same study finds that the impact of decarbonisation (implying net-zero emissions in 2050) on GDP will be limited. It projects a deviation from the baseline for GDP in 2050 between −0,28% and +2,19%, depending on the model used and the assumptions made. It should be noted that, as baseline GDP evolutions are positive, (small) negative effects of decarbonisation on GDP in 2050 do not mean an absolute decline in growth, but rather a (slightly) smaller cumulative growth. Evidently, individual sectors may be affected in ways that differ from the impact on GDP, with for instance important output declines (relative to the baseline) for fossil-fuel industries and a positive impact on electricity supply.

The study mentions social impacts related to the increasing energy costs for households in the short and medium term. Up to 2030, energy-related expenses (including fuel costs and energy equipment expenditure) per household are expected to increase significantly in absolute terms. In 2030, on average, every household is expected to spend for energy services ER 570 € per year more than in 2015 (at 2013 prices). This corresponds to a 21% increase. Households with financial means and available options will be in the position to offset higher energy costs investing in energy efficiency and renewable energy. Other households might not have this opportunity and this category includes low-income households that are more exposed to energy poverty

Short to medium term impacts (2030) of climate policies and energy transition have been studied by the Future of Manufacturing in Europe (FOME) pilot project (Eurofound, 2019b) in their "energy scenario". Macroeconomic modelling of the implementation of the Paris Climate Agreement estimates that GDP in the EU will increase by 1.1% and employment by 0.5% up to 2030. Manufacturing employment is projected to increase by 0.7%. This amounts to an additional 1.2 million jobs in the EU by 2030.

According to the authors, the modelled positive impact on GDP and employment is largely due to the investment activity required to achieve such a transition, together with the impact of lower spending on the import of fossil fuels. Furthermore, lower consumer prices, notably of solar photovoltaic electricity, boost disposable incomes, consumer expenditure and consequently the demand for consumer services, which are generally labour intensive.

The employment impacts of climate action policies would be positive and substantial in Belgium. The FOME report estimates an additional gain of almost 1% in employment (60.000 jobs) and of more than 2% in GDP, both compared to the baseline scenario and in the year 2030. Climact (2016) found a 2% growth in GDP, an increase with 0.27% of household's net disposable income (as a result of extra job creation and energy savings) and an increase in employment of 1,6% (81,000 jobs). All figures from the Climact study are for 2030 and for the so-called Core Low Carbon scenario[1], relative to the reference scenario. The energy sector in Belgium would lose about 3000 jobs by 2030[2] (compared to the reference), but all other sectors would see an increase, most notably in construction (27,000 extra jobs) and 'other market services' (40,000 extra jobs). As construction is typically labour intensive, the share of the construction sector in job creation (especially for retrofitting of buildings) is comparatively higher than its share in greenhouse gas emission reductions.

Future job creation (not taking into account climate change) is expected to increase job polarization at a European level overall, as it will be driven by digitalization and further integration in global production networks and value chains. Yet job creation due to climate change policies, albeit smaller in volume, is expected to mitigate these tendencies by adding middle-skilled, middle-paying jobs, notably in the construction sector, in industry and in services sectors. Overall, much of the expected employment creation as a result of climate change policies is found at the bottom and the middle of the wage distribution. These jobs will be filled by employees with lower levels of education performing

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[1] A scenario that balances the efforts across the emitting sectors and the type of measures and actions (behavioural vs technological) and assumes the implementation of a global carbon price combined with a specific assumption on the use of public revenues, in the context of a coordinated international policy. It assumes a 46% reduction in greenhouse gas reductions in Belgium by 2030, compared to 1990.

[2] The net result of more jobs in the sector of renewable energy but job losses in gas power generation and in the oil and gas refining industry.

less complex tasks, to a greater extent than in the baseline forecast.

Nevertheless, this will involve shifting of employment among activity sectors, which may cause social friction in the short term and will require efforts in terms of education and training. In Belgium, shifting jobs between sectors as a result of the transition to a more carbon-free economy is expected to concern only about 0.5% of jobs[1].

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[1] Montt et al., cited in the contribution of Yelter Bollen, Bert De Wel & Vanya Verschoore to the book "Klimaat en sociale rechtvaardigheid" of Denktank Minerva.

8. CASE STUDIES

In this section we gauge the reality of three sectors in more detail by collecting information from actors working in their own field. This work is not intended to be holistic in terms of the sectors covered but aims to focus a little closer to a few of them. We have chosen the sectors of Belgian beer production, Belgian fries production, and that of office labour. The first two are highly iconic and the last one covers the majority of employees in Belgium (Statbel, 2017).

8.1. FRENCH FRIES INDUSTRY

8.1.1. Context and Belgian market

Specific studies on the potato and French fries industry were confronted and completed by an interview with Julien Populin, Environmental Manager of Lutosa's plant in Leuze.

88% of Belgians consume fries at least once a week (Filagri, n.d.). The average Belgian consumes around 16 kg per year, making this country the largest consumer of frozen French fries in the world (SoSoir, 2019). Worldwide, the consumption of fries is rising sharply. Since 2011, Belgium became the largest exporter of pre-cooked frozen potato products, and keeps growing. In 2019, our country processes more than 5 million tons of potatoes, 2.23 million of which are used for fries. Although consumption is stagnating in our country, the Belgian fries are increasingly sold internationally to more than 150 countries, thanks partly to advertising campaigns abroad, making 'Belgian fries' one of our flagship specialities, just like beer or chocolate (Belgapom, 2015, 2019, 2020; Duquesne et al., 2006).

Some key facts for the Belgian potato marked in 2018 (Belgapom, n.d.) :

- The number of employees in the potato processing sector increased from 1900 to 4700 between 1998 and 2018 with a steady 3% growth rate per year. Investment in this sector is also increasing, with a new record of 315 € million in 2018.
- The area under potato cultivation is 90,000 ha in 2016 (6.6% of agricultural land), an increase of 9% compared to 2010.
- More than 50% of production is exported, with 75% of exports going to the EU-28 area, with France, the Netherlands, the United Kingdom, Spain and Germany leading the way (Poncelet et al., 2014).
- Some of the major players in Belgian potato processing: Lutosa, Mydibel, Roger & Roger, Agristo, Ecofrost, Clarebout, Pinguin, d'Arta and Westfro.
- The most produced potato variety for fries are the Bintje, and the Fontane (Belgapom, n.d.).

The market is segmented into two product categories (Filagri, n.d.):

- Pre-cut, pre-cooked and frozen fries: produced in large quantities, they are stored at -18°C and are cheap (80 - 85% of the market).
- Fresh French fries: more expensive, these 'homemade' fries are usually cut and processed at the place of consumption itself (15-20% of the market).

8.1.2. Ingredients and energy used

Main ingredients and energy flows to produce frozen French fries are the following:

- Water for the washing process and steam production
- Oil: Sunflower oil, rapeseed oil …
- Natural gas needed to produce heat: steam network and thermal oil network for the fryer
- Electricity consumption essentially consumed for storage and deep-freezing the French fries coming out of the frying process from 175°C to -18°C (Couturier, 2013).

Residual waste can be used in animal feed (especially peelings), transformed into flakes, used as natural fertilizer for soil fertilization or finally, but less common, into biogas (Jeannequin et al., n.d.; Lutosa, n.d.).

8.1.3. Vulnerability of consumption to climate change

The impact of extreme climate events on production inevitably has an impact on consumption. Thus, following the drought of 2018, the price of French fries increased by 23% for chip shops in France, while the quality of the fries decreased, de facto increasing the purchase price and reducing the affordability not only of French fries, but also of a starchy food at the base of the food pyramid (Labye, 2018). On the contrary of beer, consumption patterns of French fries do not follow temperature correlations (J. Populin, personal communication, 13 May 2020).

8.1.4. Vulnerability of production to climate change

Impact on the potato growth and production

The impact of hydric stress on potato cultivation (5.9% of agricultural area in Wallonia, see Section 3) during the potato growth season (July to September) is the main concern for the French fries industry, affecting the whole value chain.

The sensitivity of the different varieties to drought makes it possible, on the basis of the heat wave of 2018, to predict the consequences in the future of a repetition of this type of event: potatoes size and dry-matter content were reduced (the two main quality criteria in the potato production industry). A dry weather spell during September/October 2019 also affected potato grubbing process by damaging them (J. Populin, personal communication, 13 May 2020). Those factors led to an average drop of 31% in production volume in Belgium compared to 2017 (Eurostat, 2019); some of the potato transformation plants even saw a drop of about 40% in volume. This supply decrease has been seen in the whole of Europe, limiting the importation possibilities for French fries production (J. Populin, personal communication, 13 May 2020).

Rising demand on starchy food provided a boom to the French fries industry, limited nowadays on the potato volumes rather than the infrastructure. Farmers are slowly adapting their land use from sugar beet towards potatoes, which would put the sugar beet industry under pressure as well. Some farmers subcontract their production in France, concurrencing the French industry supply (J. Populin, personal communication, 13 May 2020).

As a consequence of the above phenomena, the price in 2018 saw an 23% increase on the 5 kg bag (AFP, 2018). The difficult conditions of the season affect the quality of the seed potatoes, which then affect the following season (Belgapom, 2020).

The whole potato industry reacted by adopting a new variety of potato: the market made a shift from the Bintje variety in 2018 (about 80% of market) towards the Fontane variety with similar proportion in 2019. The reason is that the Fontane variety has a better resistance to heat and water shortage. In the long run however, it is uncertain whether potato varieties could solve water stresses alone (J. Populin, personal communication, 13 May 2020).

With respect to water availability, the impact of global warming will influence the irrigation demand for potato crops. For example, water needs for potatoes are expected to increase by 14 to 30% in England, where the current irrigation network will exceed its capacity by 50% for the 2050s (Daccache et al., 2011). Globally, the expected world decrease in yield is 18% (RCP2.1) to 32% (RCP3.2) if the current production model and farming techniques are not adapted (Hijmans, 2003).

In Belgium, irrigated agricultural land in 2016 reached only 0.8% (Eurostat, data 2016; also see Section 3). This low percentage is due to general sufficient precipitation, lack of underground/ surface water availability and extra costs needed in irrigation infrastructure (Berbel et al., 2007; Dirksen, 2002; Wriedt et al., 2009). Regional disparities in the hydrological basins in Flanders and in Wallonia are worth mentioning since Walloon farmers have way more water pumping potential (J. Populin, personal communication, 13 May 2020). Water management and pricing policies are under regional control in Belgium; agricultural charges depend on the source. Farmers using tap water pay the same as households, while farmers using underground or surface water pay a levy on declared volumes (Berbel et al., 2007)

In France, The National Union of Potato Producers (NUPT) underlines a substantial difference between irrigated and non-irrigated potato yields, with a 13 ton/ha production difference, providing more stability in yields over the years (Guyomard, 2018). Sustained potato yields in irrigated fields will accelerate irrigation practices in Belgium even more if summer rainfall deficit up to 10.3% is expected by the end of the century (see Section 2 regarding precipitation).

Impact on the French fries transformation process and conservation

With respect to the fries' production process, smaller potatoes and smaller potato volume produced rise concern on the French fries quality, with an increase of black spots and poorly cut fries, which are the main criteria for quality of French fries (even before the taste), rending the transformation process more difficult (J. Populin, personal communication, 13 May 2020). This forced some frozen fryers to invest in salt baths at the reception of the potatoes (AFP, 2018).

Concerning water consumption, a general rule of thumbs says that 1 kg of French fries needs about 5 litres of potable water, this ratio being lowered to 4 litres of water per kg if a reverse osmosis ultrafiltration water treatment facility is installed. This means that a 400 000 tons/year production facility would need 16 000 000 hl per year potable water at least. The Lutosa plant in Leuze uses well water for their needs, which slowly lowers the water table level. This is a concern in the long-term future (J. Populin, personal communication, 13 May 2020).

Concerning storage, the lack of water for the 2018 crop also affected potatoes' conservation along with the risk of rot spots (Labye, 2018); this impact is different from variety to variety. The potato storage and pre-washing is made by the farmers in a growing proportion; some of them use fridges with cold group while others rely solely on ventilation, temperature control and juice drain (J. Populin, personal communication, 13 May 2020).

After the transformation process, potatoes need to be cooled from the 175 °C fryer in a freezing tunnel which brings them at -18 °C in a matter of minutes. This process, along with maintaining the fries storage at -18 °C are using up about one third of the electricity consumption on site. The cold production will see a bigger consumption following the cooling degree-days trend, as well as a need for more cold infrastructure capacity (compressors) in order to maintain stable temperatures despite the growing number of heatwaves.

8.1.5. Conclusion of climate change's impacts on the French fries sector

The table below summarizes the above-mentioned threats in the French fries industry due to climate change impacts, without adaptation.

Table 8-1. Overview of the impacts of climate change on the potato transformation sector.

Process/ ingredient	Physical impact of climate change	Consequences for French fries producers
Potato	Water stress and impact of heat on potato growth	Impact on quantity: -31% of production in 2018 Impact on quality: smaller size, lack of starch and dry matter content, losses in conservation Extra investment in irrigation facilities (when possible)
Process	Smaller potato size and smaller percentage of dry matter	Extra investment in salt baths Use of different potato varieties Impact on final quality product
	Higher energy consumption to cool French fries due to summer heatwave days	Extra cooling facilities & energy consumption
Storage	Smaller potato size and smaller percentage of dry matter	Extra storage cooling facilities & energy consumption

The transformation process and storage (both of potatoes and French fries) will need more cooling to address the rising number of extreme temperatures in the summer, increasing energy costs during peak demand period (hottest days when everyone puts the air-conditioning on).

Water demand for agriculture will rise in order to maintain potato yields. This trend will increase the pressure on water needs during heatwaves, especially in Flanders where there are less well water reserves.

The 2018 season has seen a 31% reduction in French fries production volume and a 23% price increase of potatoes for the chip shops. If we take as hypothesis a no-growth market without adaptation actions being taken in the future, given the price increase on potatoes and extra investment in storage cooling, a 31% reduction on the turnover on the long run could be a conservative extrapolation.

8.2. BREWING INDUSTRY

8.2.1. Context and Belgian market

In order to complete this study research on the micro-level analysis, two interviews with Belgian breweries were held:

- Damien Jacques, production director of the Lupulus brewery (in the Luxemburg region): a growing special beer brewery, producing about 19,500 hectolitres per year (Guiet, 2018).
- Jean-Pierre Van Roy, owner and brewer of the Cantillon brewery (in Brussels): a family owned small brewery (2,500 hectolitres/year) specialized since 1900 in lambics i.e. airborne yeast and bacteria beer fermenting. This traditional way of brewing is unique but by no mean representative in the beer production market.

The average Belgian consumes 88 litres of beer a year, and as such is in 7th place in the world on the podium of the most beer-drinking countries (Xie et al., 2018). The Belgian market is characterised by a contrast between craft and industrial beers: on the one hand the market is dominated by AB InBev, with a 26.9% (in 2017) market share worldwide (Lauwers, 2018), and on the other hand by a myriad of (small) breweries; the number of breweries has doubled since 2010, even though domestic consumption is falling. This evolution is explained by the decrease in the consumption of pils (about

70% of the market) (TerraBrew Association, 2016), with Belgians preferring to turn to special/craft beers, with a stronger taste and a higher alcohol content (Moray, 2016).

Some key figures on the economic weight of breweries in Belgium in 2018 (Belgian Brewers, 2019):

- The brewing sector accounts for approximately 4 B€ in turnover, or 1% of Belgian GDP. 304 breweries, employing 6225 people (breweries only), and producing more than 1500 different beers. 251 M€ are invested by the sector during the year.
- Of the 23.2 million hectolitres produced in Belgium, domestic consumption amounts to 7 million hectolitres (about 30% of production), a slight and steady decrease of 1.21%/year over the last thirty years in domestic consumption (12.9 million hectolitres in 1980). This decrease can be explained by a tendency to consume less but better-quality beer.
- Belgium is the world's largest beer exporter, with 16.2 million hectolitres (70% remaining), and accounts for 35% of beer exported outside the EU. Belgian exports have been rising sharply since the 1980s (2.3 million hectolitres in 1980).

8.2.2. Ingredients & manufacturing steps

The main ingredients of beer are, in order: water (90%), malt, hops and yeast (Simard, 2001; Sunier, 2007; Univers Bière, n.d.):

- Water: the mineral composition of the water and the pH have an impact on the taste of the beer. The role of water as a solvent enables the malt and hops to release their sugars and aromas.
- Malt: mainly derived from 2-row summer barley grains and several other grains such as wheat, rye, maize…, it is the main source of energy to obtain a nutritious and alcoholic product. Barley is first transformed into malt after a germination and drying phase. The selection of the barley grains depends on the size of the grain, the moisture content, the sugar and protein content, etc.
- Hops: in September, the flowers are harvested after flowering to be dried and packed in bales and vacuum-packed. Hops replaced the use of spices (cinnamon, nutmeg, ginger) from the 8th century in Central Europe. Hops compensate for the flavour of the malt, while at the same time being a natural preservative for the long-term storage of beer. Hops are classified according to 5 different varieties: spicy, minty, resinous, floral and citrus.
- Yeasts: Microscopic fungi, brewer's yeasts are grouped into about 40 different types, that are responsible of the fermentation of beer, i.e. transform sugars into alcohol and carbon dioxide.

Three types of fermentation (Simard, 2001; Sunier, 2007; Univers Bière, n.d.): by adding yeasts, this stage produces the alcohol. There are three main processes:

- Bottom fermentation lasts about ten days, at a temperature between 5 and 14°C (types of beer concerned: lagers).
- Top fermentation lasts between 4 and 8 days, at a temperature between 15 and 20°C (types of beer concerned: ales).
- Spontaneous fermentation takes place without the addition of cultivated yeast, only by contamination of airborne yeasts and bacteria (types of beers concerned: lambics).

Fermentation is usually followed by clarification to remove yeasts and impurities. Industrial beers also go through a pasteurization process to ensure an aseptic and stable product.

8.2.3. Vulnerability of consumption to climate change

Beer is a weather-sensitive beverage. The demand for beer will be determined by two factors:

1. It was observed in France that above 25°C, each additional degree leads to consumption increase from 5% to 7% of the sales volume (Casteele, 2019). Since most beers consumed are then refrigerated, this leads to an increase in energy consumption during heatwaves, when the demand for refrigeration in buildings is already at its highest.

2. Warm weather beers are usually light-bodied, with citrus or fruity flavour, floral hops, etc…, which are usually low in alcohol, such as White Ales and lagers. Following the climate trend, the market share of strong beers (e.g. trappists) might be gradually reduced for lighter beers with the increasing number of hot days (D. Jacques, personal communication, 12 May 2020; Rulková, 2019).

8.2.4. Vulnerability of production to climate change

Impact on the ingredients

Among the different impacts of climate change on the ingredients, droughts, heatwaves and summer rainfall deficit are the most critical. Below, we consider the impact of these aspects on the production process, considering barley, hops, yeast and water.

Since 97.53% of barley comes from imports, it is interesting to look at what this dependency implies. A study by Xie et al. (2018) shows that barley production is significantly reduced during drought periods: the probability of extreme climatic events (drought and heat waves) during barley-growing season and in barley-growing regions worldwide, would increase from 3.8% (RCP2.6) to 30.9% (RCP8.5) by 2050, leading to an average world loss in barley production estimated at between 3% (RCP2.6) to 17% (RCP8.5), with unchanged parameters (no adaptation). Locally, the supply decrease is the sharpest for Belgium, Czech Republic and Germany, with 27% to 38% of loss (under RCP8.5): it emerges that, because of its dependence on barley imports, Belgium will be heavily impacted by extreme climatic events. The beer production could therefore fall by about 10% (RCP2.6) to 40% (RCP8.5), as shown on Figure 8-1 because of barley shortage (Xie et al., 2018). Another trend might be a lowering of alcohol content in beer as a result of barley decrease in brewing.

As a result of the malt production from quality barley lowering, the beer might gradually become a luxe product: The average price for 500 ml of beer today on the markets in Belgium is 1.32 € (Numbeo.com, 2019); this price could see an increase of 195% by 2050 (RCP8.5), considering only the sensitivity of barley production (Xie et al., 2018).

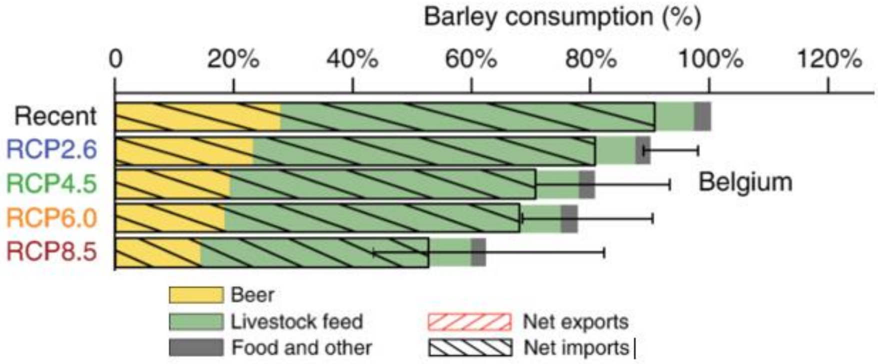

Figure 8-1. Barley consumption by type (beer, livestock and feed), as well as the share imported in hatching. The different models, for RCP2.6 to RCP8.5 by 2099 are compared with the recent situation (2010), without mitigation actions. Dashes represent percentiles (Xie et al., 2018).

The major uses of barley are malting barley (two row barley, containing more sugar) and forage barley (six row barley, containing more proteins); the first one needs to respect strict quality parameters (high germination rate, low vomitoxin content, low protein rate, low humidity rate …) (Rivard, 2010):

- Germination rate > 95 % is needed for the fermentation process.
- Vomitoxin is a fungus resulting of the fusarium disease. A high Vomitoxin rate (> 0.5 ppm) is caused by a dry summer followed by a wet autumn (harvest period) (D. Jacques, personal communication, 12 May 2020). Should the vomitoxin be too high, it would ruin the production by causing gushing at the opening of the beer: a strong overpressure and over foaming due to CO_2 particles.

- The protein rate has to be low (< 12.5%) otherwise the beer would have lumps and need extra filtration process (D. Jacques, personal communication, 12 May 2020).
- Low humidity rate < 14 % for conservation.

If those parameters are not fulfilled, malting barley is declassified and sold as forage barley, which usually contains more protein destined to livestock. However, forage barley cannot be sold as malting barley because of its high protein content. As a consequence of the quality conditions needed for malting barley, malt prices are rising and could explode in the future (D. Jacques, personal communication, 12 May 2020). As a mitigation strategy, other cereals could be used instead of barley (wheat, oat, maize…) but it would affect beer taste and quality (D. Jacques, personal communication, 12 May 2020).

Although no study showing the effect of climate change on the yield of hops (*Humulus Lupus*) was found for Belgium, its impact has been studied in a European country evolving under the same latitude, The Czech Republic. The impact of climate change on hops were estimated at 7.2% (SRES-scenario B1, 2051-2100) up to 10.5% (SRES-scenario A2, 2051-2100) of production in the Czech Republic as well as a decrease in alpha acid by 13-32%, which determines the quality of hops (Mozny et al., 2009). Alpha acids bring bitterness to beer; the alpha acid reduction (due to dry weather) could be mitigated by adding more hop.

Some hops much in fashion are sometimes out of stock which impact the recipes. Hop is also a crop that is genetically close thus quite vulnerable to diseases, which is a risk on the availability. Origin of harvest of hop give different flavours on beer taste, which is less the case for barley (D. Jacques, personal communication, 12 May 2020).

Yeasts present few vulnerabilities related to climate change, because of its small volume used compared to the other ingredients, and the controlled yeast growth process (D. Jacques, personal communication, 12 May 2020).

In addition to a fundamental impact on the taste of beer, the availability of drinking water for the production of beer might become an issue; in fact, 4.5 litres of water are consumed per litre of beer produced (Belgian Brewers, 2019), with big difference according to the brewer size: AB Inbev uses 3.1 litre of water per litre of beer, while craft breweries use around 6 litres or more (biernet.nl). Water quality is determined by the minerals contained and its pH (D. Jacques, personal communication, 12 May 2020).

Cantillon brewery is using tap water in Brussels for its production and did not face any problem with water shortage or quality. The sole issue encountered is the calcarization of heat exchangers which need bi-seasonal maintenance cleaning (J.-P. Van Roy, personal communication, 14 May 2020).

Lupulus brewery on the other hand, ensures constant properties of water using well water in order to avoid the local variability in pH and mineral contents from the distribution water brought from different sources (which is exceptional), which would affect the brewing and beer taste. The water variability could also be dealt with using reverse osmosis, which are costly equipments that could be used in bigger industries (D. Jacques, personal communication, 12 May 2020).

Climate change already affects water quality: by drought, filters get dirty if the rate of flow is high; they prevent this from happening with a buffer tank. On the long run, extra filters or investing in a deeper well might be needed (D. Jacques, personal communication, 12 May 2020). This risk might increase in the future: a summer rainfall deficit is expected by the end of the century (up to 10.3%, see Section 2 regarding precipitations), which will lead to a seasonal water stress situation.

Impact on the brewing process and storage

The brewing process needs a lot of cooling capacity before the fermentation process in order to rapidly cool beer; the electricity consumption and chilling power will rise due to higher summer temperature. In small breweries the cooling is usually done using water.

Beer is best stored in a fresh place (e.g. a cellar), to slow down the oxidization of beer, which affect the taste (Brewers journal, 2019). Due to summer extreme temperatures, a potential need towards air conditioning in such storage might arise in the long-term future (D. Jacques, personal communication, 12 May 2020).

The exception of Lambic brewers

For Lambic brewers changes in temperature have an impact on two important levels: the potential number of brewing days (thus the production capacity) and the storage of the Lambic which has been brewed for the past years.

At the Cantillon brewery, due to climate change, the potential number of brewing days went down from 165 in the beginning of the twentieth century towards 140 nowadays , gradually reducing the production season (Boffey, 2018).

The storage of lambic is made in wooden barrels where the fermentation could continue during the warm months. An incident linked with heatwaves affecting beer quality happened in 2003 by a combination of two factors : 1. an exceptionally hot period from April throughout the summer; 2. a change in barrels size that year, which influence the oxidization of lambic beer as well (J.-P. Van Roy, personal communication, 14 May 2020).

8.2.5. Conclusion of climate change's impacts on the brewing sector

The following table provides an overview of the different climate change consequences, thanks to a sectoral literature review and interviews.

Table 8-2. overview of the impacts of climate change and their consequences on the beer sector.

Process/ ingredient	Physical impact of climate change	Consequences for breweries
Malting barley	27% to 38% of yield loss (RCP8.5, 2050, no mitigation)	Beer production reduced by 40% Use of barley substitutes → impact on quality
Hop	Lower yield, lower alpha-acid content	Rise in hop volume bought & Impact of beer quality
	Supply shortage	Impact on beer quantity
Yeast	(not significant)	/
Water	Impact on availability and quality	Extra investment in deeper wells, filters or reverse osmosis infrastructures Impact on quality
Process	Higher energy consumption to cool down beer	Extra cooling facilities & energy consumption
	For lambic production: lowering of brewing days	For lambic production: loss of production potential → impact on beer quantity
Storage	High temperatures accelerate the oxidization of beer	Extra cooling facilities & energy consumption Impact on quality

As a consequence of the different risks exposed, we will see an increase in beer prices and fall of production of 40% by 2050 already (Xie et al., 2018) on a 23.2 million hectolitres production per year (Belgian Brewers, 2019), as well as supply shortage because of Belgium's dependence on malt barley imports. Without mitigation, the trend towards less but better quality-beer already observed today will be fostered by increasingly costly ingredients (malt barley, hops) and infrastructure need (filtering, extra cooling, cooled storage areas). Beer might become a luxe product, seeing the market share of pils (~70%) slowly reduced. Consumers will also appreciate lighter beer during hot days, that will be rising.

Climate change may also affect cultural heritage. The traditional lambic beer production was the unique way to brew since ancient times until the early twentieth century. The loss of the few traditional lambic brewers left in the Belgian brewing landscape today as a result of climate change has little economical weight, but would certainly put a blow to our unique beer cultural heritage and ancestral expertise.

8.3. OFFICE WORK

This case study on the Brussels-Capital Region (BCR) is based on the available literature and data and on a series of interviews of actors. The interviews have been conducted in order to challenge the existing literature with real cases.

Labour productivity in offices has been studied under various angles and presented in Sections 3.2 and 6.3 of this report. However, a few more technical informations are required in order for the reader to understand what follows.

According to the meteorological definition (in contrast to the definition used for health purposes, see Section 2), a heatwave is a period of 5 consecutive days of maximum daily temperature above 25°C with at least 3 days above 30°C (météobelgique.be). The weather condition for a heatwave to occur in Belgium are such that a high-pressure system remains in place bringing hot air from the South and a clear sky conditions that allows maximal radiation (météobelgique.be). Heat island effect in cities worsens the heat conditions both during days and nights.

The interviews were conducted with a range of people working in offices in the region of Brussels or to its close proximity. The sampled people worked in different type of buildings in terms of architecture, build year and temperature regulating system. Both the private and the public sectors are included.

The focused period for the interviews was the summer of 2019 where Belgium experienced three heat waves in June, July and August of respectively 5, 8 and 6 days. The 24th and 25th of July 2019 reached a new maximum recorded temperature above 40°C across the whole country (meteobelgique.be, n.d.). This summer 2019 was the most remembered in people's mind.

Table 8-3. Summary of interviews of office workers in Brussels regarding their experience of the heatwaves of the summer 2019.

INSTITUTION	BUILDING TYPE	LOCATION	HEAT CONTROL	EXPERIENCE
ING central Bank	old building	Mérode	climatisation	bad
Ideal Standart	old building	Zaventem	climatisation	very bad
PWC	glass	Zaventem	climatisation	good
Proximus	glass tower	Brussels Nord	climatisation	good
Actiris	passive tower	Madou	climatisation	good
Actiris	old building	18 communes of Brussels	ventilation/ climatisation	good/ bad/ very bad

Heat above a certain threshold ranging from 20 to 25°C undermines productivity which is in line with the literature cited before. Offices equipped with top of the range temperature regulating systems generally record little felt labour productivity losses during heat waves. In this case, labour productivity can drop in case of home working because conditions are less favourable at home. It is worth considering that air conditioning in time of heat wave is not ideal and can lead to side effects such as airways irritation, brow bronchial infections, allergies, getting a cold, sore neck, and temperature shock entering or leaving the building. Those effects are due to the drying of the air (in the process of cooling), the amount of cooling, and the ventilation required to homogenise temperature in a room. Those effects are therefore proportionate to the outside temperature but also to the amount of solar radiation that a building receive, which depends on building architecture and will be highest with uncoated glass facade.

Unfortunately, not all office buildings are equipped with efficient temperature regulating systems and a number of them are ill suited to important thermal and radiation stresses that typically occur during heat waves. In those buildings, there are no outdoor blinds, or active cooling systems. In that case the ventilation (active and passive) is not sufficient in maintaining a comfortable working environment so that labour productivity can drop to a felt 50% because of a range of issues. These issues are the heat, the lack of oxygen, the disturbance from improvised measures, the search by employees for a more comfortable working spot in the building, the allergies that arise from portable cooling and ventilation devices, a strict dress codes, and the exposition to direct radiation (sunny windows). In these types of buildings, home working can be an option thanks to the lack of dress code and the possibility of cooling showers. In some buildings, the conditions are just impractical that employers need to temporally close them as a last resort meaning a 100% loss of productivity (if home working is not adequate or bears the same exposure to heat).

These findings of high ratios of possible productivity loss (50% -100%) contrast with the numbers found for a “typical office building in Antwerp” studied in Hooyberghs et al. (2017) that give 5%, 7% and 16% of productivity loss for the time horizons of 2013, 2050 and 2100.

The bigger the company or the public organization, the better prepared they are able to cope with heatwaves situations. This seems to arise from wider range of strategies at hand. Indeed, large organizations have more control over the level of comfort of their buildings, they can have prevention teams in place, and can benefit from multiple sites where to move their staff.

Office buildings that are not climate resilient for excess heat and solar radiation will experience loss of productivity in a linear manor with each degree of warming (2% loss per °C of warming above 20°C and until 35°C, Seppanen et al., 2004) until reaching a point where the building has to be closed in accordance with social laws (emploi.belgique.be).

According to Wouters et al., 2017 (see Section 2), the number of heatwave days in urban areas where offices are located are 5.1 now, 6.4 to 41.5 per year by mid-century. for the respective RCP2.6 and RCP8.5 scenarios. Since there is no sign of inflection of the global CO_2 emission curve (see scripps.ucsd.edu), we must choose the scenario closest to BAU, namely the RCP8.5. This gives us 5.1, and 41.5 as number of heatwave days per year today, by mid-century.

The mean rate of office stock renewal over the past two decades in the BCR is 1% (see Figure 8-2), the present stock being 12,669,163 m^2 (perspective.brussels, 2019). This means a 30% renewal rate by 2050 and a 70% renewal rate by 2100. Given that 55% of the office park is older than 30 years, we make the assumption that this represents the fraction that needs to be renovated in order to efficiently cope with heatwaves. This gives us a share of 55%, 25% and 0% of ill-adapted buildings by the year 2020, 2050 and 2100.

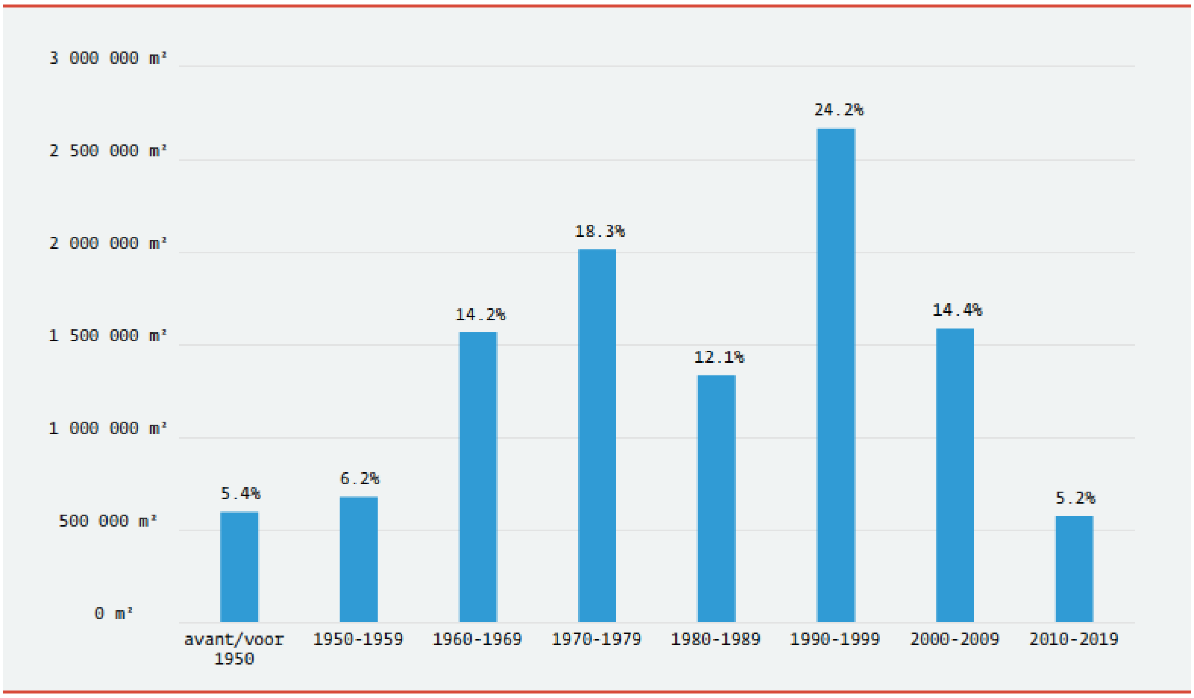

Figure 8-2. Decadal construction of office buildings (< 1000 m^2). Source: Perspective.brussels, 2019.

If we take the conservative numbers of office workers from the insurance & credit and the public administration sectors in BCR, these add to 33% of the workforce in Brussels or 232,000 employees (Michiels, 2015). The Belgian hourly average employer cost is 39.7 € (CSE, 2019). This conservative rate – at least for the insurance & credit sector – leads to a cost of 286 € per employee per day (or 66 M€ per day for 232,000 employees).

Taking into account the projected numbers of heatwaves (HW), the percentage of ill-adapted buildings in a given time (iaB), a constant number of office workers (OW), daily cost per office worker (DC_{OW}) and a productivity ratio (P_r) for workers in ill-adapted buildings, this gives us the following equations:

$$Costs = HW \times iaB \times OW \times DC_{OW} \times P_r$$

If productivity losses for ill-adapted building is 50%, then we find yearly office labour losses of 93.06 M€ in 2020 and 344.20 M€ in 2050 (see Table 8-4).

Table 8-4. Office labour productivity losses (in €) in BCR as a consequence of heatwaves. Projected numbers of heatwaves (HW), percentage of ill-adapted buildings in a given time (iaB), number of office workers (OW), daily cost per office worker (DC_{OW}) and a productivity ratio (P_r) for workers in ill-adapted buildings.

Year	**2020**	**2050**
HW	5.10	41.50
iaB	0.55	0.25
OW	232,000	232,000
DC_{OW} (€)	286	286
P_r	0.50	0.50
Costs (M€/yr)	93.06	344.20

For this assessment of the office labour productivity losses during heatwaves in Brussels, two chosen figures need to be better delimited: the proportion of ill-adapted buildings to heatwaves and the productivity ratio related to those types of buildings. For that, a statistically representative categorization of office building resilience to heatwaves needs to be done.

In order to minimize the costs related to office labour productivity losses as a consequence of heatwaves, private and public organizations should have heatwave plans with measures ready to be deployed and communicated to their employees. Some of these measures are organizational and require little effort in order to be effectively implemented. Others are structural and will need adaptive measures going from technical renovation (new cooling system and ventilation, installation of outdoor blinds) to changing office building.

9. CONCLUSIONS

In Belgium, climate change is expected to induce hotter and dryer summers and milder and wetter winters. Heatwaves, flooding and drought appear to constitute the main share of climate hazard. Vulnerability to these hazards in Belgium is enhanced given the large proportion of urban areas, which exacerbate the adverse effects of heating (urban heat island effect) and flooding (impermeable surfaces). It is expected that groups within society that already today exhibit vulnerability (people with poor health, low income, or inadequate housing), are often also the most vulnerable to climate change effects.

Climate change is also expected to affect a large number of economic sectors in Belgium, inducing large costs but sometimes also gains, the figures ranging from several hundreds to thousands of M€/yr, as shown in Figure 9-1. The total costs, which are mainly caused by extreme heat, drought and flooding, amount to nearly 9,500 M€/yr, which is approximately 2% of the Belgian GDP. Conversely, the gains, which are associated with milder winters, approximately reach 3,000 M€/yr, or 0.65% of the GDP. While the picture is incomplete, towards the end of the century the sectors representing the largest costs show a trend of a stronger increase in the costs than in the gains of climate change.

It should be noted that the high share of heat-related labour productivity loss in the total economic costs constitutes a somewhat unexpected result. It is wholly related to the inclusion of the services sector in the assessment. Indeed, while often this sector not accounted for and while the impact of heat on the services sector is less important than on sectors based on outdoor work (agriculture, construction), the high share of the services sector in the national GDP more than compensates for this lesser climatic sensitivity.

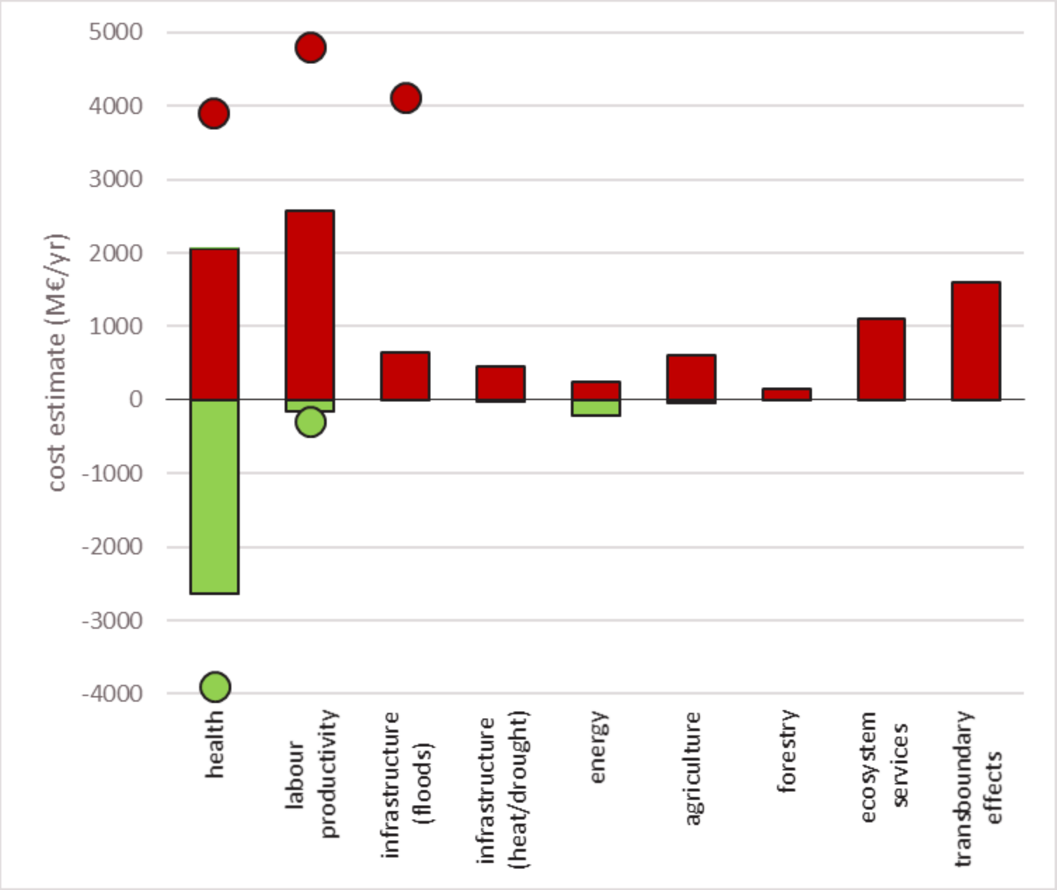

Figure 9-1. Estimated economic costs (red) and gains (green) of climate change per sector, as compared to present-day conditions, considering climate scenario RCP8.5 and the year 2050 (stacks) and 2100 (dots). The numbers contained in this figure represent average values of the cost ranges provided at the end of Section 6. Note that the health costs only pertain to the impacts of heat and cold.

It is important to realise that the figures and cost estimates presented here are not forecasts; instead they constitute scenarios and projections. Also, as mentioned before, they represent the costs incurred in the absence of any additional climate adaptation measures.

To put these cost figures into perspective, it is enlightening to compare them – just by way of example – to (possibly) more familiar costs, such as the annual budget of the Federal Public Service of Justice in 2019 (1,950 B€), the burden of COVID-19 measures on the budget of the Walloon Region in 2020 (1,800 B€), the annual budget of the Flemish Region for Mobility and Public Works in 2019 (4,100 M€), or the cost of 3,800 M€ for the purchase of 34 fighter jets F-35.

It should be mentioned that caution is in order when considering Figure 9-1 since, while it provides a general overview, it is by no means complete. According to Szewczyk et al. (2018), economic climate impacts can be classified into three types: known-knowns, known-unknowns and unknown-unknowns. Figure 9-1 contains the known-knowns. On the other hand, several impacts, while identified ('known') have not been included because of a general lack of information or because of finite available resources to conduct this study. One example is the neglect of economic costs associated with withdrawing groundwater levels, and the associated risk of a forced shutdown of drinking water to residences and businesses. There could of course also be unknown unknowns, i.e., impacts we are currently not even aware of. A good example of such a situation (in a slightly different yet related domain) is the ozone hole, which was discovered by surprise, no one having anticipated its existence, and yet there it suddenly was, taking the scientific community by surprise (Solomon, 2019).

Another limitation of our study is that it has mainly considered *direct* climate change impacts, i.e., damage costs incurred within specific sectors. Yet, the actual economic cost, including *indirect* or 'knock-on' effects, may well work through beyond that sector, causing damage to the overall economy in addition to the sole sectoral damage cost. Indeed, in case climate change causes damage to a sector, such as reduced production, employees working in that sector may find their income to be adversely affected. This affects their disposable income, which then reduces consumption, resulting in a decrease of the GDP. In fact, studies that considered such indirect effects appear to often encounter a doubling of an initial damage cost when its effect on the economy as a whole is taken into account (see Houghton, 2015; Sieg et al., 2019; Ciscar et al., 2018b; Botzen, 2018).

Indirect effects are to some extent related to the phenomenon of cascading effects. To illustrate this, consider extreme heat causing a failure in the energy sector (electricity network), this in turn triggering a whole range of secondary effects, including electrical trains that get stuck and without cooling, hospitals that get in trouble by a lack of network power and ICT infrastructure that breaks down, among others; see QUT (2010) for an account of an actual event.

Finally, an aspect not included in this study is related to tipping points, i.e., thresholds that, when exceeded, can lead to large changes in the state of the climate system. Known examples are the accelerated melting of the Groenland and West-Antarctic ice caps above some threshold temperature, the release of massive amounts of methane from melting permafrost, or the Amazon forest turning into an enormous source of atmospheric CO_2 in case excessive drought were to cause the decline of the forest. While the probability of these things happening may be rather low for the moment, they are by no means excluded and, if they materialised, might cause enormous damage.

As a final remark, it should be realised that the cost estimates presented here are subject to a high level of uncertainty, which is related to the uncertainty on the climate information itself, on the assumptions to assess the physical impacts of the changing climate and on the unit economic cost assigned to this damage. Nevertheless, at the time of writing the impacts and cost estimates presented above constitute the most complete and detailed overview of the socio-economic impact of climate change in Belgium, thus hopefully constituting a firm basis to inform future climate policy and actions.

APPENDIX. SECTORAL CLIMATE IMPACTS MATRIX

The table below provides an overview of climate change impacts per sector that have been considered in the present study. Given finite resources only a portion of these impacts has effectively been assessed in our study.

<table>
<tr><th></th><th>rising temperatures and extreme heat stress</th><th>drought</th><th>peak precipitation and extreme weather (storms)</th><th>river flooding</th><th>sea level rise</th></tr>
<tr><td rowspan="3">biodiversity / ecosystem services</td><td>deterioration, loss or migration of marine species</td><td>loss of peatlands, wetlands & groundwater dependent species</td><td rowspan="2">damage to ecosystems from erosion, storms, hail</td><td rowspan="2">damage to unmodified terrestrial ecosystems
pollution</td><td rowspan="2">drowning of coastal estuaries and wetlands
higher groundwater position and salinity in coastal ecosystems
changes in sludge & tidal land areas</td></tr>
<tr><td colspan="2">deterioration, loss, or migration of terrestrial species
degradation of surface water quality in natural areas
phenology changes</td></tr>
<tr><td colspan="5">changes in habitat, species composition, ecosystems (services); increase of CO2 concentration: acidification of marine environment, (potential) growth of primary production; ecosystem services compromised: carbon capture/storage, pollination, water regulation, recreational activities, …</td></tr>
<tr><td>emergency planning</td><td>enhanced deployment of ambulances
electricity blackout
threatening hospitals</td><td></td><td colspan="2">access roads to emergency sites blocked
equipment and consumables storage</td><td></td></tr>
<tr><td rowspan="3">agriculture</td><td>thermal stress for livestock and crops
sunburn damage to crops
stables (livestock): less winter heating, more summer cooling</td><td>loss of soil organic matter
drought stress</td><td rowspan="2">rinsing of arable land
damage to agriculture flood
damage to agriculture caused by storms, hail, ...</td><td rowspan="2">damage to agriculture from flooding</td><td rowspan="2">damage to agriculture during flooding events
loss of farmland by coastal erosion and salinisation</td></tr>
<tr><td colspan="2">change in length of the growing season
changes in temperature and moisture regime for crops
change in incidence of plant/animal diseases & pests
threat from nature/forest fires</td></tr>
<tr><td colspan="5">changes in crop selection, changes in revenues, changes in food and feed availability and prices of agricultural crops; increase of CO2 concentration: increased (potential) primary production; social impact on farmers; increase interannual variability</td></tr>
</table>

	rising temperatures and extreme heat stress	drought	peak precipitation and extreme weather (storms)	river flooding	sea level rise
energy	increased energy demand (cooling) transformers overheated reduced efficiency of photovoltaic panels (renewable energy) energy distribution losses (current mean is 7-8%)	reduced potential for hydro-electricity	damage to infrastructure for generation, transmission and distribution – including renewable energy (wind turbines) damage caused by trees falling on power lines during storms enhanced southerly wind direction correlates with lower wind speeds hence reduced yield of wind turbines		
	reduced availability cooling water for thermal and nuclear power plants				
	changes in demand and supply, damage to infrastructure for generation, transmission and distribution				
fisheries	changes in commercially relevant species (migration in and out)		impact of extreme events (storms) on fleet and infrastructure		moorings compromised
	overall impact of fisheries decline on social/health aspects of fishermen				
forestry	high ozone affecting trees changes in incidence of pests and diseases thermal stress	drought damage increased risk of forest fires	damage caused by extreme weather events	damage and loss of area through flooding	damage and loss of area through flooding and salinisation
	reduced resilience of trees (e.g. against pests)				
	changes in productivity and functions of forests; ecosystem services compromised: wood production, water regulation, natural protection, recreation, …				

	rising temperatures and extreme heat stress	drought	peak precipitation and extreme weather (storms)	river flooding	sea level rise
health	heat-related morbidity & mortality new diseases vectors enhanced food spoilage less cold-related disease increase of allergies and changes in season (e.g. hay fever onset) psycho-social impact	threatened drinking water	water-related diseases diseases due to floods effects of floods and other extreme events on mental health injuries and deaths caused by extreme weather		
	health impact of deteriorating water and air quality				
	changes in morbidity and mortality; advance of tropical disease vectors; vulnerable populations are less informed and often lack the means to adapt (and may therefore get ill sooner)				
industry & services	impact of heat on labour productivity (in particular outdoor workers) cooling units (e.g. meat storage) breaking down	farmers insurance for drought related damage (Fl Region, 2020)	impact of floods and extreme weather phenomena on buildings and supply lines (in/out) damage to property (insurance is sensitive through assets & claims)		
	impact of heat and water shortage on production processes (beer, textile industry, agri-food)				
	impact on the supply chain over the impact on raw materials and commodities, and transportation; changes in demand for certain goods or services; impact on the insurance services sector;				
tourism	changes in attractiveness summer vs winter tourism reduced (and sometimes increased) income for tourism sector		flash floods – accessibility issues	river flooding – accessibility issues	beach erosion flooding (?)
	more seasonal pressure on water resources and utilities		damage to tourism infrastructure		
	changes in touristic potential; changes in side effects (e.g. pollution) that are attributable to tourism				

	rising temperatures and extreme heat stress	drought	peak precipitation and extreme weather (storms)	river flooding	sea level rise
transport & infrastructure	bent rails, asphalt bulging compromised moving parts of bridges and locks reduced air cargo (enhanced take-off distance) overheating electrical components of transport systems train wagons overheating and/or airco breaking down reduced problems related to snow and ice	cracking in private and public buildings by changing soil moisture conditions impact of drought on navigability of rivers and canals drought-induced forest fires affecting road/rail transport	impact of extreme weather events and floods on infrastructure (roads, railways, ports, networks, ...) damage from flash floods & river flooding temporarily reduced accessibility damage caused by groundwater salinization		
	impact of climate change on maintenance of infrastructure and rolling stock, changes in accident frequency, accessibility and evacuation compromised in emergency situations, impact of extreme weather events and their effects (heat, flooding, erosion, landslides, ...) on infrastructure and the functioning of networks (including data networks, utilities, ...)				

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