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UNITED ARAB EMIRATES
MINISTRY OF FOREIGN AFFAIRS

IRENA
International Renewable Energy Agency

REmap 2030
A Renewable Energy Roadmap

RENEWABLE ENERGY PROSPECTS:

UNITED ARAB EMIRATES

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Masdar Institute of Science and Technology is the world's first graduate-level university dedicated to providing real-world solutions to issues of sustainability. The Institute's goal is to become a world-class research-driven graduate-level university, focusing on advanced energy and sustainable technologies. Located in Masdar City, Abu Dhabi, the capital of the United Arab Emirates, Masdar Institute aims to support Abu Dhabi's economic diversification by nurturing highly-skilled human and intellectual capital and partnering with industry leaders, support the transformation to a knowledge-based economy, and enhance the Emirate's position as a leader in global energy.

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The Ministry of Foreign Affairs' Directorate of Energy and Climate Change (MOFA-DECC) is the UAE's international lead on energy and climate change issues and supports elaboration of domestic policy. It serves as the UAE representative to IRENA.

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Renewable Energy Prospects: United Arab Emirates

REmap 2030 analysis

March 2015

Masdar Institute of Science and Technology

International Renewable Energy Agency (IRENA)

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FOREWORD

REmap 2030 represents IRENA's assessment of how countries can work together to double the share of renewable energy in the global energy mix by 2030. It represents an unprecedented international effort that brings together the work of more than 90 national experts in nearly 60 countries. Following the global REmap report released in June 2014, IRENA is now releasing a series of country-specific reports built on the same detailed analysis.

This continually expanding roadmap offers both a call to action and a remarkable piece of good news. It confirms that rapid deployment of renewable energy is now cost-competitive on a purely 'project economics' basis in many countries around the globe – even before accounting for critical external costs, such as health and environmental impact. REmap analysis highlights concrete options for decision makers to raise the renewable share in the energy mix, as well as specifying costs, benefits and the actions needed to accelerate the energy transformation. The consequent findings, moreover, underline that countries can take action now – in contrast to data from earlier decades suggesting renewable energy was out of reach.

I am pleased that IRENA's host country, the United Arab Emirates, is our partner on one of the first REmap country reports. The UAE took a bold stance to embrace renewable energy – a stance that captured the attention of countries throughout the Middle East and the world. But it was the right choice, as this report demonstrates. Renewable energy makes economic sense for the region decades earlier than expected, and the UAE now stands ready to benefit from its first-mover advantage. I look forward to seeing what the country does next.

Adnan Z. Amin
Director-General
International Renewable Energy Agency

Few industries have seen change like renewable energy, where 5 years are like 20 years in other fields. Global installations of renewable power capacity now outpace those of fossil fuels and nuclear power combined. In the region, we have gone from 10 megawatts (MW) of solar photovoltaic power in the UAE in 2009 to over 60 gigawatts (GW) by 2032 from announced projects across all six Gulf countries.

The UAE made a bet on this transition. Our leaders recognised that the times called for new thinking on energy, and that we had much to gain by being its champion. This outlook led to the region's first renewable energy investments, including the Shams 1 solar plant, and the pioneering establishment of Masdar Institute, the Middle East's clean-tech research leader. It also globalised our vision. Our companies have brought online over 1 GW of commercial renewable energy projects overseas, with another 0.5 GW announced just this year. We have allocated over USD 500 million in development assistance for renewable energy in the last 12 months, with projects in over 15 countries. And, of course, we led unprecedented engagement with the international community to establish IRENA here in Abu Dhabi – a new voice in the heart of the hydrocarbon industry.

REmap 2030 is a perfect example of the symbiotic relationship between IRENA and its member states, especially here in the Middle East. It provides the objective, customised data we need to make smart energy choices, and it unites us with experts and institutions far beyond the reach of any one country. We are especially pleased that REmap analysis can leverage the research capabilities of Masdar Institute, which has a unique understanding of the region's energy markets and systems, as well as the mandate to produce rigorous work that challenges the status quo.

As you will see, the findings in this report are striking – calling for renewable energy deployment at a dramatic scale. They not only underscore how much renewable energy will matter in the coming years, but how much need there is for a platform like IRENA. Demand is only going up.

Dr. Thani Al Zeyoudi
Permanent Representative of the UAE to IRENA, Director of Energy and Climate Change
UAE Ministry of Foreign Affairs

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- Renewable energy is now economically attractive in the United Arab Emirates (UAE). In fact, a 10% share of renewable energy in the total energy mix – as detailed in this study – could generate annual savings of USD 1.9 billion by 2030 based on avoidance of fossil fuel consumption. When accounting for health and environmental benefits additional net annual savings of USD 1 billion to 3.7 billion by 2030 could be generated.

- Rapidly increasing natural gas prices and decreasing renewable energy costs are the main drivers. As recently as 2010, natural gas was available in the UAE at less than USD 2 per million British thermal units (MBtu). Today, marginal import prices are in the range of USD 9-18/MBtu, even after accounting for the potentially temporary price decline of late 2014 and early 2015. New domestic gas production is approaching USD 8/MBtu in cost and is insufficient to limit growing import requirements. By contrast, local solar photovoltaic (PV) module prices have fallen around 75% since 2008.

- A number of renewable energy technologies – such as solar PV, wind power, and waste-to-energy – are already economic in the UAE above USD 8/MBtu, with solar PV potentially competitive with gas prices as low as USD 4.5/MBtu. There is a clear financial rationale for accelerated and greater deployment, surpassing the UAE's existing targets in the power sector. A 25% share of renewables in power generation by 2030 could be cheaper to achieve than the current targets.

- The most important enabling factor for renewable energy in the UAE will be the empowerment of government agencies to take holistic, comparative views of energy costs – and to act on these through regulation and/or tendering. The governance model in the Emirate of Dubai, and the creation of the UAE federal energy policy taskforce, are key local references.

- In November 2014 the results of a bid for a 100 MW solar PV plant in Dubai were released, setting a world-record low for cost at just US 5.98 cents per kWh and highlighting solar PV's competitiveness in the Gulf region.

The big picture

A major rethinking of the UAE national and emirate-level energy strategies is due: as of 2014, renewable energy is cost-competitive in the country for the first time – and possibly even the cheapest source of new power supply. Based on current incremental energy prices, the UAE could achieve at least 10% use of renewable energy in its energy mix by 2030 (and 25% in its power generation mix) with estimated net savings for the economy of USD 1.9 billion annually. This is before considering health and environmental benefits or the potential to export hydrocarbons liberated from domestic consumption. The country's pioneering push into renewables – based on longer-term, 'patient capital' goals like economic diversification, sustainability, and job creation – can now be justified by short-term economics.

The REmap report and findings

REmap 2030, a global roadmap project by the International Renewable Energy Agency (IRENA), examines the realistic potential for higher renewable energy uptake in a variety of countries and markets. This country-level analysis covers all parts of the UAE's energy system, including power, industry, buildings and transport. Importantly, REmap 2030 benchmarks against alternative sources of supply like natural gas, oil, coal and nuclear power, using a combination of local and international cost data. The analysis takes a moderate approach: the first case assumes USD 90/barrel oil and USD 8/MBtu natural gas (below current UAE marginal gas prices), the second assumes USD 120/barrel oil and USD 14/MBtu gas (similar to recent UAE marginal gas prices). While the price of oil has fallen by around 50% since mid-2014, the gas price is the more critical reference for renewable energy competitiveness in the UAE – and remains consistent with the analysis assumptions even as of early 2015. It also conservatively projects gradual cost changes for all technologies, avoiding favouritism for renewable energy, which has actually experienced the most dramatic cost declines in the energy sector in recent years.

The report lays out a "business as usual" scenario (known as the "Reference Case") derived from current policies and plans, which projects that 0.9% of total final energy consumption (TFEC) would come from renewable energy by 2030. It then presents the REmap 2030 Case, which applies current and projected cost data to measure the economic attractiveness of different technologies that could achieve – without net costs – 10% renewable energy in the national mix. The percentage was selected as a relatively modest, achievable number, though higher penetration of renewables is of course possible. Since some technologies are cheaper than others, the report assumes that the savings these generate are reallocated to offset costs for more expensive technologies when estimating the total substitution cost of the portfolio.

The building and power sectors dominate in the REmap 2030 findings, achieving renewable energy shares of 29% and 25%, respectively. The industry and transportation sectors follow with 5.5% and 1.1% renewable energy shares, respectively. The difference owes largely to the cost of deployment and related technology maturity, as well as the UAE's subsidisation of natural gas for industry and gasoline for transport.

Five key insights emerge from the results:

- Deployment of PV, wind, and landfill gas (for power and industry) and solar water heating (for buildings) represent low-hanging fruit for the UAE. These investments – such as a capacity addition of 17.5 gigawatts (GW) of solar PV – would "pay for themselves" at natural gas prices of USD 8/MBtu or even as low as 4.5/MBtu for solar PV, much lower than current marginal prices. Delaying in anticipation of further cost reductions is counter-productive, as it could mean missing the opportunity already afforded and because scaling up takes time.
- Solar is the critical resource and focus for the UAE. Different forms of solar energy would account for more than 90% of renewable energy use in REmap 2030.
- There would be major opportunity costs, as well as health-environmental costs, if renewables are not deployed. For instance, domestic consumption of oil – which cuts into lucrative exports – could be reduced by up to 8.5%, and gas by up to 15.6%. Avoided national carbon dioxide (CO_2) emissions could total 29 megatonnes (Mt) per year, and avoided health and environmental costs could reach USD 1 billion to USD 3.7 billion annually by 2030. Such benefits, although not financially accounted for in the analysis, suggest significant implications for energy policy, even based simply on a net view of the economy.
- The potential for renewable energy deployment in industry is large – and renewable energy penetration could be higher if industries were encouraged to make investment decisions based on actual, and not subsidised, gas prices. Geothermal and solar thermal energy for industry could all be economically viable between USD 8 and USD 14 per MBtu, depending on the application. Solar PV could even be competitive as low as USD 4.5/MBtu if the Dubai bid results are considered.
- While dispatchable renewable energy technologies like concentrated solar power (CSP) with thermal energy storage are more expensive compared to conventional energy counterparts, these additional costs can be offset by savings achieved with other renewable energy technologies. The combination enables a network that can mimic and complement the UAE's gas-fired generation at a competitive total cost and with lower socio-environmental impact.

Energy cost dynamics

The REmap 2030 findings stem from two key, recent shifts in the UAE. First, the cost of renewable energy continues to decline dramatically. Local installed costs for utility-scale solar PV, for instance, have fallen from USD 7/Watt in 2008 to less than USD 1.5/Watt in mid-

2014, a roughly 75% drop. For the price of a 10 megawatt (MW) plant in 2008, the UAE can now build 46 MW. This high rate of cost decline can also be seen in the recent bid results for a 100 MW solar PV plant in Dubai, with bids coming in as low as US 5.98 cents per kWh.

Second, incremental (marginal) natural gas costs in the UAE are increasing, which reframes the attractiveness of renewable energy. Historically, the UAE was able to produce or import gas for less than USD 2/MBtu. Today, due in part to high sulphur content, new domestic production could cost up to USD 8/MBtu, while liquefied natural gas (LNG) imports – which started in 2010 in Dubai and may begin on a larger scale in Abu Dhabi as early as 2016 – cost USD 12-18/MBtu, with some cargoes temporarily available at 9-10/MBtu because of the oil price decline. Additional pipeline imports reportedly cost USD 14.4/MBtu. Import requirements continue to grow despite the cost. Solar PV, by contrast, is cost-competitive with high-efficiency natural gas plants for incremental daytime power supply at USD 8/MBtu, and possibly now even USD 4.5/MBtu - and is already cheaper than LNG. In terms of avoiding gas consumption, mainstream renewables like solar PV and wind are, moreover, estimated to be cheaper than nuclear energy and potentially imported coal, which, if deployed, would reverse many of the UAE's gains in reducing greenhouse gas emissions.

Government action

The new business case for renewables, however, will not be realised without policy reform and stakeholder awareness. The federal and emirate-level governments will need to clarify their respective responsibilities for project initiation and implementation, regulate the integration of renewable energy technologies where needed, and set timelines. To date, many governing institutions have now been empowered to take a holistic view of the energy sector (comparing different supply options), or to introduce a deployment programme and schedule that could incentivise local industry development and further bring down costs. The Dubai Supreme Council of Energy provides a valuable domestic model, bringing the emirate's key producers and consumers to the table for policy formulation. The UAE's new federal energy policy taskforce also represents a crucial, initial action to facilitate policy and investment coordination across the seven emirates, which are largely sovereign in their energy policy.

Key government planning documents and processes – like Vision 2021, the Abu Dhabi Economic Vision 2030, and the Dubai Integrated Energy Strategy (DIES) – must also be continually updated to reflect changes in energy costs. For instance, solar power prices today are already lower than those predicted for 2020 by the DIES when it was produced in 2010.

On a smaller but important level, the UAE could also revisit its tariff system for waste disposal to support waste-to-energy conversion, and could consider federalisation of existing emirate-level regulations for both metering (of decentralized renewable energy) and solar water heating (which has been cost-effective for some time under the current power pricing).

An economic tipping point for the industry?

The UAE has overturned many assumptions about the Middle East and hydrocarbon-exporters with its embrace of renewable energy. The cost-competitiveness of renewable energy gives the country the opportunity to dramatically increase its ambition and demonstrate the industry's financial viability in the region, while also securing a stable and very low-risk supply of energy, thereby extending the lifetime of its fossil fuel reserves. While energy costs may vary by location, the implications of solar PV parity with gas at prices of USD 4.5-8/MBtu stretch beyond the UAE. This amounts to a clarion call for all energy producers, as well as energy importers, to closely examine their investment choices.

1 INTRODUCTION

The Ministry of Foreign Affairs (MOFA) of the United Arab Emirates (UAE) commissioned Masdar Institute to help produce this report as part of IRENA's REmap 2030 project, aiming to contribute internationally as well as ensure value for domestic discussion. IRENA is the steward of the goal, expressed in the United Nations-led Sustainable Energy for All (SE4ALL) initiative, to double the share of renewable energy in the global energy mix by 2030. In that capacity, the intergovernmental agency created the REmap 2030 framework to outline an ambitious, yet realistic, roadmap for renewable energy deployment. The roadmap and its findings demonstrate how individual countries can contribute to the global SE4ALL objective of 36% renewable energy use (up from 18% at present), based on the cost-competitiveness of renewable energy technologies in the power, heating, transport, and industry sectors.

In this report, Masdar Institute analyses the potential for renewable energy growth in the UAE. Best-known as a hydrocarbon-exporter, the country has emerged as a significant investor in renewable energy globally and a political advocate for these technologies. It announced the first renewable energy targets in the Middle East in 2009 and in 2013 commissioned the region's largest clean energy project to date, the 100 MW Shams 1 CSP plant. At the same time, renewable energy is relatively exotic in the local market, and policy frameworks are under development, making the UAE an interesting example in the REmap and SE4ALL contexts.

This report starts with a brief description of the REmap 2030 methodology (Section 2). It continues by explaining the UAE's energy landscape and renewable energy activities in particular (Section 3). Section 4 discusses the country's policy frameworks for renewable energy. Section 5 provides the UAE Reference Case – the expected energy profile under existing and confirmed policies and activities. Section 6 discusses renewables' physical potential and recent cost developments. Section 7, the heart of the report, presents the REmap 2030 quantification of different technologies' realisable potential to contribute to 10% renewable energy in TFEC[1]. This is followed by a discussion of the opportunities and barriers for renewable energy in the UAE (Section 8). Section 9 provides policy options for accelerated renewable energy uptake.

1 In this study TFEC includes the consumption of industry (including blast furnaces and coke ovens, but excluding petroleum refineries), buildings (residential and commercial) and transport sectors only.

2 METHODOLOGY AND DATA SOURCES

This section explains the REmap 2030 methodology and summarises sources for background data. Annexes provide these background data in greater detail.

REmap 2030 initially assesses 26 countries in its quantitative analysis of pathways to achieve a doubling of the global share of renewable energy by 2030: Australia, Brazil, Canada, China, Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, **the United Arab Emirates** (the study at hand), the United Kingdom and the United States.

REmap follows a consistent cross-country methodology, firstly to construct the Reference Case and secondly to evaluate the portfolio of technologies (known as the "REmap Options") that produce the REmap 2030 energy mix. The analysis starts with national-level data covering both end-use (buildings, industry and transport) as well as the power and district-heat sectors. National energy (not just renewable energy) plans using 2010 as the base year are the key reference, enhanced with the inclusion of major plans and policies announced through 2014. Together these form the Reference Case, which includes the TFEC of each end-use sector and the total generation in the power and district heat sectors, with a breakdown by energy carrier for the period 2010–2030.

Comprehensive country-wide, energy-related data and projections are not readily available in the UAE (Reiche, 2010). For this report, data was collected from various government and media sources, and supplemented with analysis by Masdar Institute. TFEC projections (by sector) for 2020 and 2030 were based on extrapolated historical trends whenever possible, primarily using International Energy Agency (IEA) statistics going back to 2000 (IEA, 2013) and using informed estimates where such statistics were unavailable. Electricity-related projections were largely based on emirate level of projections by the Abu Dhabi Water and Electricity Company (ADWEC, 2011), extrapolated to the federal level.

REmap 2030 is then constructed through the selection of renewable energy and renewables-enabling technologies that could be deployed in the UAE – and by evaluating their potential to displace the non-renewable resources (especially natural gas in the case of the UAE) used in the Reference Case.

REmap 2030 is an exploratory study and not a target-setting exercise and therefore the study considered that a renewable energy share of 10% in the TFEC (from less than 0.1% today) makes a reasonable benchmark for assessing the potential of technologies in a wide portfolio – neither too ambitious as to be infeasible in this timeframe, nor too timid as to become trivial. In addition, at this rate of penetration, there are no significant additional costs in the integration of renewable energy with the current energy system – it is low enough to be located near existing transmission lines and no additional storage is needed as the current fleet of combined cycle plants can do the load following. As a result, no additional costs were included in this calculation aside from the energy supply system costs. This does not mean that higher percentages are not feasible or desirable, but the report leaves later studies to assess higher penetration and associated pathways.

The selection of appropriate technologies for REmap 2030 is based on experience from existing and planned activities in the UAE, as well as the renewable energy resource assessments conducted by Masdar Institute's Research Center for Renewable Energy Mapping and Assessment as part of an IRENA initiative, the Global Atlas for Renewable Energy.

To evaluate the cost-effectiveness of the REmap Options, IRENA developed a REmap tool that allows staff and external experts to input data in an energy balance for 2010, 2020 and 2030. The analysis uses the REmap tool and adjusts costs (capital, operation and maintenance) and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional (fossil fuel, nuclear and traditional use of biomass) technologies to UAE conditions for each of the four sectors: industry, buildings, transport, and power.

Each option is characterised by its costs and deployment potential, which are used to estimate its *substitution cost* – *i.e.*, the difference between the annualised cost of the REmap Option and the conventional technology it replaces, divided by the total renewable energy use in final energy terms (in 2010 real US Dollar (USD)[2] per gigajoule (GJ)). This indicator provides a comparable metric for the desirability and viability of all options identified in each sector. A negative substitution cost indicates that the REmap Option provides savings.

Using the substitution cost and potential of each REmap Option, cost-supply curves were developed from two perspectives for the year 2030: (1) government and (2) business. The UAE does not tax energy use and instead provides subsidies for final energy consumption – supporting both gasoline and electricity consumption but at differentiated levels. The "business perspective" for REmap 2030 therefore considers the costs of the alternatives at the subsidised level, while the "government perspective" accounts for the subsidy and therefore represents the true total cost. A differentiation is also made in discount rates for the two perspectives, with 6% used for the business perspective and 10% rate used in the government perspective. The latter is a standard international rate used in REmap allowing comparison of country results.

This report also discusses the finance needs related to increased renewable energy deployment. Three finance indicators are developed, namely net incremental system costs, net incremental investment needs and subsidy needs. These indicators are briefly defined as:

1) **Net incremental system costs:** This is the sum of the differences between the total capital (in USD/year) and operating expenditures (in USD/year) of all energy technologies based on their deployment in REmap 2030 and the Reference Case in the period 2010-2030 for each year.
2) **Net incremental investment needs:** This is the difference between the annual investment needs of all REmap Options and the investment needs of the substituted conventional technologies, in which the UAE would otherwise invest. Investment needs for renewable energy capacity are estimated for each technology by multiplying its total deployment (in GW) to deliver the same energy service as conventional capacity and the investment costs (in USD per kilowatt (kW)) for the period 2010-2030. This total is then annualised by dividing the number of years covered in the analysis.
3) **Subsidy needs:** Total subsidy requirements for renewables are estimated as the difference in the delivered energy service costs for the REmap Option (in USD/GJ final energy) relative to its conventional counterpart multiplied by its deployment in a given year (in petajoules (PJ) per year).

Additionally, external costs related to health and environment are calculated, but are not included in the analysis – only presented alongside for reference. Impacts related to greenhouse gas (GHG) emission reductions and outdoor and indoor air pollution from the decreased use of fossil fuels have been estimated. As a first step, for each sector and energy supply source, GHG emissions from fossil fuel combustion are estimated. For this purpose, the energy content of each type of fossil fuel was multiplied by its default emission factors (based on lower heating values, LHV) as provided by the Intergovernmental Panel on Climate Change (IPCC, 2006). Emissions were estimated separately for the Reference Case and REmap 2030. The difference between the two estimates yields the total net GHG emission reduction from fossil fuel combustion due to increased renewable energy use. To evaluate the related external costs related to carbon emissions, a carbon price range of USD 20-80 per tonne of CO_2 is assumed (IPCC, 2007). This range was applied only to CO_2 emissions, but not other GHGs. According to the IPCC (2007), carbon price should reflect the social cost of mitigating one tonne of CO_2 equivalent GHG emissions.

The external costs related to human health are estimated in a separate step, which excludes any effect related to GHG emissions. Outdoor air pollution is evaluated from the following sources: (1) outdoor emission of sulphur dioxide (SO_2), mono-nitrogen oxides (NO_x) and particulate matter of less than 2.5 micrometres ($PM_{2.5}$) from fossil fuel-based power plant operation, and (2) outdoor emissions of NO_x, and $PM_{2.5}$ from road vehicles. To evaluate the external costs related to outdoor emission of SO_2, NO_x and $PM_{2.5}$ from fossil power plant operation, the following parameters for respective pollutants were used: (a) emission factor (*i.e.*, tonne

2 In 2010, 1 USD was equivalent of 3.67 Arab Emirates Dinar (AED).

per kilowatt-hour (kWh) for 2010 and 2030 taken from the IIASA GAINS database ECRIPSE scenario (IIASA, 2014), and (b) unit external costs (*i.e.*, Euro-per-tonne average for the European Union (EU), adapted for the US from the EU CAFE project (AEA, 2005). Potential differences in external effects between the EU and the UAE values are accounted for based on the difference in gross domestic product (GDP) values.

Further details of the REmap 2030 methodology and technologies can be found online at: *www.irena.org/remap.*

3 RECENT TRENDS FOR RENEWABLE ENERGY AND THE PRESENT ENERGY SITUATION

Steep price increases for natural gas are currently the defining story of the UAE's energy sector, driven by fast population and economic growth, sulphur removal processing requirements of domestic gas supplies, and prodigious use of gas in enhanced oil recovery (EOR). The cost of incremental production and LNG imports has added a new dimension and urgency to the country's aggressive diversification plans, which already called for nearly 20% low-carbon electricity (nuclear and renewables) by 2020, up from less than 1% today. Nuclear reactors with 5.6 GW nameplate capacity are under construction, and existing renewable energy plans call for up to 2.5 GW of solar, wind, and waste-to-energy by 2030. Currently, the UAE's primary energy mix is almost exclusively natural gas (71%) and oil including bunker fuels (28%), with gas accounting for nearly 100% of power generation. Outside power and water heating, renewable energy is at the pilot or early stages.

As shown in Figure 1 in the breakdown of UAE's TFEC, industry accounts for the largest share of consumption at 63% or 1.2 EJ, followed by transportation with 0.4 EJ, followed by the residential and commercial sector (together mentioned as buildings in this report) at 0.3 EJ. Electricity, derived from natural gas, accounts for 15% of the TFEC.

3.1 The country in brief

The UAE is a federation of seven emirates, each retaining autonomy in local affairs (including energy). With a fishing, pearl-diving, and Bedouin legacy, the country achieved independence from the United Kingdom in 1971 and has tapped into its vast hydrocarbon endowment for rapid transformation. The country's population now stands at around 9 million, up from 3 million in 2000, and less than 300000 in 1971; over 85% of residents are expatriates. Large state investment in education and health has propelled the country to 40th in the 2014 Human Development Index (in the top development category), and the World Bank estimates its GDP per capita among the 10 highest in the world. Economic growth has averaged over 4% per year in recent years, with a government focus on diversification away from hydrocarbons. Abu Dhabi and Dubai are the two most populous emirates and the main centres of government and business activity.

3.2 Fossil fuels

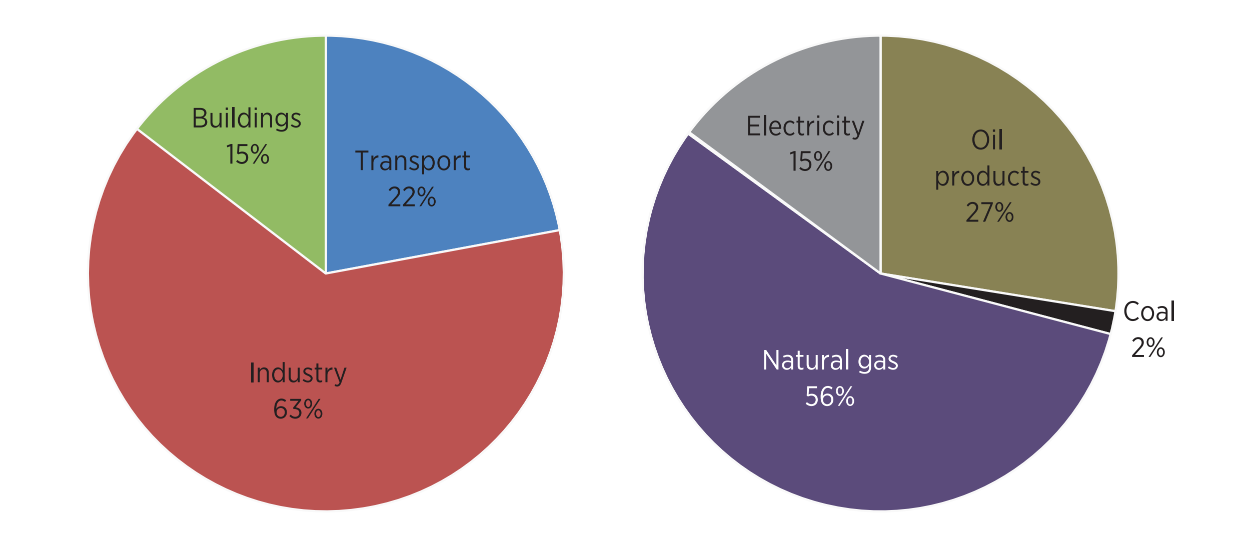
The UAE's hydrocarbon markets are undergoing their most marked change since independence in 1971, with knock-on effects for renewable energy.

The country is one of the world's largest hydrocarbon reserve-holders and exporters. According to data from Organization of the Petroleum Exporting Countries (OPEC) for 2013, the UAE's proven oil reserves were the seventh largest in 2013, at 97 800 million barrels, and its gas reserves ranked sixth or seventh, at 6.1 trillion cubic metres. At 2.8 million barrels/day, the UAE is also the eighth largest oil producer but, more crucially, the world's third largest oil exporter (US EIA, 2012), and at 9.4 billion cubic feet/day, it is the 17th largest gas producer. Oil production is targeted to increase to 3.5 million barrels/day by 2020. The UAE has exported LNG to Japan since 1977.

This endowment has facilitated high dependency on oil and gas. In 2011, the UAE's primary energy consumption amounted to 87.2 million tonnes of oil equivalent (Mtoe), with oil and bunker fuels accounting for 28% (24.4 Mtoe), primarily used in transport, and natural gas accounting for 71% (61.9 Mtoe), used as feedstock for the manufacturing industry and for electricity and water generation (BP, 2012).

The historic low production costs and domestic pricing of oil and gas has furthermore resulted in very high per capita energy consumption. Per capita power consump-

Figure 1: Energy consumption in TFEC, breakdown by sector and fuel inputs in 2010



Source: IEA (2013)

tion of 9 855 kWh in 2010, for instance, put the UAE at number 12 globally. The impact on fossil fuel demand is pronounced given the tripling of the UAE's population in the last 15 years and the UAE's major expansion into energy-intensive industries (such as petrochemicals, basic metals, and fertiliser), which often receive gas allocations at sub-market prices and grow accordingly. Cumulatively, demand began to outstrip domestic gas production in 2010, and the UAE has become a net-importer of gas.

The UAE is now facing its first-ever shortage of low-cost gas. Historically, the UAE has been able to produce associated gas (from oil production) for less than USD 2/MBtu[3], and in 2010 signed an agreement with Qatar to supply gas also at less than USD 2/MBtu through 2032 via the Dolphin pipeline. However, this deal is not expected to be renewed on such favourable terms – additional, interruptible supply from Qatar through Dolphin is already at USD 7/MBtu, and the Northern Emirates are reported to pay as high as USD 14.4/MBtu for supply. Because of limited growth in domestic production, the UAE turned to LNG in 2010 in order to ensure gas supply and is set to increase LNG imports by 2016-17. However, LNG typically costs between USD 12 and USD 18 per MBtu in today's market, making it an expensive option. LNG prices have fallen in some cases to USD 9-10/MBtu as a result of the oil price decline in late 2014 and 2015; however, the softening may be temporary, and still represents a major increase from the UAE's historic levels.

Import costs have consequently renewed interest in domestic production – but it will come at a higher cost than in the past, due in part to the sulphur content of local gas, which requires treatment. New sulphur-rich fields were originally estimated to require USD 6/MBtu, but costs as high as USD 8/MBtu are now being estimated. Therefore, even if the UAE ramps up domestic production enough to avoid more LNG imports, it could be looking at a 400+% hike in incremental gas costs vs. 2009.

In terms of current gas supply and consumption, the UAE consumed around 8.9 billion standard cubic feet per day (bscf/d) for domestic needs in 2012: 3.4 bscf/d for domestic industry, 2.8 bscf/d for well-reinjection for EOR, and 2.7 bscf/d for power and water generation going to residential and commercial uses. While domestic gas production is at 9.4 bscf/d, approximately 1.8 bscf/d is lost to shrinkage and safety flaring, making 7.6 bscf/d available for use. LNG exports to Japan under long-term contracts constitute 0.7 bscf/d. Consequently, 2.2 bscf/d of imports are required: 2 bscf/d through the Dolphin

3 1 MBtu is equivalent to 1.055 GJ or 1055 megajoules (MJ). 1 kilowatt-hour (kWh) is equivalent to 3.6 MJ. 1 toe is equivalent to 41.868 GJ.

pipeline from Qatar and another 0.2 bscf/d from Qatar as LNG through Dubai (Sgouridis *et al*., 2013). The forthcoming Emirates LNG project (in the emirate of Fujairah and funded by Abu Dhabi) could bring as much as 1.2 bscf/d additional LNG imports into the country. The first phase of 0.6 bscf/d import capacity will come online as early as 2016-17. Domestic gas production will increase – with major fields like Bab and Shah under development – but is not expected to displace LNG; rather, it would satisfy growing demand. The pricing threat of LNG and incremental domestic production has drawn new attention to options to reduce gas consumption. Some of these – including renewable energy – are described in sections below.

On the oil side, domestic dynamics are less consequential – the UAE is at no risk of becoming a net oil importer in the near term – but rising domestic demand and subsidisation are affecting government budgets. Indicatively, in 2011 the UAE had the seventh-highest per capita petroleum consumption in the world (US EIA, 2013). Car ownership is a standard feature of UAE life, and cities are built on car-scale.

On a federal level, the price of gasoline is regulated and is currently set at 1.7 AED/litre (0.46 USD/litre ~ 55 USD/bbl), which is lower than the oil price in the international markets. However, this remains the highest price among all neighbouring Gulf Cooperation Council (GCC) countries (Lahn and Stevens, 2011). The price of diesel is not fixed by the federal government and largely reflects international pricing with the exception of Abu Dhabi emirate where it is still subsidised. Diesel is used for commercial freight transport and for the private and public fleet of large buses. The sulphur content of the marketed diesel is higher than that in the EU and the United States, but efforts are ongoing to provide low-sulphur diesel in the local market.

3.3 Electricity markets

The UAE's power markets are defined by natural gas-fired generation, cogeneration for desalination, and both subsidised and unsubsidised pricing. There are four main utilities – ADWEA (Abu Dhabi), DEWA (Dubai), SEWA (Sharjah), and FEWA (Ajman, Fujairah, Ras Al Khaimah, Umm Al Quwainn) – which each have their own rate structures and planning and investment processes.

The UAE's net electricity generation in 2012 was over 106 TWh from some 27 GW of installed power generation capacity, up from 97.3 TWh from 23 GW in 2009 (US EIA, 2012; UAENBS, 2012).

Nearly 100% of generation is gas-fired, with heavy oil and diesel used in the increasingly rare circumstance that natural gas supplies are insufficient (*e.g.*, diesel constituted 3% of Abu Dhabi power supply owing to a summer peak several years ago) – although use of diesel for power in the Northern Emirates may be understated. Diesel may also be used for off-grid power, which accounts for less than 1% of the market. Small amounts of solar are also part of the mix. Total installations are approaching 150 MW, notably with the 100 MW Shams 1 CSP plant having come online in 2013.

In Abu Dhabi, the UAE's largest emirate, the breakdown of electricity consumption in 2008 was 39% residential, 29% commercial, 21% institutional, and 11% agriculture (ADRSB, 2013). These statistics do not include the industrial demand satisfied by in-house generation, referred to as autoproducers. For example, the state-owned aluminium producer, Emirates Global Aluminium, has a total generation capacity of approximately 4.3 GW, in addition to its offtake from the grid (ADWEA, 2014).

Electricity demand in the UAE exhibits a strongly seasonal effect due to the changes in ambient temperature and humidity. The primary electricity loads in the UAE are cooling, lighting, refrigeration and other appliance loads. In Abu Dhabi, the residential electricity load distribution is 47% for cooling (but can exceed 60% during the summer peak), 7% for lighting, 3% for refrigeration and 35% for other appliance loads (Smith, 2012). Cooling is highly correlated to weather temperature and humidity (Mokhtar *et al.*, 2010) and is also related to the quality of thermal insulation, the air gap tightness of the building envelopes, and the state of maintenance of the air conditioning (A/C) units (Ali *et al.*, 2011).

The constitution of industrial and commercial loads is similar to residential, but with different usage patterns and priorities. Large-scale industrial users, including smelters, refineries, and extraction platforms, have historically relied on the supply of natural gas, which they use at their own facilities for power generation. Many of the new industrial loads, however, are planned for direct connection to the grid. Table 1 shows the peak annual demand from *grid-connected* industries in the UAE.

Table 1: UAE annual grid-connected industrial peak power demand of electricity

	2011 Industrial demand
Abu Dhabi Industry • Emirates Steel • Zones Corp • Khalifa Industrial Zone Abu Dhabi (KIZAD) • Chema Weyaat (Abu Dhabi National Chemical Company) • Basic Industries Corporation (ADBIC)	600 MW
ADNOC	500 MW forecasted to >2GW by 2020
Dubai Industry	300 MW

Source: Sgouridis et al. (2013)

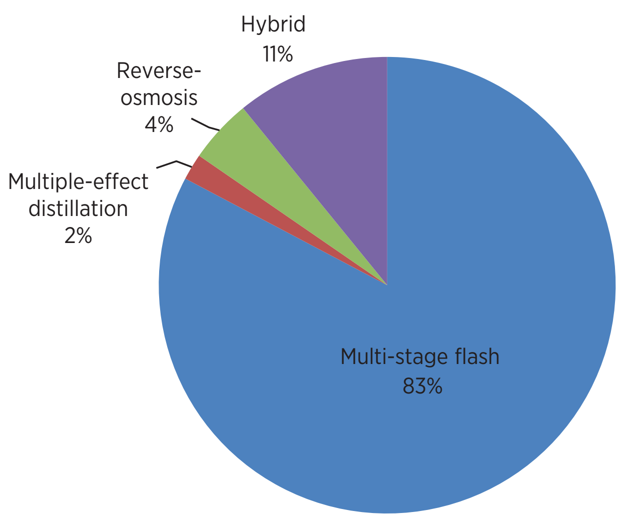
Water cogeneration

Seawater desalination provides almost all residential and industrial water supply in the UAE. Agriculture uses fossil water extraction from aquifers, which are already showing signs of stress and salinisation, indicating that in the future at least part of the agriculture production will need to switch to desalination as well.

A key feature of the UAE electricity market is its interlinkage with water production, which for the most part occurs at combined-cycle, cogeneration thermal plants. Water cogeneration impacts power plant efficiency for electricity generation. This is especially true in the winter due to the reduced demand for electricity while water demand stays the same – dropping the power-to-water ratio (PWR) to much lower than optimal efficiency for the power plant operation (Lin *et al.*, 2011).

The total installed desalination capacity in the UAE is 1583 million imperial gallons per day (MIGD). Thermal co-generation using the robust but inefficient multi-stage flash (MSF) technology provides more than 80% of water generation capacity as shown in Figure 2, with

Figure 2: Breakdown of UAE desalination capacity in 2012



the much more efficient reverse-osmosis (RO) at less than 5%.

The historical preference for MSF is partly due to the pace of institutional change but also the low need for pretreatment of the water intake. RO is perceived as less robust due to its greater vulnerability to seawater intake quality (*e.g.*, red-tide events), with higher need for pre-treatment. Recent membrane developments have already reversed many of these disadvantages. Additionally, the expansion of the UAE's strategic water reserve will permit a greater reliance on RO at no additional risk of disruption, as charging of a UAE aquifer with desalination water will increase the water reserve duration from the current 3 days to 6 months.

Located on the Gulf of Oman coast, the Fujairah F2 power plant is currently the only utility-scale RO plant in operation in the UAE. The Arabian Gulf poses increased challenges for reverse osmosis operations due to the higher salinity and temperature of water, although a number of RO plants have been in operation in other Gulf countries.

Pricing

Electricity tariffs vary widely by emirate, and are also differentiated between UAE nationals and expatriates. Tariffs are considerably higher than in other countries in the region (El-Katiri, 2011).

In Abu Dhabi, tariffs have been raised to AED 21 fils/kWh across all sectors, but UAE nationals are given a preferential rate of 5 to 5.5 fils/kWh (RSB, 2012). The average actual cost of generation has been cited as around 36 fils/kWh (USD 0.098/kWh), more than double the standard rate and seven times the UAE national rate – this rate is based on cost recovery and therefore does not include the opportunity cost of gas in its calculation.

In Dubai and the northern emirates, the electricity tariff follows a slab structure (*i.e.*, higher rate for higher consumption level). In Dubai, the lowest consumption category (less than 2 000 kWh per month) for residential and commercial users is 23 fils/kWh and the highest (above 6 000 kWh per month) is 38 fils/kWh. An LNG surcharge sometimes applies as well. In the northern emirates, using the same consumption categories, residential and commercial rates start at 20 fils/kWh and max out at 33 fils/kWh. For industrial users, the northern emirates charge a flat rate of 40 fils/kWh, and Dubai has two tiers (below and above 10 000 kWh per month) at 23 and 38 fils/kWh, respectively. In early 2015, a tariff increase of 5 fils/kWh was announced for the northern emirates.

In Sharjah, a rate of 30 fils/kWh is charged for residential consumers and 40 fils/kWh for industrial consumers regardless of consumption. Commercial consumers below 10 000 kWh per month are charged 30 fils/kWh, above at 35 fils/kWh (MOENR, 2013).

GCC grid

On top of the domestic, inter-emirate exchanges of electricity and water, the GCC interconnector system became operational in 2013 (El-Katiri, 2012). Currently it is focused primarily on grid-stability and inter-temporal exchange rather than an open electricity market system. A major obstacle will be aligning the different subsidy regimes across countries into a market system, as well as the fact that no country currently has surplus capacity during the peak summer months.

3.4 Transport market

Mobility needs are overwhelmingly met by private vehicles, with a small contribution from recent investment in public transportation, such as the Dubai metro system, the first in the GCC, and buses. Abu Dhabi has plans for a light rail system as well. A successful highway toll system relying on the use of radio frequency identification (RFID) transponders, Salik, has been operational in Dubai since 2009, producing funds for transport infrastructure investment.

The ports in Jebel Ali and Abu Dhabi and the industrial zones around them are key freight transport hubs for the region. All freight is transported by trucks pending realisation of the USD 11 billion, 1200 kilometer (km) Etihad Rail project. Phase 1 of 264 km was completed at the end of 2013 and is geared entirely for the transport of sulphur; Phase 2 – which will extend the network by 630 km with freight and passenger capability – will come online toward 2018 (Etihad Rail, 2012; 2013).

The aviation industry is also a key feature of the UAE market, with the state-owned companies Emirates Air-line (Dubai) and Etihad Airways (Abu Dhabi) among the fastest-expanding airlines in the world.

3.5 Nuclear power

The UAE's largest push in incremental energy supply is its USD 40 billion investment in 5.6 GW of civil nuclear energy, with one 1.4 GW reactor coming online each year between 2017 and 2020. The plant is expected to meet around 20% of national power demand and eliminate a commensurate amount of gas demand and greenhouse gas emissions. The Abu Dhabi government initiated the project in light of concerns about gas dependency and climate change. The project has been recognised by the International Atomic Energy Agency (IAEA) for its transparent development approach.

3.6 Coal power

Two coal projects have been proposed in the UAE to diversity supply: 1.2 GW in Dubai and 270 MW in Ras Al Khaimah. Both are designed to be carbon capture and storage (or utilisation) ready. The Dubai project is the most advanced and an exploratory tender was issued by the Dubai utility, DEWA.

3.7 Renewable energy

Renewable energy is on an upward trajectory in the UAE – although one much lower than this report would recommend based on new cost data. Power has been the main focus of activity, led by solar, waste-to-energy, and wind, although there are pilot projects in thermal cooling and transport fuels.

The momentum for renewable energy began in 2008-09, when Abu Dhabi, in a first for the region, set a target to achieve 7% renewable energy power generation capacity (approximately 1500 MW) by 2020. Dubai then also announced a target of 5% renewable energy power consumption (approximately 1000 MW) by 2030. Despite doubt regionally and internationally about the odds for renewable energy in hydrocarbon-exporting countries, the UAE's deployment and promotion of renewable energy has had a significant normalising effect for it.

The UAE, however, lacks some of the urgent financial case seen in neighboring GCC countries. Many of them burn petroleum for power, cutting into their export potential. Renewables free up petroleum and therefore enable the countries to generate significant new export revenues. Bloomberg New Energy Finance (BNEF) has estimated that Saudi Arabia could generate returns around 20% on solar PV plants based just on liberated oil exports. For countries like Kuwait, that both import LNG and burn petroleum for power, the value of renewables is even higher. As shown in this report, the UAE's commercial case for renewable energy largely owes to avoidance of using high cost natural gas for electricity production.

Solar

Solar power has been the primary focus of UAE efforts to date. Abu Dhabi saw the commissioning of the 100 MW Shams 1 CSP plant, the largest-ever renewable energy project in the Middle East, and Dubai inaugurated 13 MW of solar PV as the first phase of the eventually 1000 MW Mohammed Bin Rashid Al-Maktoum Solar Park in Dubai. In August 2014, Dubai issued a tender for 100 MW of PV, also in the Park. The results of the tender, published in November 2014, broke world records for cost-competitiveness, with the lowest bid at US 5.98 cents per kWh and many below US 8 cents per kWh. Some 10+ MW of rooftop PV is also scattered across the country, and may expand further with new metering regulations in Dubai and approval of wiring regulations in Abu Dhabi.

The UAE is also looking at solar power for desalination. In May 2014, Masdar signed contracts for 4 pilot projects that use highly energy-efficient membrane technologies to produce around 1500 cubic meters of water per day. If successful, they will pave the way for renewable energy to power electricity-driven desalination at large scale.

Generally speaking, solar PV is increasingly seen as the most attractive technology in the UAE in the near-term due to cost and resource availability. CSP with thermal energy storage, however, remains attractive for its potential to provide base load power.

Water-heating from solar thermal collectors is also commercially available but its use is currently limited to large installations (mainly hotels), Dubai (where it is required in new buildings), and government-funded housing for UAE nationals in Abu Dhabi. There is very significant untapped potential.

Waste-to-energy

Waste-to-energy has generated significant interest given the UAE's urgent waste disposal challenges and the success of Northern European countries in minimizing the environmental footprint of mainstream technologies. The country's waste profile is well-suited for waste-to-energy, although emirate-level government reluctance to raise or, in some cases, charge disposal fees has created complications around financing.

Promisingly, an engineering, procurement and construction (EPC) contract has been awarded for a 53 MW facility in Sharjah by Bee'ah, one of the Middle East's most advanced waste management companies. A 100 MW facility is also under development in Abu Dhabi by the state-backed company Taqa.

The UAE has started to look at landfill methane recovery too. A 2 MW facility is operational in Ras Al Khaimah, and a 1 MW facility was commissioned in Dubai in 2013. An initial study estimated potential of 12 MW at one of Dubai's major landfills.

As another facet of waste-to-energy, the Dubai aluminium company Dubal has run a successful pilot for over a year to convert process waste heat into onsite cooling using absorption chillers. While details are unavailable, expansion is believed to be commercial under future incremental gas prices.

Wind

The UAE has commercial-quality wind resources along its Indian Ocean coastline in the emirate of Fujairah, although land use issues have prevented development to date. In Abu Dhabi, Masdar has also explored resources on Sir Bani Yas Island and identified potential for roughly 30 MW, though the project has not yet been greenlighted.

Transport fuels

Transport is a very recent consideration for renewable energy deployment in the UAE, largely owing to an abundance of oil and low pricing, which have not created the same psychological impact as rising gas costs. Efforts are focused on biodiesel and aviation fuels, where costs and/or political commitments create incentives for change.

Notably, the Masdar Institute of Science and Technology, the Boeing Company, Etihad Airways and UOP (a Honeywell Company) have joined forces as founding members of the Sustainable Biofuels Research Consortium (SBRC) to develop a domestic sustainable aviation biofuel industry. UAE airlines have committed to an industry-wide target of carbon neutral growth after 2020, as well as a 50% reduction of global international aviation CO_2 emissions by 2050 compared to 2020 – creating pressure for solutions, of which biofuels is one to complement efficient operations. The partnership is investigating a novel integrated agriculture/aquaculture system for producing aviation biofuels and electricity as well as fish and shrimp on marginal desert land. A 2 hectare pilot of the system is currently being developed at Masdar City.

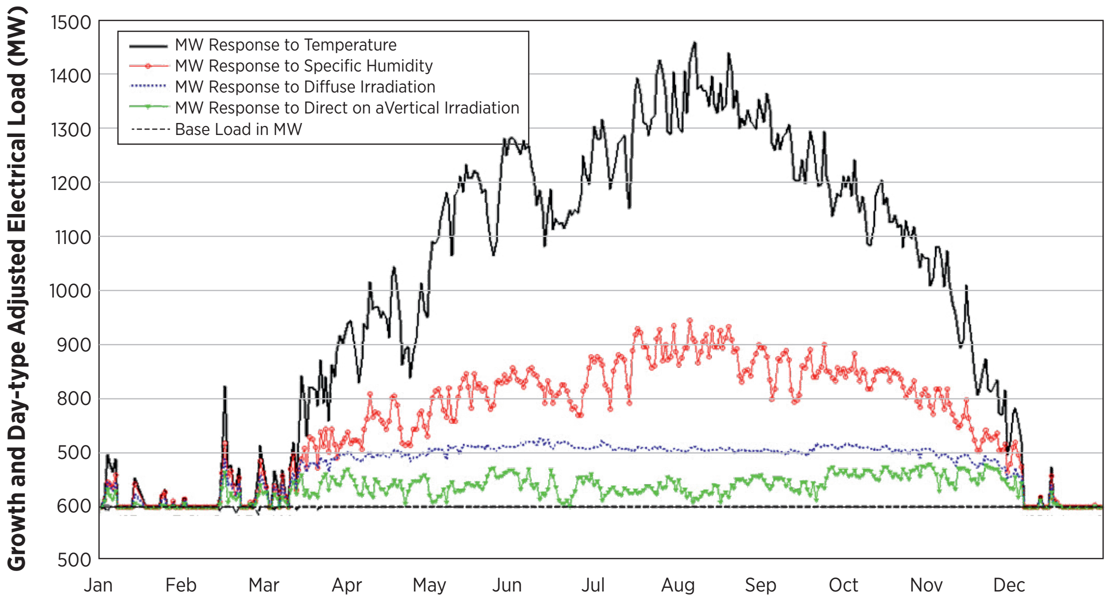
Since 2011, a commercial venture led by NeutralFuels operates a waste-oil to biodiesel facility. In an exclusive partnership with a large, fast-food chain, it processes their waste oil using a transesterification process and sells the biodiesel back to the company at a price that is competitive with the diesel price at the pump. The process can be viable, as diesel prices in Dubai are high enough to justify substitution.

Renewable cooling

Energy for cooling is a very significant component of demand (also cf. Section 3.3). Figure 3 shows the importance of climate in the power demand over a full year using data from Abu Dhabi.

Renewable cooling can be achieved using two main pathways: (i) renewable electricity into vapour compression (VC) chillers (which are the majority of the chillers in operation), and (ii) renewable heat into absorption chillers (AC). The type and technological advancement of the chillers can in both cases significantly affect the coefficient of performance (COP) and by implication the levelised cost of the operation. Chillers can range in size from split units for room or apartment size use to large units for hundreds of households or industrial complexes using a district cooling system.

Figure 3: Breakdown of power demand due to climatic components for cooling



Source: Based on Mokhtar et al. (2010)

A 2010 study by Mokhtar *et al*. (2010) found that large-scale, grid CSP plants with VC had a cost advantage followed by district cooling systems with triple-effect (high COP) absorption chillers a close second (Mokhtar *et al.*, 2010). With the continuous drop of solar PV prices since then, this relationship has likely switched to solar PV's favour. Finally, a possibility to use geothermal heat for the AC pathway was also considered an option in certain favourable locations.

Currently there are only two renewable cooling schemes with absorption chillers at the pilot level: a comparative pilot of around 600 kW using Fresnel, parabolic troughs, and evacuated flat panels at Masdar City and the afore-mentioned process heat reuse at Dubal. With the increasing penetration of renewable electricity at utility scale, the VC chillers' normal operations will be partly using renewable electricity.

4 CURRENT POLICY FRAMEWORK

There is no federal energy policy at this time. Under the UAE's constitution, individual emirates have autonomy in management and regulation of energy and resources. To date, only a few energy regulations have been federalised, such as the phase-out of incandescent light bulbs and inefficient air-conditioning units through the Emirates Authority for Standardization and Metrology. Pricing of gasoline is also federally mandated and regulated. However, there is growing recognition of the need for coordination, consistency, and co-investment among emirates. The Ministry of Energy is accordingly leading the country's first effort to develop a national strategy. It is expected to cover deployment of different supply technologies, demand-side interventions, and energy system standards, among other components.

Emirate-level policies vary throughout the UAE, and energy policy is not consistently codified or developed. Abu Dhabi and Dubai are arguably the most advanced and have introduced independent regulators (known as the Regulatory and Supervisory Bureau in Dubai and the Regulation and Supervision Bureau in Abu Dhabi) for their power and water markets. Dubai notably established the Dubai Supreme Council of Energy in 2011, which is the most centralised and formalised energy decision-making body in the country. It unites the emirate's largest energy producers and consumers to collectively determine policy and investment across all energy sectors. Abu Dhabi is considering a similar model, with the Abu Dhabi Energy Authority under development. Presently only the Abu Dhabi hydrocarbon sector has a unified governance structure under the Supreme Petroleum Council, established in 1988.

In terms of renewable energy policy, the most relevant is competitive tendering for power plants. Projects are traditionally originated by the government and competitively tendered, with a tariff (originally at a premium to that for gas-fired generation) negotiated with the winner. The government typically retains a majority stake in the project, with independent power producers taking the remainder. For instance, Shams 1's equity is split among state-owned Masdar (60%), Total (20%), and Abengoa (20%). The tariff was agreed between the consortium and Abu Dhabi's utility (ADWEA), and approved by the Regulation and Supervision Bureau.

A metering framework has been announced in Dubai to encourage rooftop solar PV and the most recent building code requires that new buildings meet 75% of their water heating requirements by solar power. Government-sponsored villas for UAE nationals in Abu Dhabi are required to have solar water heating, equating to 50-80% of their needs. Solar water heating can also be used to satisfy parts of the mandatory Estidama green building code for new construction.

Outside power and heating, the emirates may fund specific renewable energy research, demonstration, and development initiatives, as well as education. Most notably, the Abu Dhabi government finances the Masdar Institute of Science and Technology and has undertaken pilot projects like solar-powered desalination. The emirate of Ras Al Khaimah also supports a graduate-education campus of the École Polytechnique Fédérale de Lausanne focused on sustainability.

5 UAE 2030 REFERENCE CASE

Based on "business as usual" (*i.e.*, existing policies, plans, and trends), the Reference Case projects UAE energy demand to increase from 1.8 EJ in 2010, to 2.8 EJ in 2020 and 3.4 EJ in 2030. It moreover estimates that the Reference Case would achieve only 0.9% renewable energy share in TFEC. The analysis is provided through the four key sectors: industry, buildings, transport, and power.

5.1 Industry

The industry sector in the UAE used a total of 1.2 EJ in 2010 (excluding feedstocks used by the petrochemical industry). The aluminium industry accounts for the largest share, mainly from natural gas-based power demand. With the exception of cement manufacturing (which is the only known industry in the UAE that uses coal as a fuel input, in order to heat the kiln (GAN, 2009)), the other industries in the UAE are heavily reliant on natural gas as fuel inputs for industrial power, heat and processing. As much as 1.1 EJ (91.2%) of industrial final energy consumption comes from natural gas.

Autoproducers are found in a number of energy-intensive industries in the UAE. The three largest industries with their own power generation include aluminium smelting, steel production and fossil fuel refining. There is no comprehensive data on autoproducers in the UAE. However, most are not connected to the grid, and thus a precise determination of their demand is difficult at present. Consequently, autoproducers are largely included in the Reference Case and projections as non-specified industries that consume natural gas.

By extrapolating from current trends, energy consumption for the industry sector in the UAE is projected to increase to a total energy use of 1.6 EJ in 2020 and 2.0 EJ in 2030. The majority of energy consumption comes from natural gas used for processing and manufacturing purposes. In other words, the industry sector is still expected to heavily depend on natural gas as fuel inputs for energy use. The petrochemical industry will also use oil products for non-energy use through 2030, but its assessment is beyond the scope of this report.

Table 2: Growth in TFEC in industry sector, 2010 and Reference Case

	2010	2020	2030
Industry TFEC (EJ/year)	1.2	1.6	2.0
Annual growth rate compared to 2010 (%/year)		3.5	2.6

5.2 Buildings

The building sector used a total of 0.2 EJ in 2010, with the majority of this consumption coming from electricity use, and a small share (4.0%) coming from oil products, primarily LPG used for cooking purposes.

A/C electricity consumption accounted for 41.7% of the total building energy consumption, with the remaining 19.6% for appliances, 5.6% for water heating, 18.3% for others, 1.0% for cooking and 13.7% for lighting. These current values are largely based on available data from both residential and commercial buildings' energy use in Abu Dhabi (Smith, 2012). A/C approximately doubles and peaks during the summer months (*i.e.*, May to October) and is at its lowest during the winter with building electricity demand following accordingly.

The buildings sector's total energy use is expected to reach 0.5 EJ by 2020 and 0.7 EJ by 2030. These electricity forecasts are in line with Abu Dhabi's Water and Electricity Company (ADWEC) forecasts until 2030, which project that the majority of electricity consumption in 2030 will come from residential and commercial buildings (including the exports to the Northern Emirates) extrapolated to include Dubai, Sharjah and the local generation of the Northern Emirates). In the period 2005-2010, UAE population growth was more than 14% per annum, and the UN projects this rate of growth to slow down. However the UAE population will still reach about 12.5 million by 2030 (a 50% increase from 8.4 million in 2010) (UN DESA, 2012; UN ESCWA, 2012). By that time, it is expected for the per capita energy service demand to increase proportionally to the ratio of wealthier residents.

Projections for non-electricity use in buildings indicate an expectation for non-electricity energy share to reduce from 4% of total buildings' energy share in 2010 to 2% by 2030. Although the current dependency on cooking fuel is for LPG, already many residential buildings have transitioned over to using electricity instead. Projections for 2030 however, still suggest a small amount of energy being used for cooking by LPG. The Reference Case for 2030 also includes a small amount of solar water heaters in place.

Table 3: Growth in TFEC in buildings sector, 2010 and Reference Case

	2010	2020	2030
Buildings TFEC (EJ/year)	0.2	0.5	0.7
Annual growth rate compared to 2010 (%/year)		8.8	6.1

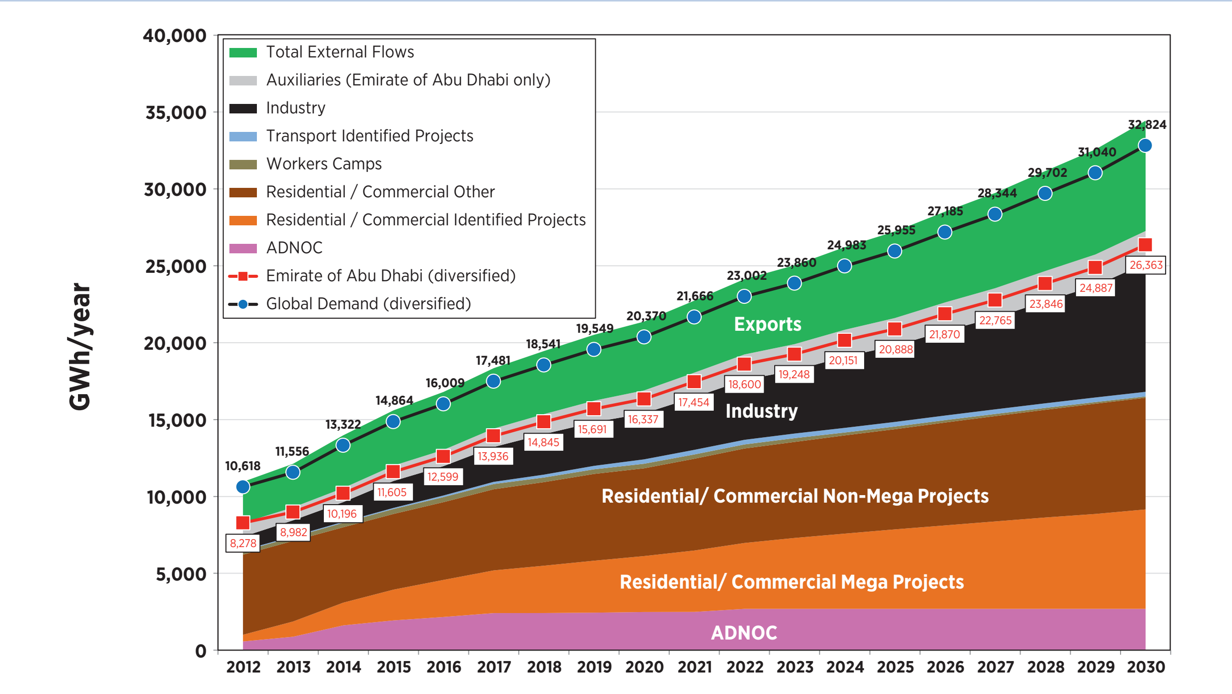
5.3 Transport

The transport sector in 2010 used a total of 0.4 EJ. The vast majority (99%) of transportation within the UAE occurs by road using oil product inputs such as gasoline and diesel fuel. Personal vehicles in the UAE are generally gasoline-powered to take advantage of subsidised fuel prices and no fuel taxation. However, commercial and industrial vehicles often use diesel and are therefore subject to price fluctuations, as there are fewer subsidies for diesel fuel. With the gasoline fuel subsidies, average engine efficiencies are low and public transportation alternatives are not developed except in the densest of urban areas.

Given the growth of the UAE's economy and lack of other viable commercial transportation options, it is projected that consumption will continue to increase. Extrapolating from historical data, transportation-related consumption is projected to increase to 0.6 EJ in 2020 and 0.8 EJ in 2030 in the Reference Case. Road transportation will account for a large share of the diesel and gasoline consumption, assuming that current subsidies remain in place. While the expansion of current metro coverage will be significant (in Dubai and also with a planned system in Abu Dhabi), it is not assumed to cause a major modal shift in transportation behaviour. Additional diesel consumption from the Etihad Rail operation by 2020 for both freight and passenger travel is also taken into consideration in the Reference Case.

While there are a few electric vehicles in use currently in Abu Dhabi (namely in Masdar City), private electric

Figure 4: Breakdown of energy demand forecasts for Abu Dhabi emirate, including exports to other emirates



Source: ADWEC (2012)

Note: Abu Dhabi profile used as basis for extrapolation to the rest of the UAE.

vehicles are not considered to be part of the Reference Case for 2020 and 2030, as there has been limited push to date to support deployment through charging stations or financial incentives. Similarly, the Reference Case also does not include hybrid vehicles.

Compressed natural gas (CNG) has been promoted in Abu Dhabi as a potential alternative fuel to gasoline. Although it was not included in the 2010 Reference Case, as only a small number of Abu Dhabi taxis currently run on natural gas, its use has been projected to increase to 1% of vehicles by 2020 and 2030 (Chinery, 2010), and thus has been included in the Reference Case projections.

Table 4: Growth in TFEC in transport sector, 2010 and Reference Case

	2010	2020	2030
Transport TFEC (EJ/year)	0.4	0.6	0.8
Annual growth rate compared to 2010 (%/year)		5.3	3.7

5.4 Power

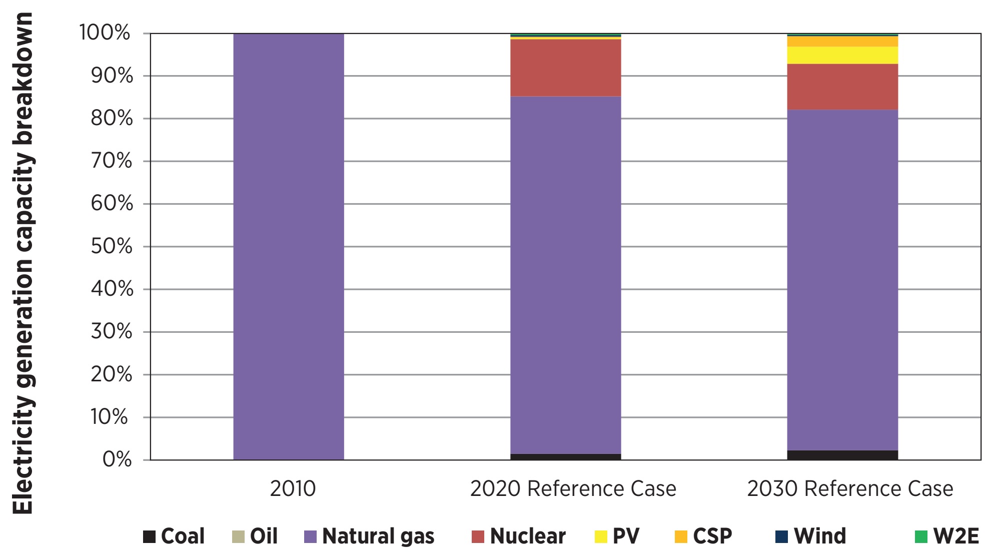
In 2010, the UAE had a total generation capacity of 23 GW and produced 98 TWh of electricity. The emirates of Abu Dhabi and Dubai collectively consumed approximately 78 TWh in 2010, constituting approximately 80% of the UAE's total electricity consumption (Abu Dhabi about 44% and Dubai about 36%) (UAENBS, 2012). The majority of the fuel used for power generation comes from natural gas, although a small amount of generation comes from oil during times of peak load. As stated previously, the power generation comes largely from natural gas fired co-generation electricity and water plants. Incorporating the latest forecasts from ADWEC extrapolated to the current power base of the rest of the Emirates (Figure 4), the Reference Case projects that power generation capacity should increase to 42 GW in 2020 and 52 GW in 2030.

The 2030 Reference Case for power production capacity includes announced projects and those underway, notably the 5.6 GW of nuclear in Abu Dhabi, 2.5 GW of renewables in Dubai and Abu Dhabi under their targets, and the 1.2 GW of coal proposed in Dubai.

Table 5: Growth in power capacity and share of renewable power in generation, 2010 and Reference Case

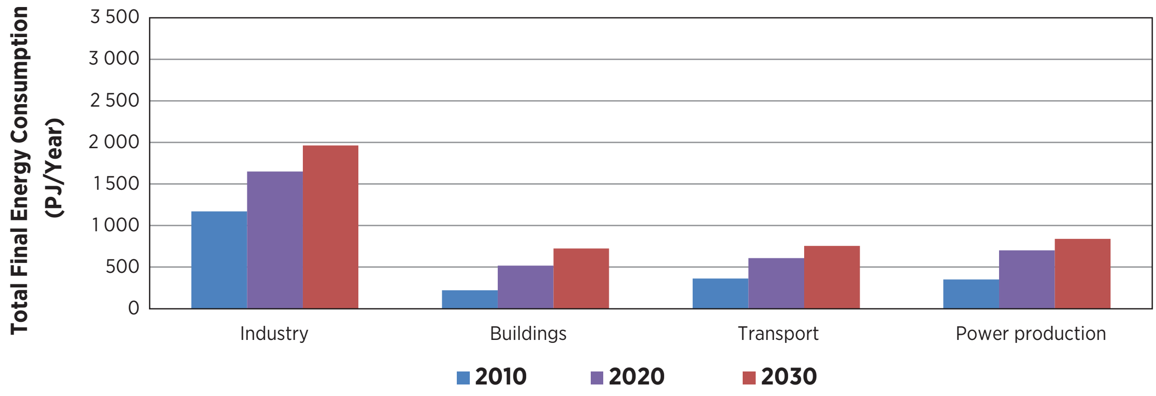
	2010	2020	2030
Total power capacity (GW)	23	42	52
Annual growth rate compared to 2010 (%/year)		6.2	4.2
Renewables share in generation (%)	0.1	0.8	3.4

Figure 5: Breakdown of electricity generation capacity in the Reference Case, 2010-2030



Note: W2E, Waste-to-Energy by producing electricity through municipal waste or landfill gas utilisation.

Figure 6: UAE Reference Case, 2010-2030



5.5 Total final energy consumption in the UAE

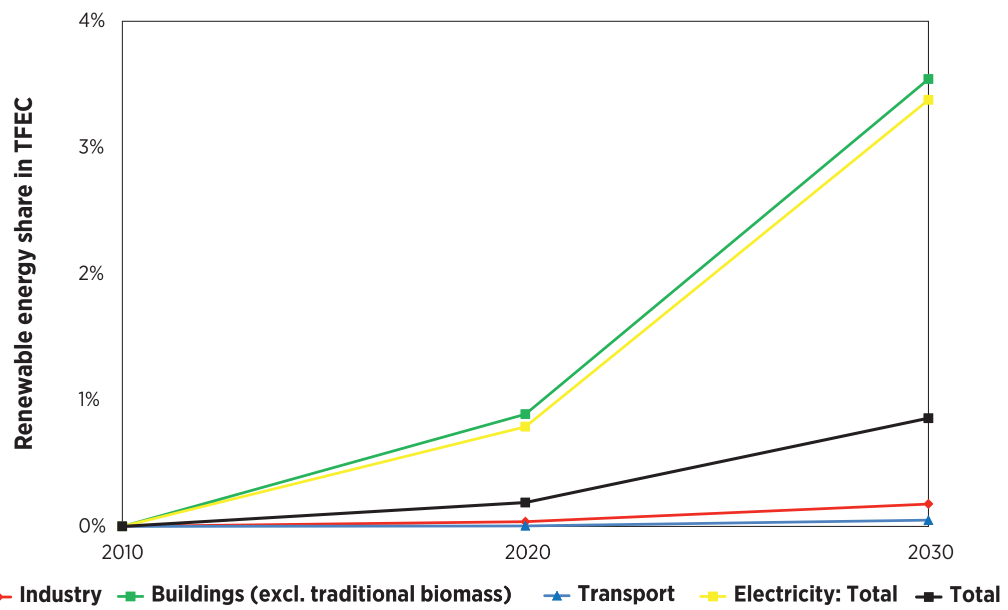
With the combined sectoral forecasts, TFEC in the UAE is expected to increase from 1.8 EJ in 2010, to 2.8 EJ in 2020 and 3.4 EJ in 2030 (approximately 3.4% annual growth between 2010 and 2030). The figure below summarises expected energy demand growth by sector.

For renewable energy as a share of TFEC, the Reference Case shows increases from 0% in 2010, to 0.2% in 2020 and 0.9% in 2030. The highest share is achieved in the building sector at 3.5%, followed by about 3.4% in the power sector, 0.2% in industry (incl. electricity), and 0.1% share in the transport sector by 2030.

Table 6: Growth in TFEC and renewable energy share, 2010 and Reference Case

	2010	2020	2030
TFEC in the UAE (EJ/year)	1.8	2.8	3.4
Annual growth rate compared to 2010 (%/year)		4.7	3.4
Renewables share in TFEC (%)	0	0.2	0.9

Figure 7: Renewable energy share in the Reference Case, 2010-2030



6 REMAP TECHNOLOGIES: UAE RENEWABLE ENERGY RESOURCES AND COSTS

Based on resource availability, solar technologies (solar PV, CSP, solar hot water) are the primary REmap Options for UAE. Wind, waste-to-energy, and geothermal also have potential that should be considered as part of a comprehensive renewable energy portfolio. This section reviews the UAE's resource base, as well as recent energy supply cost dynamics.

6.1 Solar PV and CSP

The UAE receives over 10 hours of daily sunlight on average – highly significant considering that on average the country has roughly 350 sunny days per year. Total solar energy received is about 6.5 kWh/m^2/day and direct normal solar radiation is 4-6 kWh/m^2/day, depending on location and time of the year (Alnaser and Alnaser, 2011).

The main challenges in deploying large-scale solar in the region is the dust particles/haze and humidity that cause (1) a significant reduction in the direct normal irradiance (DNI), afflicting CSP operations primarily, and (2) soiling of panels and mirrors, necessitating frequent cleaning. Most plant operators, including Shams I, have found ways to address soiling through cleaning. Research is ongoing to improve both cleaning processes and the actual surface-resistance to dust accumulation. This is done in collaboration with real-time weather and dust data monitoring by Masdar Institute's Research Center for Renewable Energy Mapping and Assessment. As the existing plants gather operational experience, more conclusive information on the impact of soiling in the region will be obtained.

Currently, CSP technologies for power generation are at a cost disadvantage vs. solar PV and require sophisticated operations. Relying on dry cooling for the power cycle heat exchangers is possible, thus alleviating pressure on scarce water resources. However, this comes at a capital cost and reduced plant efficiency. CSP's primary advantage lies in the ability to provide energy storage via thermal media options (from molten salts to concrete and sand). Given this, CSP will remain a valuable renewable energy generation option, though it is not expected to scale up as quickly as solar PV.

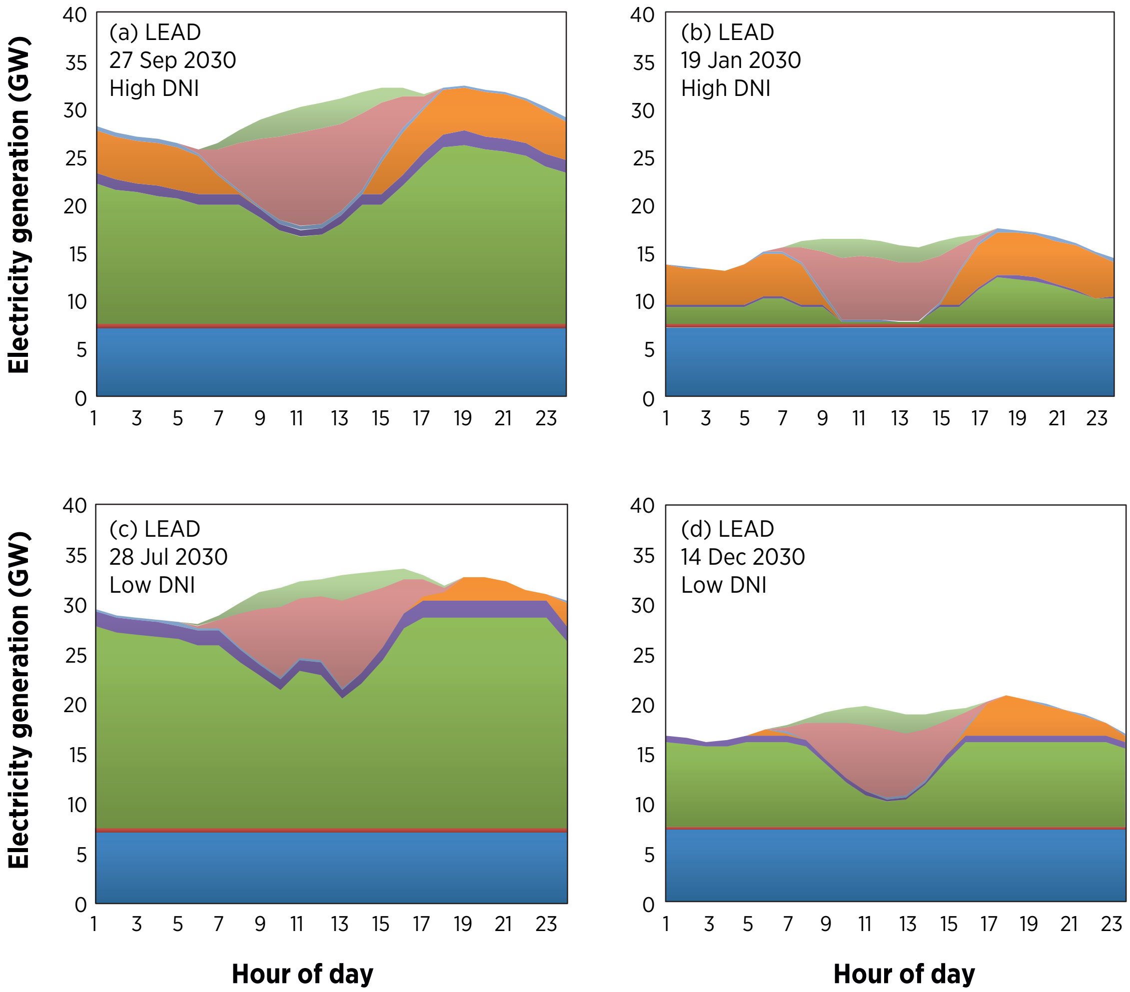
While some of the challenges facing CSP exist for solar PV, solar PV's modular scalability, operating simplicity, and ability to utilise diffuse light make it better for providing the largest contribution of renewable energy in the Gulf region. PV has a proven track record in the operation of the 10 MW facility at Masdar City (both crystalline and thin film Cd-Te), and, although high temperatures reduce performance (this effect is reflected in our performance assumptions), it adequately matches the daily profile of demand peaks, providing valuable reduction in demand for low-utilisation peaking plants that run on expensive fossil fuels. Actual practice from the 10 MW solar PV installation at Masdar City shows that for solar PV, 1700 full-load hours (FLH) can be achieved, and higher values should be expected in locations further inland due to the lower atmospheric dust concentrations.

A portfolio of solar PV and CSP with thermal energy storage installations provides good integration opportunities to meet daytime and evening demand requirements. A study simulating the hourly demand and expected solar energy generation based on the measured irradiance of an actual year shows that even on "bad" solar days (low DNI), solar PV and CSP with thermal energy storage can eliminate the diurnal mid-day and evening peak seen by the electricity system (Figure 8).

6.2 Wind

The UAE's wind resources are much less abundant compared to solar, but they still show reasonable potential, especially in the Northern Emirates or off-shore for specific application and local island grids. Average wind

Figure 8: Renewable energy contribution given different irradiance and demand profiles in the UAE



Source: Sgouridis et al. (2013)

Note: BIPV or SRT: Rooftop Solar, Legacy Cogen: Gas Turbine (as opposed to combined cycle)

speeds are shown in Figure 9. The UAE's wind and solar resources are shown below.

6.3 Waste to energy

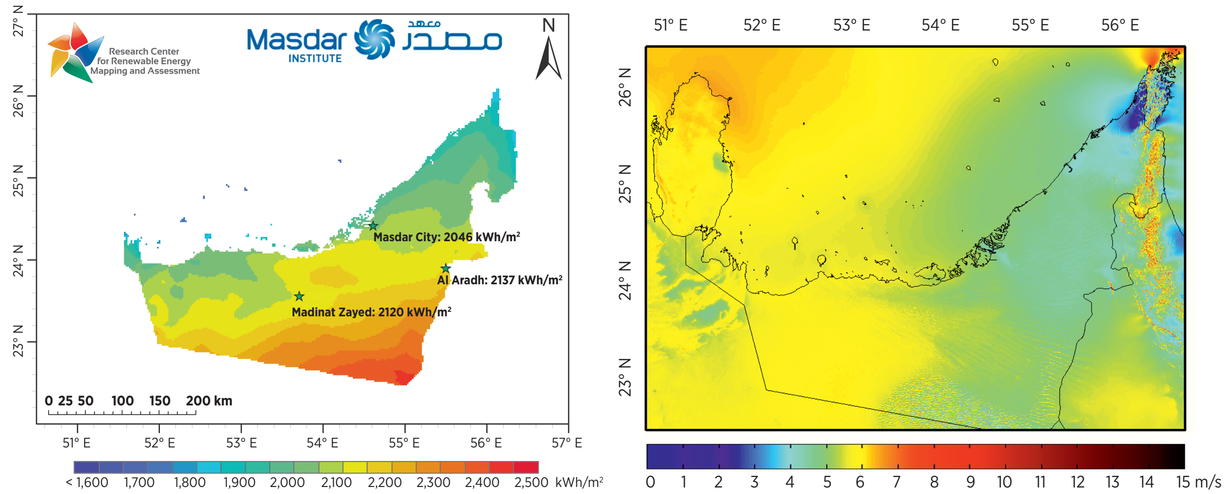
The UAE has a high per capita waste generation, which is primarily disposed at unlined landfills. Non-recyclable waste can provide a dependable but limited energy source that can be used for base load power, albeit constrained by the expected volume of non-recyclable waste available to approximately 900 MW (Atkinson, 2013). The planned TAQA 100 MW waste to energy plant with a 90% load factor is expected to combust around 1 million tons per year of municipal solid waste. Since Abu Dhabi generates 33 000 tons of waste per day and Dubai a similar amount, 900 MW potential is reasonable but conservative.

6.4 Other renewable resources

Geothermal

While the UAE is not located on a high geothermal gradient, there are areas that could provide a sufficient supply of hot water for thermal applications (primarily base-load cooling using absorption chillers, and to a

Figure 9: UAE wind and solar map



2010 Global Horizontal Irradiance Map

Average Wind Speed Map 100 m

Source: Masdar Institute Research Center for Renewable Energy Mapping and Assessment

lesser extent thermal desalination using multiple-effect distillation (MED) technology).

Geothermal for cooling and desalination, sea currents and direct deep sea-water cooling should also be investigated, but are unlikely to provide a substantial contribution before 2030.

Hydro/ocean

Hydro power is not available as an energy generation option due to the extremely arid climate. The Northern Emirates' geomorphology of high mountains next to the coast could allow the use of sea-water based pumped-storage hydropower systems, but they would be an expensive option requiring the construction of fully sealed reservoirs, as the karstic geology is extremely porous.

Wave and tidal energy options are very limited, although the possibility of using sea currents needs to be investigated further, as anecdotal evidence indicates very strong currents are present on the Gulf of Oman side. Finally, the option of using the deep cold layers of the Gulf of Oman waters for cooling of the nearby cities could also be investigated, although this has not been included in the REmap Options.

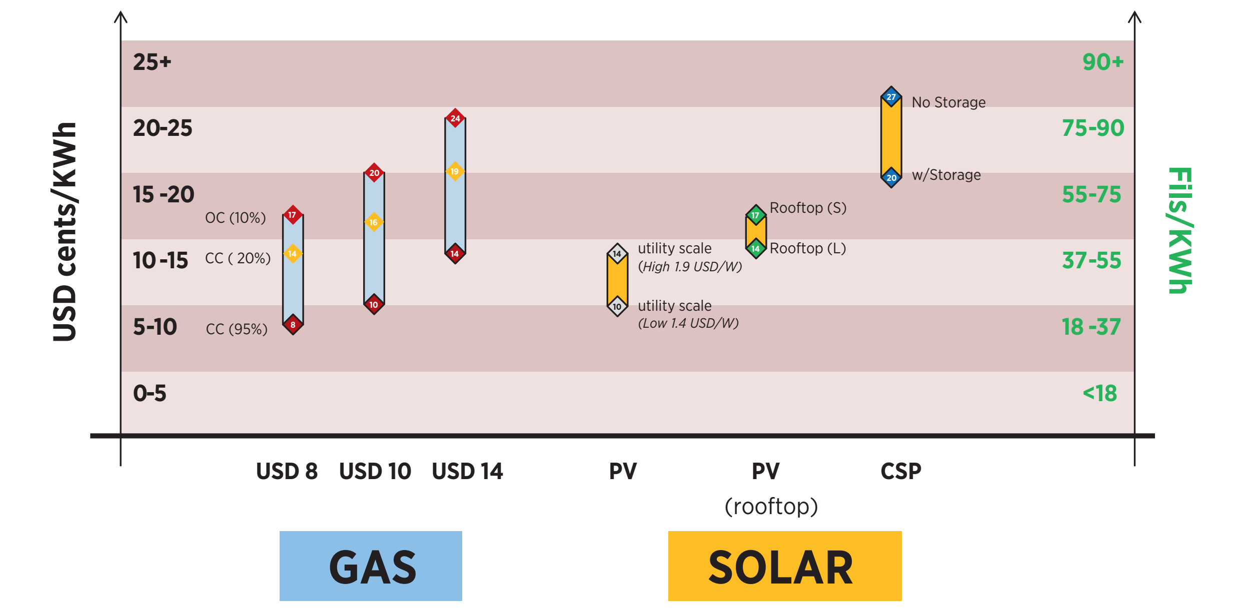
6.5 Comparative energy costs

Renewable energy costs in the UAE – in line with global trends – continue to rapidly decline, favourably reframing their attractiveness vs. other supply technologies. For instance, local solar PV costs have fallen from USD 7/Watt in 2008 to less than USD 1.5/Watt today (over 70% decrease). At the same time, short run marginal gas prices in the same period have risen from less than USD 1.5/MBtu to over USD 12/MBtu (about 8 times increase).

The levelised cost of electricity (LCOE) is one way to understand the country's new cost dynamics – and the implication for the economic potential of renewable energy. Figure 10 below evidences the impact, showing LCOEs for gas at different prices and for three solar applications. Although solar PV would not cover night-time generation (not reflected in LCOE), its potential for day-time fuel-saving is pronounced.

The chart also importantly frames competitiveness in terms of USD/MBtu, which is the key reference for the UAE power market as it faces incremental costs of up to USD 8/MBtu for new domestic production and USD 12-18/MBtu for imports. It indicates that above USD 8/MBtu, solar PV is economically viable as a fuel saver. Giv-

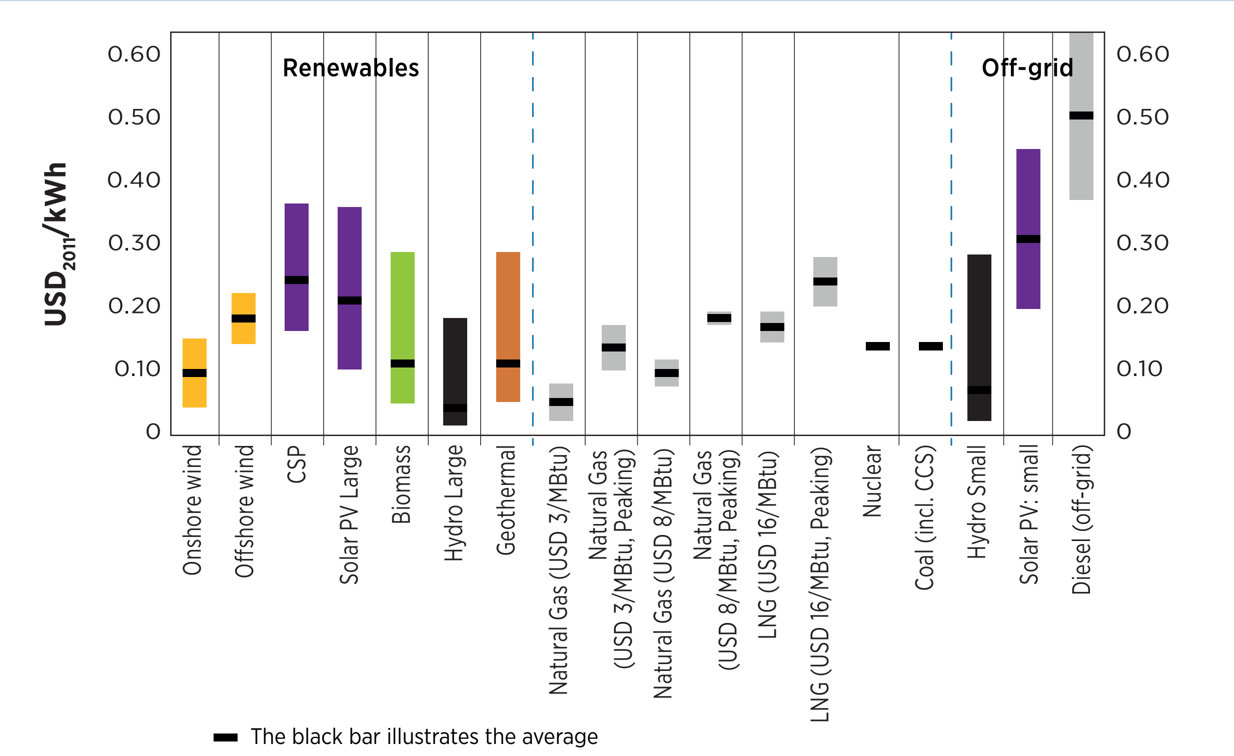
Figure 10: Levelised costs of electricity: Indicative current estimates for solar and gas-fired power



Source: UAE MOFA, Directorate for Energy and Climate Change

Note: 2013 and 2014 cost estimates. Assumes weighted average capital costs of 8%. LCOE is one way to examine the cost-competitiveness in a static analysis. LCOEs do not substitute for the need to do detailed, nodal modelling of the electricity system if one wants to identify the least cost combination of new generating capacity, type and location to achieve a least cost expansion or maintenance of the electricity system; the analysis would also need to include the demand-side, such as efficiency and demand-side management levers. Bid results from Dubai's November 2014 tender for 100 MW of PV have not been incorporated into the graph.

Figure 11: Levelised costs of electricity: Utility and off-grid power in OECD countries



Source: IRENA (2014b)

en that the UAE is already an LNG importer and paying over USD 12/MBtu, solar PV is therefore highly attractive for curbing energy costs. The November 2014 bid results in Dubai imply solar PV could even be attractive above USD 4.5/MBtu. CSP with thermal energy storage could also be economically competitive when gas prices are above USD 14/MBtu.

Renewables also compare well with non-gas supply options. Recent research in Abu Dhabi indicates that coal without carbon capture and storage would be economically viable above USD 7/MBtu – though this leaves out the hundreds of millions of dollars required to build coal import and handling facilities, which would markedly reduce competitiveness. It also assumes no cost (financial or reputational) from carbon emissions. Nuclear is estimated to be economically competitive with gas-fired generation above USD 9.5/MBtu.

UAE-specific data on nuclear and coal is unavailable, as plants are not yet built, but international LCOE data from IRENA's REthinking Energy publication (Figure 11) provides a potentially useful international context (IRENA, 2014b). It underscores renewable energy's new competitiveness with traditional generation technologies.

7 REMAP OPTIONS AND REMAP 2030

The analysis for REmap 2030 finds that a 10% renewable energy share is economically feasible for the UAE – and can generate net savings for the economy even before accounting for external costs associated with human health and the environment. This section describes the key assumptions to estimate the deployment potential of the REmap Options that can be applied in the industry, buildings, transport, and power sectors, capped at 10% of TFEC by 2030. The percentage was selected as a relatively modest, achievable number, though higher penetration of renewables is of course possible. The section evaluates the effect the selected technologies have on financial indicators of the energy system and compares them to the Reference Case. Each technology's and sector's potential is reviewed, and separately, health and environmental benefits and fossil fuel savings are estimated. A cumulative discussion of results concludes the section. While the November 2014 bid results in Dubai for 100 MW of solar PV have been not included in the analysis, as the project has not been realized, they imply even greater savings from renewable energy deployment in the UAE.

7.1 Industry

Two REmap Options are defined, namely solar thermal and geothermal for industrial heat. Grid-connected industry would also use renewables deployed in the power sector and described later in this section. Collectively, renewables are estimated to meet 5.5% of industrial energy needs by 2030.

REmap suggests that solar thermal could provide up to 3.3% of industrial energy needs by 2030. Several industrial processes including cement, ceramics manufacturing and food processing require substantial amounts of process heat as an input (US EIA, 2014), presenting a significant opportunity for renewable energy integration. CSP systems are an option (especially Fresnel or small parabolic trough systems) for higher grade heat, while evacuated tubes and evacuated flat panels can provide lower cost and only slightly lower quality heat that could fit multiple applications.

Geothermal energy could provide around 0.8% of industrial energy needs by 2030. Deployment involves the drilling of at least two deep wells that are used in a closed circuit. Hot brines from the geologic formation wells are pumped to the surface, pass through a heat exchanger to recover their heat content and are then reinjected. Alternatively, in the absence of aquifers, there is the possibility of artificially fracturing the formation and using water from elsewhere as a heat transfer fluid, although this is unlikely to be used in the UAE. Geothermal energy is somewhat more expensive than solar thermal since the UAE does not have a significant geothermal gradient potential, but it permits very high levels of availability as it is independent of the climate. Given this, it was also considered as a REmap Option for the portion of the renewable sources for process heat required in low temperature process heat applications.

Table 7: Renewable energy consumption breakdown in the industry sector, 2010 and REmap 2030

	2010 PJ/year	2030 PJ/year	Share of TFEC (%)
TFEC	1169	1962	–
		REmap Options applied:	
Solar thermal	0	65.6	3.3
Geothermal	0	16.4	0.8
Renewable electricity from the grid	<1	25.0	1.3
Total	<1	107	5.5

7.2 Buildings

Three specific options for the building sector were applied in the UAE analysis for REmap 2030: (1) solar water heating, (2) cooking with electricity from renewables, and (3) significantly, solar space cooling (A/C) contributing to centralised district cooling systems. Collectively, when also including renewable electricity consumed by other appliances in the sector, renewable energy is estimated to meet 29% of the building sector's energy needs by 2030.

Solar water heaters together with solar cooling could provide almost 8% of building energy needs by 2030, as solar water heaters in particular are already competitive under current energy prices in the UAE – and will become even more so as gas prices rise.

Table 8: Renewable energy consumption breakdown in the buildings sector, 2010 and REmap 2030

	2010 PJ/year	2030 PJ/year	Share of TFEC (%)
TFEC	222	710	–
		REmap Options applied:	
Solar water heating	0	16.5	2.3
Cooking electricity (renewable power demand)	0	5.8	0.1
Solar space cooling	0	38	5.3
Renewable electricity	<1	156	22
Total	<1	210	29

7.3 Transport

REmap 2030 evaluates the potential of four technology options: (1) modal shift passengers from road to electric tram, (2) modal shift freight from road to electrified rail, (3) passenger battery electric vehicles, and (4) plug-in hybrid vehicles. While not necessarily renewable energy technologies by themselves, they shift demand through electrification into the power sector, where REmap 2030 estimates that renewable power could provide almost a quarter of supplied electricity. For this reason, these REmap Options are estimated to enable 1.1% renewable energy consumption in the transport sector by 2030; electricity cumulatively amounts to around 4% of sector TFEC.

The number of vehicles in Abu Dhabi alone is projected to increase from approximately 600 000 in 2010 to between 1.5 and 2 million in 2030, although the number of vehicles per capita is expected to level out by this time. Abu Dhabi emirate estimates vehicle ownership at about 387 vehicles/1 000 people in 2010, with this number increasing to 581 vehicles/1 000 people in 2020 and 642 vehicles/1 000 people in 2030 (Chinery, 2010). In comparison, the UAE's vehicle ownership in 2010 was reported to be at an estimated 264 vehicles/1 000 people (WHO, 2013). There exists a potential for replacement with electric vehicles, alternative fuel vehicles and/or hybrid cars. Pure electric vehicles have demonstrated their ability to operate in the climate of the UAE through a pilot effort at Masdar City where a fleet of Mitsubishi MiEVs has been operational for more than three years.

Electrifying the transportation sector (whether through electric hybrid vehicles or electrified railway networks) would provide sufficient savings to be cost effective when accounting for the opportunity cost of fuel, carbon and pollutant emissions avoidance (Al-Hadhrami, 2009). However, such changes are likely to occur in significant numbers only through regulatory intervention – either by revisiting fuel subsidies, or through fleet emissions standards (similar to the US' CAFE) and purchase incentives. The latter have the potential to address the principal-agent problem where savings from switching to electric transport go to the government (through fuel subsidy reduction) and not the consumer.

Public transportation has generally faced a slow uptake but the success of the Dubai metro in providing mobility is encouraging. With ridership exceeding 120 million person-trips (Al-Sharfan, 2013), the potential is significant. Furthermore, the Etihad Rail project has the potential for real savings in heavy goods transportation emissions and fuel consumption as compared to road transportation of such goods (Etihad Rail, 2013). Were this rail to be electric and fuelled by renewable energy instead of diesel, the savings could be even greater. The expansion of the Dubai metro, as well as the addition of the Abu Dhabi metro, has the ability to offset some

Table 9: Electricity consumption breakdown in the transport sector, 2010 and REmap 2030

	2010 PJ/year	2030 PJ/year	Share of TFEC (%)
TFEC	222	718	–
		REmap Options applied:	
Plug-in hybrid	0	0.4	0.1
Battery electric	0	3.2	0.4
City tram	0	0.7	0.1
Long-range train for freight	0	0.5	0.1
Renewable electricity from other transport demand	0	2.8	0.5
Total	0	7.6	1.2

of the personal vehicles and inefficiencies due to traffic congestion, but it is unclear at the time of this writing what exactly that offset would be (ADB, 2013).

With these factors considered, REmap 2030 estimates that 14% of passenger vehicles in the UAE could become plug-in hybrid or pure electric vehicles, 5% of passenger transportation needs could move from passenger vehicles to electrified mass transit (trams and metro) , and the Etihad Rail project could be electrified, instead of using diesel as planned. Even with these options, the remaining road transportation (for both passenger and freight) still utilises diesel and gasoline mainly.

7.4 Power

REmap 2030 evaluates the potential of six renewable technology options in the power sector: (1) solar PV (utility-scale), (2) solar PV – rooftop, (3) solar PV for RO desalination, (4) landfill gas, (5) wind onshore, and (6) solar CSP parabolic trough (PT) with Thermal Energy Storage. Collectively, they are estimated to provide 25% of power output by 2030. The REmap Options also explore and suggest resolution of the critical linkage between power and water production.

Electricity consumption is expected to increase substantially between now and 2030. Despite efforts to diversify the energy mix with large-scale renewable energy, clean coal and nuclear power projects (all on the horizon), the UAE will still be overwhelmingly dependent on natural gas cogeneration to produce electricity and desalinated water in the future. However, with the declining cost of renewable energy, and the feasibility of RO increasing, utility-scale renewable energy plants and large or commercial rooftop PV make economic sense for the utility if policies can be put in place to support this. Viewed as fuel extenders or savers, the installation of renewable energy capacity will allow an easier transition to higher imported natural gas prices, especially after the current Dolphin project[4] is up for renegotiations in 2032. As electricity is linked to all of the above mentioned sectors in the UAE, diversifying electricity production is vital in order to prevent shortages or outages in the future. The contributions of each technology are shown in table 10.

Table 10: Renewable power generation breakdown, 2010 and REmap 2030

	2010 TWh/year	2030 TWh/year	Share of total power generation (%)
Power generation		232	–
		REmap Options	
Solar PV (Utility)	~0	28.6	12.3
Solar PV (Rooftop)	0	13.9	6.0
Solar PV for RO Desalination	0	3.2	1.4
Landfill Gas ICE	0	2.1	0.9
Wind Onshore	0	1.2	0.5
Solar CSP	0	9.4	4.1
Total	0	58.3	25

The deployment scale of renewable technologies in the Reference and REmap 2030s is contrasted in Figure 12. Whereas in the Reference Case almost all renewable energy is in the power sector, in the REmap 2030, the share of renewable-sourced heat (also used for cooling) increases from 6% to 43%. However, renewable power is still the largest source of renewable energy, with solar PV making up over 40% of all renewable energy, followed by solar thermal heat with over one-third, and CSP with 12%. Solar energy collectively makes up 90% of all renewable energy in REmap 2030, with the remaining 10% provided by geothermal heat, wind power and waste-to-energy systems.

Figure 13 additionally illustrates the implications for generation capacity, and compares them to the Reference Case. Notably, solar PV installations jump from 1.6 GW to 21 GW, and solar CSP expands from 1.3 GW to 5.8 GW with new CSP including thermal energy storage. The reduction of 5.5 GW in natural gas capacity is offset entirely by dispatchable CSP. While the capacity additions are significant, they are economically justified by the savings on fossil fuel costs. It is notable that there is no additional coal and nuclear capacity.

REmap 2030 also addresses the linkage between water desalination and power production by assuming the in-

4 The Dolphin Gas Project is a joint, cross-border gas transmission project between Qatar, the UAE and Oman. Natural gas is produced and processed in Qatar and subsequently transported by subsea pipeline, through Qatari-UAE waters, to the United Arab Emirates and Oman. The first cross-border energy-related venture in the region, the Dolphin project is developed and operated by the Abu Dhabi-based Dolphin Energy Limited.

Figure 12: Renewable energy deployment by technology in 2030: Reference Case and REmap 2030

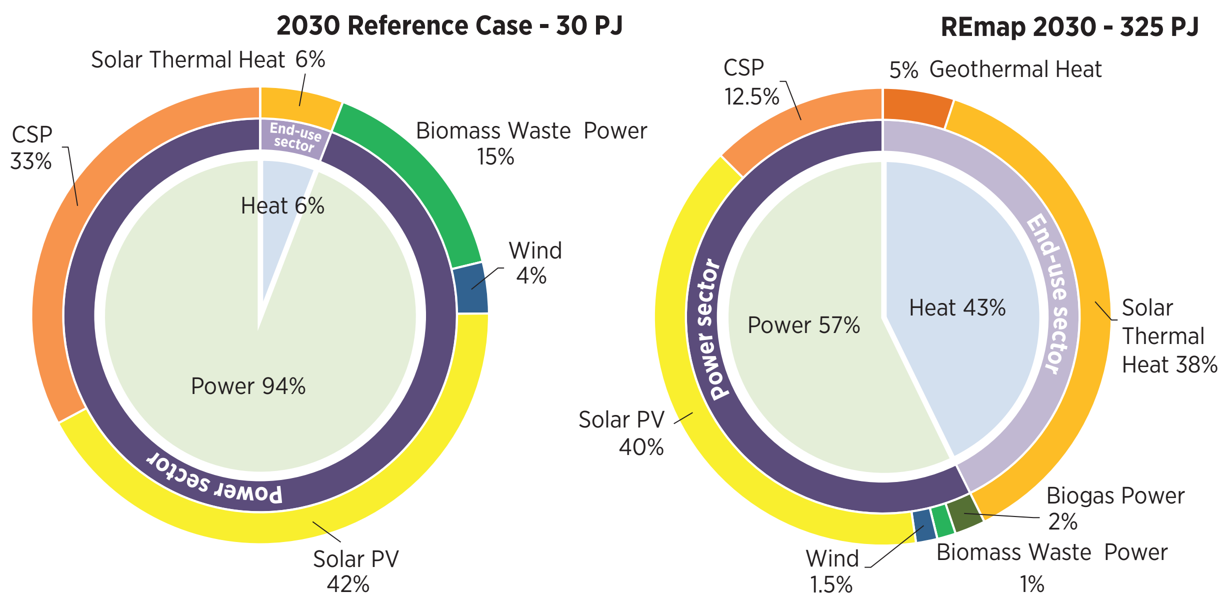
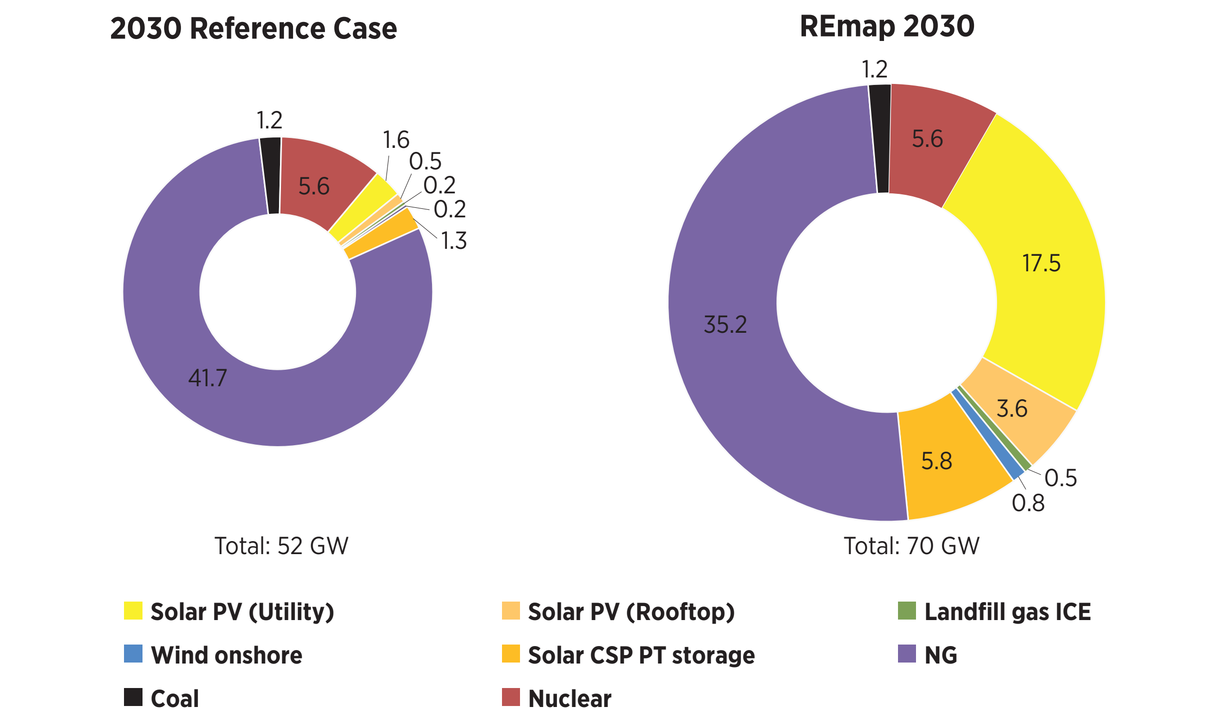


Figure 13: Power capacity breakdown in 2030: Reference Case and REmap



stallation of sufficient capacity of RO to meet the water demand that is not satisfied by the water generated by the thermal desalination plant when operated at their optimal PWR (MW/MIGD) point. For the initial purpose of REmap 2030 analysis, it is estimated that every kWh of power that is diverted from thermal generation results in a reduction of ~0.02 m^3 of desalinated water production, assuming a PWR of 15. This water "gap" would need to be covered either by RO plants or through new MED plants that use low-grade heat from solar or geothermal. Typically RO requires 3–5.5 kWh/m^3 and MED 4.4–6.7 kWh/m^3. In this case we choose to work with RO and assume that approximately 3.5 kWh of electricity will need to be provided for every m^3 of displaced water generation. It should be noted that currently in the winter the system operates at PWR points of 5 or below. With this assumption, we therefore increase the total system-wide energy efficiency of water desalination compared to current operations.

In REmap, additional solar PV capacity was assigned to power desalination plants (PV desalination), to which we included the RO costs as an additional technology in the REmap Options. Based on the substituted natural gas in REmap, an additional 1.5 GW or 3.2 TWh of solar PV would be required to produce 200 MIGD using RO plants (assuming a PWR ~ 15:1). As discussed earlier in Section 3, this implies an additional capacity of 12% of the total UAE installed desalination capacity of 1583 MIGD in 2012.

7.5 Discussion of REmap findings

REmap 2030 shows that achieving 10% renewable energy in TFEC is technically feasible and economically preferable, vs. the 0.9% share in the Reference Case. This section explains the ramifications and underpinning data in five steps: (1) a summary of renewable energy penetration in each sector, (2) a description of the economic performance of the different technologies under USD 8/MBtu and USD 14/MBtu gas assumptions, (3), an analysis of gas and oil savings, which could even result in new export revenue and even greater economic attractiveness of renewables, (4) an analysis of carbon savings, and (5) a discussion of the key insights.

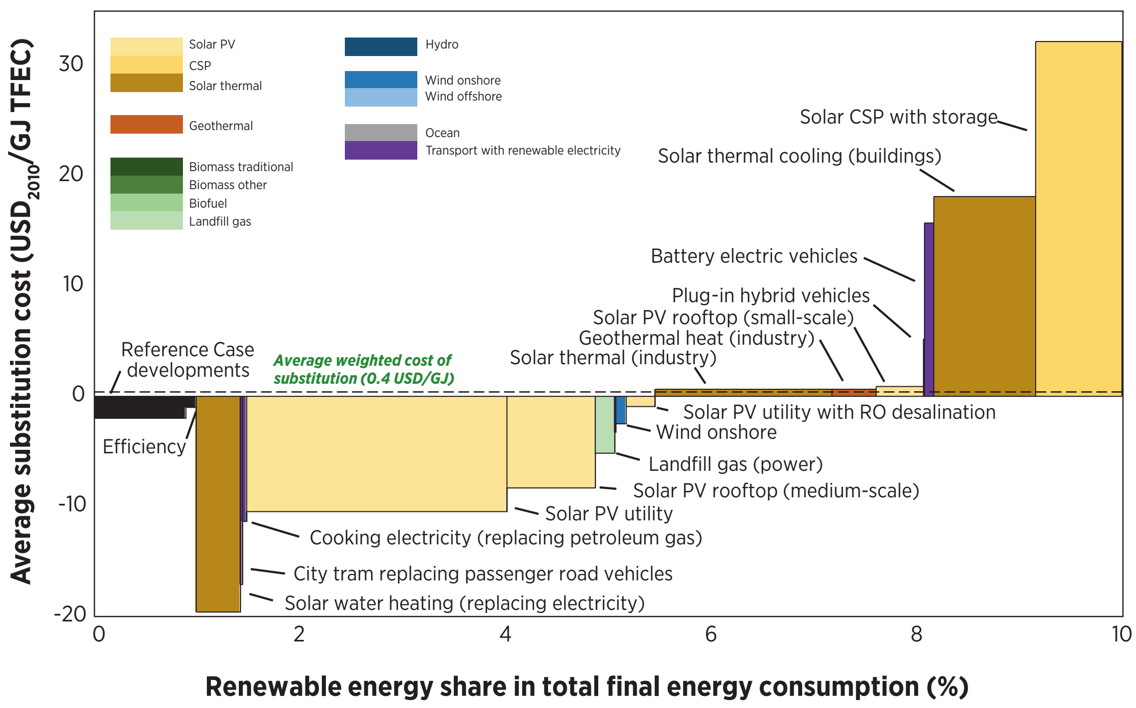
Renewable Energy Penetration by Sector

Table 11 shows the contributions to renewable energy deployment as a percentage of TFEC by sector. The buildings and power sectors lead the REmap results with 29% and 25% renewable energy shares, respectively, with the industry and transportation sectors behind in terms of overall renewable energy share, at 5.5% and 1.1% , respectively. For industry, this limited share is largely due to the expectation that manufacturing and heavy industry sectors will still be dependent on natural gas. For transport, the result owes to the expected continued dominance of gasoline-powered passenger vehicles, with limited uptake of electrified public transport.

Table 11: Summary of REmap 2030 for the UAE

	Renewable share of:	as % of:	2010	2030 Reference Case	REmap 2030	RE use REmap 2030 (PJ/year)
Industry	Heat only	Heat consumption	0%	0%	4.6%	82
	incl. renewable electricity	Sector TFEC	0%	0%	5.5%	107
Buildings	Heat only	Heat consumption	0%	11%	80%	56
	incl. renewable electricity	Sector TFEC	0%	4%	29%	210
Transport	Fuel only	Fuel consumption	0%	0%	0%	0
	incl. renewable electricity	Fuel TFEC	0%	0%	1%	7.6
Power		Generation	0%	3%	25%	210
Total		**TFEC**	**0%**	**1%**	**10%**	**325**

Figure 14: REmap Options: Cost supply curve by resource, from the business perspective



Note: Natural gas is priced at USD 8/MBtu, and crude oil at USD 90/bbl.

Costs of REmap Options

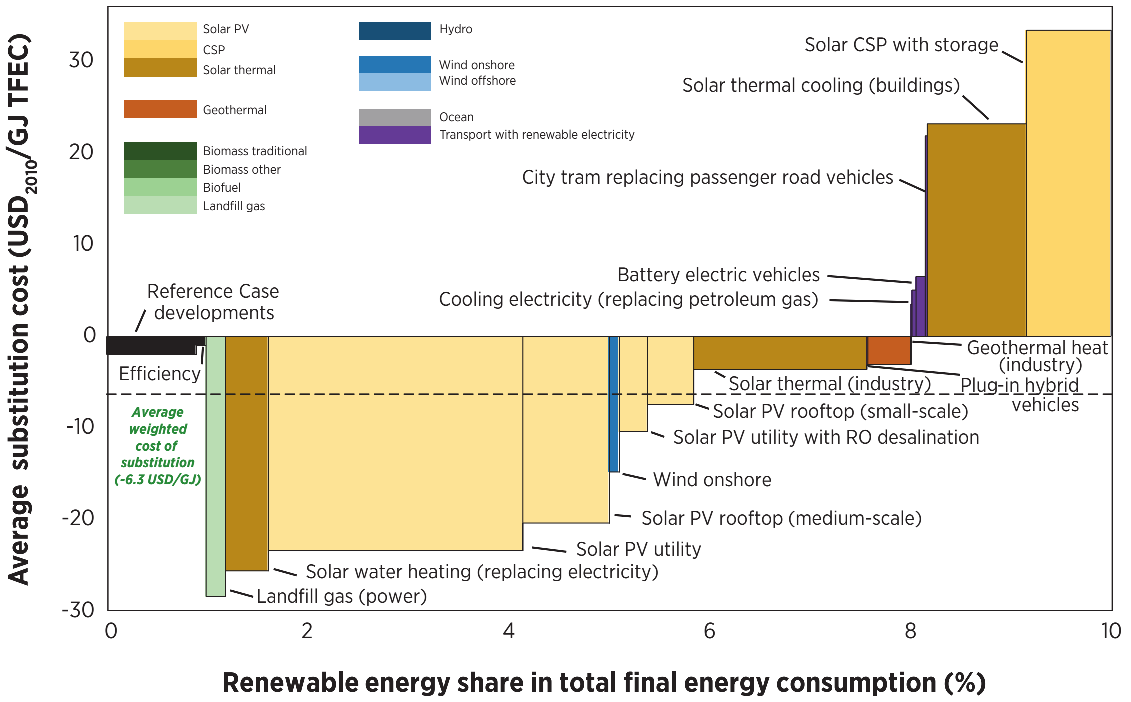
The two charts in this section show the substitution cost and potential of the REmap Options, based on the perspective of business and government. The combined portfolio of technologies can achieve 10% renewable energy in TFEC with net savings in the energy system of USD 1.9 billion in 2030 when viewed from the government perspective.

On the y-axis is the average substitution cost (in USD_{2010} per GJ of final renewable energy), *i.e.*, moving from fossil fuels to renewable energy. If the bar for a technology is below the x-axis, it generates net savings for the energy system – and therefore "pays for itself." Technology bars above the x-axis require additional financial support (*i.e.*, a subsidy) to be viable. The further the technology bar extends from the zero level on the x-axis, the cheaper (negative) or more expensive (positive) the technology is compared to the fossil fuel it could replace. On the x-axis is the contribution of each technology to the renewable energy share in TFEC, capped at 10%. The wider the width of the bar, the greater the contribution of that REmap Option to the 10% share.

For the business perspective, Figure 14 shows the marginal substitution costs if oil is at USD 90 per barrel and gas is at USD 8/MBtu (below the current incremental cost of gas in the UAE). This is a reasonable scenario. As described in the methodology, from the business perspective, any subsidies are included in the cost analysis, and a standard 6% discount rate is used.

The cost-effectiveness and deployment potential of solar PV (utility and auto-producer) and solar water heating are immediately obvious. They easily "pay for themselves" and together contribute nearly 4% to TFEC. Onshore wind and landfill gas, also generate slight net savings. Solar thermal heat in industry, geothermal heat, and rooftop solar PV nearly break-even and could contribute 2% to TFEC. The large contributions of solar space cooling for buildings and solar CSP with energy storage, however, would result in higher additional cost (though, again, would be offset by the savings from

Figure 15: REmap Options: Cost supply curve by resource, from the government perspective



Note: Natural gas priced at USD 14/MBtu, oil at USD 120/bbl.

cheaper renewable energy technologies). The average substitution costs for the entire portfolio is USD 0.4 per GJ – indicating a minor incremental cost above the Reference Case to achieve 10% even under conservative oil and gas prices.

The picture becomes overwhelmingly cost-effective when the analysis looks at higher fossil fuel prices of USD 120/barrel oil and USD 14/MBtu (the recent marginal gas cost in the UAE), as shown in *Figure 15*. This case, known as the government perspective, with a discount rate of 10%, shows that the majority of the technologies become cost-effective, with only electric vehicles, CSP, and electrified public transport, and solar cooling still being more expensive than the conventional counterpart. The average substitution costs for the entire portfolio is USD -6.3 per GJ, indicating substantial savings for the UAE's total energy system.

The associated investment requirements and paybacks for the 'government perspective' are detailed in Table 3. By achieving a share of 10% renewable energy in REmap 2030, the UAE would generate annual incremental savings of USD 1.9 billion by 2030 vs. the Reference Case.

The investment requirements for the 10% share would be USD 7.3 billion per year (average between today and 2030), compared to the Reference Case's USD 2.3 billion allocation for renewables, which covers already announced projects and targets. REmap 2030 would also avoid the need for USD 0.1 billion of fossil fuel-fired power capacity, resulting in a net incremental investment requirement for renewables of USD 4.9 billion vs. the Reference Case.

But this investment comes with high paybacks from avoided fossil fuel consumption. The REmap Options that are cheaper than fossil fuels (*i.e.*, those with bars below the x-axis) result in energy system savings of USD 4.5 billion per year by 2030. The REmap Options that are more expensive (*i.e.*, those with bars above the x-axis) would require USD 2.6 billion per year by 2030 of government support to make them viable (indicated

Table 12: REmap Options: Financial indicators from the government perspective

Changes in the costs of the energy system (in 2030)	**(USD bln/year)**
Incremental savings from REmap 2030 vs. Reference Case	1.9
– Savings from REmap Options cheaper than fossil fuels	4.5
– Subsidy needs for REmap Options more expensive than fossil fuels	2.6
Total health and environmental savings from REmap 2030 vs. Reference Case	from 1.0 to 3.7
– Savings from reduced human health externalities	from 0.2 to 0.6
– Savings from reduced CO_2 externalities	from 0.8 to 3.1
Total incremental savings from REmap 2030, including externalities	from 2.9 to 5.6
Investments (average between today and 2030)	**(USD bln/year)**
Total Reference Case investment needs for renewable energy	2.3
Total investment needs specifically for REmap Options (additional to Reference Case)	5.0
Total renewable energy investment needs for REmap 2030 (REmap Options + Reference Case)	7.3

as "subsidy needs" in the table) – but would be offset by the USD 4.5 billion annual savings for an annual energy system savings of USD 1.9 billion.

Table 12 also includes the quantified health and environment benefits from replacing fossil fuels with renewable energy. These benefits are estimated to range from USD 1 to 3.7 billion annually by 2030, based on pollutant and CO_2 cost estimates described in the methodology section. From a net economy perspective, these are substantial additional incentives for deployment. When taken into account, total savings from REmap 2030 increase from USD 1.9 billion per year in 2030 to between USD 2.9 and 5.6 billion.

Fossil fuel savings and CO_2 emission reductions

REmap 2030 shows not just gains in renewable energy deployment, but also major reductions in domestic consumption of oil and natural gas. Oil consumption – namely through deployment of vehicle and freight alternatives – drops a sizeable 8.5% in REmap 2030 compared to the Reference Case in 2030. This is espe-

Figure 16: How renewables can offset fossil fuels in 2030 Reference Case and REmap

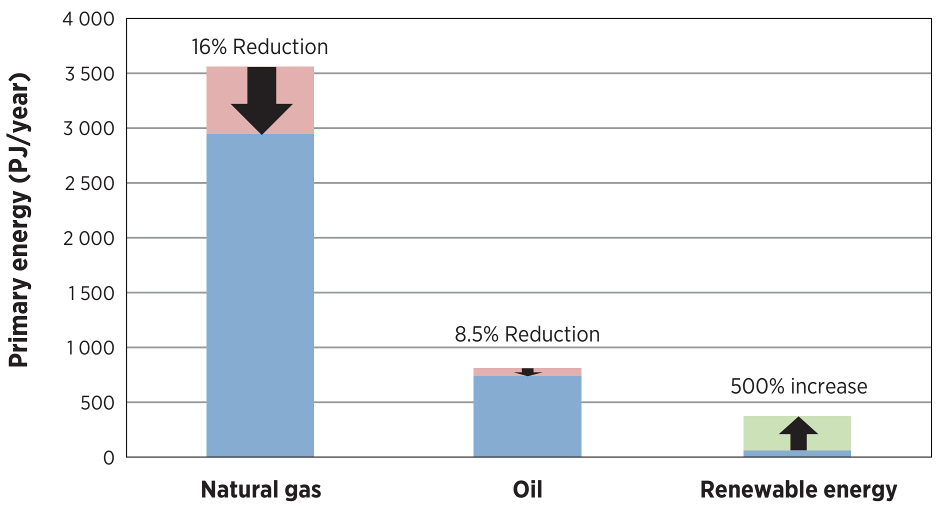
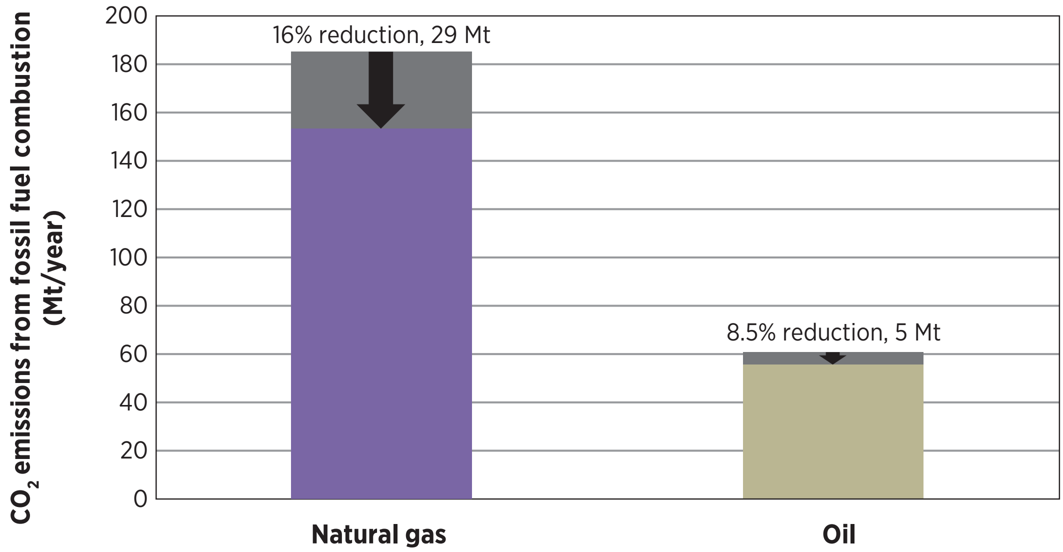


Figure 17: CO_2 emission reductions based on REmap Options



cially relevant given the UAE's role as one of the world's largest oil and oil product exporters. Some portion of that 'liberated' oil could potentially be channelled into the UAE's export stream, generating substantial new revenue for the country.

On the gas side, REmap 2030 estimates reductions of 16% in domestic consumption. While rapid demand growth in the UAE means that repurposing of these savings for exports is less likely, the potential for avoidance of additional gas imports is significant – especially with marginal costs of imports temporarily as low as USD 9-10/MBtu and more recently over 12/MBtu.

Savings in fossil fuels directly translate into mitigation of CO_2 emissions compared to the Reference Case in 2030. According to Figure 17, 34 Mt of CO_2 can be avoided annually in 2030 as the share of renewable energy in the TFEC increases to 10%. This is equivalent to 13% reduction in CO_2 emissions in the total energy system of the UAE in 2030 over the reference case.

Key Insights

The sector and economic performance of the different technologies in REmap 2030 provides five key insights.

First, power and building technologies are the low-hanging fruit for renewable energy in the UAE. Because of high incremental fossil fuel prices, major expansion into renewables is financially attractive. On the power side, an addition of 19.4 GW of solar PV (on top of the 1.6 GW envisaged by the Reference Case) pays for itself even at incremental gas prices of USD 8/MBtu. If the 100 W PV plant in Dubai is realized at the LCOE in its bid from November2014, the case could be even stronger. Onshore wind and landfill gas pay for themselves as well. The financial benefits are even higher compared to gas prices of USD 14/MBtu.

On the building side, solar thermal water heating – already economic today in the UAE – shows substantial potential, and solar thermal for cooling purposes (about 8 GW potential) offers significant additional potential, albeit at higher cost. Phase-out of LPG for cooking and substitution with renewables-powered electricity also generates major savings, though its contribution to TFEC is minimal, owing to the low share of cooking energy demand.

Second, there are major opportunity costs if renewables are not deployed. Domestic consumption of oil – which cuts into exports – could be reduced by up to 8.5%. There is accordingly a latent value to the economy if these savings can be redirected to exports. If it is assumed that savings on domestic gas consumption (up to 16%) will not be directed to exports, it is still worth noting that such savings reduce pressure on the UAE's lucrative LNG exports to Japan. These kind of trade-offs are not quantified in this analysis, but indicate that a net view of the economy could have significant implications for energy policy.

Third, the potential for renewable energy deployment in industry is large – and could be larger if industries are required to make investment decisions based on actual and not subsidised gas prices. Both solar thermal and geothermal heating are economically viable under conservative fossil fuel prices. The constraint is these industries' access to subsidized gas, which allow them to make incremental energy supply choices that make sense from their own perspective, but are uneconomic from the net perspective of the economy.

Fourth, while dispatchable CSP with energy storage is expensive, its costs can be offset by savings from other REmap Options, like utility-scale solar PV. The combination enables a network that can handle seasonal fluctuations in demand, evening demand, and solar intermittency – at no extra cost compared to the Reference Case. The combination of solar PV and CSP with energy storage notably would also dramatically reduce the carbon footprint of the sector compared to other baseload options like gas and coal. As a locally available resource, it would additionally avoid supply security risks that face coal and uranium imports.

Fifth, the transport sector will require a much greater regulatory push to viably adopt renewable energy. Given this challenge, it may be wisest in the near-term to focus on subsectors (such as aviation) where renewable energy is one of the only options to achieve the subsector's targets (like decarbonisation) – or simply to prioritise energy efficiency. However, a long-term strategy to transform the sector is needed, as it will otherwise remain a hold-out for carbon pollution and opportunity cost (loss of potential export revenue through domestic consumption).

8 BARRIERS AND OPPORTUNITIES FOR RENEWABLE ENERGY TRANSITION

Despite the findings of the REmap Case, exploitation of lower-cost renewable energy faces five key challenges in the UAE: (1) awareness of comparative energy costs among stakeholders, (2) concerns about the need to provide baseload power, (3) concerns about desalination, which is traditionally linked to power generation, (4) subsidised fossil fuel pricing, which primarily slows consumer-driven distributed generation, and (5) most importantly, disaggregated energy decision-making structures that may not enable economically optimal choices for an emirate or the country. However, there are signs that these challenges could be substantially mitigated by a combination of cost-effective technology and policy – and especially through the recent creation of several energy authorities and strategy processes that are empowered to take a holistic view of investment and policy choices.

8.1 Awareness of comparative energy costs

The cost-competitiveness of renewable energy, most notably solar PV, is a new phenomenon in the UAE and counters a decade's worth of conventional thinking that renewable energy is largely strategic and cannot compete with fossil fuels on cost. As recently as Abu Dhabi's decision to invest in nuclear in 2008/9 and Dubai's to consider coal in 2010/11, renewable energy was indeed more expensive.

While solar PV prices have drastically changed since then, perceptions among policymakers and the resulting strategies have not moved at the same pace. The price reductions assumed to be reached by 2020 or even 2025 at the time have in fact arrived in 2014. The economic rationale would hence dictate that 2030 targets are attractive for 2020, and that 2030 targets should be higher.

Equally, the out-of-date perception of "cheap gas" in the region via the Dolphin pipeline of USD 1-2.5/MBtu skews perceptions further against renewables (and all other gas-alternatives for that matter). The fact that Dolphin capacity at those price levels is fully committed – and hence not available for new capacity/demand growth – is easily misunderstood. New power capacity in the UAE should actually be compared with imports at USD 12-18/MBtu or, in a best-case scenario, domestic gas production as high as USD 8/MBtu.

Increasing awareness about these cost shifts will therefore be critical for smart future investment in energy supply capacity. Perhaps the most promising vehicle for rapid dissemination of the new data is the Ministry of Energy's federal policy taskforce. It both convenes the key decision-making entities in the energy sector and is mandated to foster debate about the right mix. The UAE Federal Green Growth Strategy, currently before the cabinet, could also be a key channel, as it evaluates options to retain robust economic growth without unnecessary environmental and carbon impacts. Renewable energy plays a large part in all UAE Green Growth scenarios, where substantially faster deployments were modelled to reveal positive cost, GDP, and employment impacts.

8.2 Baseload power concerns

The variability of solar PV and wind supply is another perception challenge for greater deployment. While grid stability has been a relatively muted concern because of the UAE's modern, flexible energy system, there is a traditional focus on building flexible base load capacity or 'dispatchable' power that can be switched on and off. Solar PV and wind, while likely less expensive than or competitive with gas, nuclear, and coal, might therefore be discounted because they cannot provide the same consistency of 24-hour power supply or on-and-off options.

Three key insights emerge from this concerns. First, that renewable energy in the UAE has an attractive role to play outside of base-load power. Although not as perfect a match between peak demand and peak PV supply availability as some might believe[5], the natural overlap of power demand for cooling and solar power supply when the sun is out provides a structural comparative advantage for the MENA region.

Second, the intermittency of renewables has brought about an increased focus on demand forecasting for integrated demand-supply planning. This opens new and valuable opportunities for optimising the system as daily and seasonal demand curves are better understood and become direct drivers for the generation mix.

In 2030, the UAE would have a minimum daily demand of 14 GW (*e.g.*, during a winter night), and a peak of 30+ GW during a summer day when cooling requirements are highest. Because gas-fired plants can fairly easily ramp-up and ramp-down their output, especially if they are relieved of partial water generation load (unlike nuclear and coal, which are preferred to have steady output), the UAE could manage peak demand with them. However, large, expensive gas plants are sometimes idle outside the peak, reducing the efficiency of investment, and building smaller, faster gas plants specifically for the peak results in lower efficiency of gas consumption. Moreover, LNG imports – the UAE's most expensive source of incremental energy supply – are required largely to provide fuel for the peak.

Interestingly, because solar PV generation coincides with much of the UAE's peak demand period, it may be able to take pressure off conventional power requirements. The forthcoming nuclear reactors and the existing supply of lower-cost gas (less than USD 2.5/MBtu) could be used to cover minimum demand, with PV covering a greater share of the peak. In the long-term, if gas prices remain high, the UAE may in fact be economically best off to encourage demand to move to the peak to utilise the lower-cost solar resource, which would shift the current grid-management paradigm. Solar could not only cover peak demand but potentially even meet minimum power requirements during daylight hours.

Third, more sophisticated demand analysis and demand forecasting also enable better demand side management to reduce overall demand intensity and align demand and supply curves – "Negawatts" (power plants not built) being the most cost-effective alternative to conventional Megawatts. Accurate data collection, analysis, and use in short- medium- and long-term planning has grown as the energy mix is being diversified. This has had positive improvements in showing how demand can be managed to accommodate the intermittency of solar and wind versus base-load power.

5 A/C load is highest when the sun is hottest and when solar production is highest – there is a lag of 1-3 hours and 'secondary' evening demand peaks are being observed in parts of the UAE.

8.3 Concerns about desalination impacts

An important concern in the wider uptake of renewable energy (and in nuclear energy for that matter) in the UAE is the difficulty of decoupling energy and water production. In other words, if renewable energy provides only electricity, and water generation continues to be supplied by the desalination stage of the thermal cogeneration plants, the total fuel efficiency of the system will plunge. Any introduction of an alternative electricity generation technology at scale will require a proportional capability to produce water so that it can allow the thermal plants to operate at their most efficient PWR.

A partial decoupling of the water generation from the thermal plants can occur through:

- electricity-based desalination that is indifferent to the energy source (primarily RO) and
- low temperature thermal desalination from alternative heat sources using MED; sources could be geothermal, or solar hot water

As of 2010, RO technology has been used in six desalination plants on the Gulf of Oman coast of the UAE (FEWA, 2010). Although these RO plants require more maintenance than a thermal cogeneration plant and thus far have mainly been located in areas of lower salinity seawater such as the Gulf of Oman, they are significantly more energy-efficient than cogeneration plants. Utilising electricity to desalinate water, these plants can use RE resources in the future (IEA-ETSAP/IRENA, 2012; Ficthner, 2011). REmap 2030, for instance, shows an economically viable pathway marrying RO with solar power.

8.4 Fossil-fuel pricing

Subsidised energy pricing can have a slowing effect on the growth of consumer-led distributed generation and renewables for transport, but is arguably much less important for larger-scale investment, where the problem lies in energy governance.

Power and fuel costs are largely cost-reflective in six of seven emirates (Abu Dhabi excepted), meaning that some financial incentives for solar water heating and other renewable energy interventions already exist. Even in Abu Dhabi, solar water heating already makes economic sense, although the emirate's heavy subsidisation of power undermines consumer rationale for distributed generation. Further tariff reform could be useful in Abu Dhabi, but the experience in the other emirates shows that consumers – who are frequently cost-indifferent – might benefit most from a mix of regulation and options to have external companies make improvements for them. In Dubai, for instance, households and businesses will shortly be able to feed solar power into the grid – and use recently-authorised energy service companies to install solar systems for them in exchange for a share of the savings in energy bills. Consumers are also already required by regulation to use solar power for 75% of their water-heating needs. These levers, in combination with energy pricing, could encourage consumer-level deployment, which has been successful in Europe and elsewhere due to its decentralised, low-risk financing and ownership.

On the utility level, by contrast, subsidisation is not particularly influential for renewable energy deployment. The state-owned utilities' goal is to reduce the subsidy bill; thus, they prioritise the most economical supply option. In a highly subsidised pricing regime, the government pockets the saving that solar PV would enable; in a cost-reflective pricing regime, the consumer would. In both scenarios, there is an economic rationale for lower cost renewables. The lack of awareness about renewables' competitiveness would then presumably be a greater challenge than pricing.

A similar story plays out in most of the transport sector. The federally mandated price of gasoline, if high by GCC standards, provides little to no incentive for consumers to move into hybrids, electric vehicles, or biofuels (or more efficient engines for that matter) and limits their interest in public transport. This limits the scope for renewable energy in the sector.

For the government – which absorbs the difference between the production cost and the market price (not to mention the potential opportunity cost of lost exports) – there is already an incentive to invest in whatever transport technology reduces its subsidy bill. Educating government stakeholders about cost-effective renewable energy options for transport is therefore valuable – in particular regarding electrified public transport, which both decouples transport from fossil fuels and has of course multiple other social and economic benefits vs. individual passenger vehicles (congestion, road safety, air and noise pollution, etc.).

8.5 Decision-making structures

Renewables are perhaps most hamstrung by the lack of governance structures that consider net costs and benefits. Take, for instance, certain cases of industrial planning. The state-owned company in charge of an energy-intensive industry often receives gas at a fixed, submarket price from the government gas supplier. The company then bases its economics on that price, instead of the actual local market value or opportunity cost of incremental gas (potentially USD 8-18+/MBtu), and would accordingly deprioritise renewables and other gas displacement measures. At the same time, the government gas supplier would not have the mandate to consider the opportunity cost or question the company's investment decisions. The supplier furthermore might not even be the same entity that procures imports at over USD 12/MBtu and is therefore not aware of the disconnect between cost and benefit. Thus, the governance structure effectively puts 'blinders' on the different entities, encouraging or allowing them to make decisions that are acceptable for themselves, but harmful for the overall economy.

In the utility sector, there are similar examples of structural barriers where the beneficiaries and the sponsors or renewables are not the same entity or sector. For instance, the entity requiring funding to develop solar plants (a utility) is not the entity which will pocket the savings of gas freed-up by solar generation (*e.g.*, the oil & gas company) unless it pays market prices for gas. By contrast, in Dubai, the utility saves expensive LNG imports when it finds cheaper alternatives and hence is less impeded to make the most efficient economic choice.

This kind of situation is widely recognised as a problem for the energy sector, and the Ministry of Energy's federal policy taskforce is intended to highlight these challenges and propose institutional solutions. It will be critical to connect funds raised from saved gas with investments in technology that further the gas savings.

The taskforce may be able to draw on the model of the Dubai Supreme Council of Energy. With its composition of all major energy producers and consumers and collective decision-making, it is easier to ensure that cost and benefit information is shared and actively evaluated. Promisingly, this approach may be used in Abu Dhabi under the recently announced Energy Authority, which is under development. This emirate-level action is especially vital as individual emirates will retain authority over energy investment decisions.

9 SUGGESTIONS FOR ACCELERATED RENEWABLE ENERGY UPTAKE

This section highlights a number of measures that could allow the UAE to capitalise on renewable energy's new cost-competitiveness, building on opportunities and challenges identified in Section 8. Initial policy work by government could focus on deployment of the technologies and applications that are economic (without subsidies) given current and expected oil and gas prices, with a longer-term plan for bringing on technologies that are currently more expensive.

9.1 Energy authorities with comprehensive review powers

To ensure attention to economical use and supply of energy – and other criteria such as environmental sustainability – emirates would benefit from empowerment of authorities that have jurisdiction over all energy types and are mandated to develop deployment strategies. One of their most important tasks would be evaluation of gas allocation and procurement, given that imports (at over USD 12/MBtu) are now the marginal cost of energy in the UAE and therefore the key benchmark for investment decisions concerning energy efficiency, renewables, nuclear, and other technologies. The Dubai Supreme Council of Energy provides a potential model, as energy procurement and allocation activities are supervised under one roof.

Ideally, the emirates would also coordinate – and propose co-investment – through the mechanism of a nationwide committee. For instance, Abu Dhabi and Dubai might find co-investment in a wind farm in Fujairah, or a centrally located waste-to-energy plant, to be their most economic renewable energy deployment option. Standardised regulations on distributed generation could also expand the market – and bring down costs. The Ministry of Energy's federal policy taskforce could be a prototype for this cooperation.

9.2 Mandated cost comparison – and a loading order

The UAE would be well-served by a requirement for comparative cost analysis of supply technologies prior to energy investment decisions. This would ensure that energy authorities and other stakeholders are using up-to-date, accurate information when determining how to meet (or reduce) demand. Given market dynamics in the UAE, this approach would likely accelerate deployment of renewable energy.

The UAE could also consider a more prescriptive strategy using cost analysis. An interesting example comes from California, where investments are guided by a 'loading order' for meeting energy demand. Each resource option must be pursued to the extent that it is economically feasible before turning to the next option. California first requires consideration of energy efficiency and demand response, then renewable energy, and finally high-efficiency natural gas. Since this is roughly the sequence of cost-attractiveness in the UAE, a loading order for the energy sector would ensure evaluation of cost while prioritising cleaner technologies.

9.3 Deployment programme and timeline

A clear deployment programme would be a boon for renewable energy – and likely further reduce costs. After determining economic and environmental attractiveness, energy authorities would be able to reap the benefits by announcing and following an investment regime. Most likely, this would take the form of a feed-in tariff (under which both state-owned and private companies could propose projects) or a schedule for government-led competitive tendering, either way with a known quantity (or cap) of projects.

The scale and consistency of such a programme is also highly valuable for cost reduction. Marking a global breakthrough, South Africa was able to bring the cost of wind below that of coal by proceeding with a large number of projects on a known timeline. This signalled to companies that they could build a meaningful revenue stream in the country, incentivising them to invest and resulting in economies of scale.

9.4 Tipping fee to support waste-to-energy solutions

Waste-to-energy is poised to make a small but significant contribution to the UAE's sustainability, producing renewable energy, reducing landfilling, and avoiding greenhouse gas emissions. A stumbling block for projects, however, has been the lack or low level of fees for waste disposal (for residents and companies), which is typically a revenue stream for waste-to-energy plants. Without this fee, UAE utilities would have to pay a premium tariff to the plant owner for its electricity output to make the economics work, which is an unattractive proposition for the utilities.

A new waste disposal fee system – or way to provide revenue – could therefore accelerate deployment. Sharjah in particular, under the leadership of Bee'ah, has produced a more nuanced and supportive fee structure that could be referenced by other emirates or the Ministry of Environment and Water. As an alternative example, the Qatari government simply funded 100% of capital and operating expenses for its 50 MW waste-to-energy plant, which came online in 2011, believing that the waste disposal challenges were so urgent as to justify full subsidisation.

Also in waste-to-energy, the government could consider regulation of methane emissions from landfills. This would provide the greatest incentive for waste management authorities to capture it for electrical or other energy uses. Alternatively, the technology could also be integrated into a government feed-in-tariff or tendering schedule.

9.5 Feed-in-tariffs / distributed generation framework

While large power plants may offer cost efficiencies through economies of scale, a policy framework for distributed generation could mobilise private investment and social support for renewable energy. The new regulations in Dubai will be the key domestic reference for other emirates or a federal approach. At the very least, even if government did not offer a premium tariff, regulations and a gas-comparable tariff would encourage interested parties to take action.

9.6 Solar water heating regulation

Solar water heating is already economic in the UAE, even under subsidised prices, making it potentially attractive for government intervention. The UAE has periodically required certain technologies and products to be used once their pay-back period is understood and deemed attractive, as in its ban on the lowest-performing 20% of air-conditioning units in the national market. Emirate-level governments could therefore follow Dubai's path and require solar water heating for new buildings – or even existing buildings. Federalisation is another option.

9.7 Transport

Renewable energy for transport is one of the more expensive deployment options in the UAE at present, but requires planning and analysis now given the potential scale of its impact. The largest contribution would come from government investments to displace gasoline with cheaper fuels – and therefore reduce the subsidy bill and possibly free up oil products for export. As seen in this report, support of hybrid and electric vehicles would be one lever, such as through subsidisation of the initial purchase cost or operating expenses. Electric vehicles would arguably have a greater impact in the long-run though, and thus government must evaluate solutions to the chicken-or-egg challenge of needing enough infrastructure to encourage EVs, and needing enough EVs to justify infrastructure. Dubai has announced plans for government-funded EV recharging stations in the lead-up to the 2020 World Expo, which could help to tip the scales. National coordination and investment, however, would be necessary for meaningful deployment, given the relatively small size of the UAE and the large commuter and traffic flows among the emirates.

More immediately in transport, replacement of (expensive) market-priced diesel is the most economically attractive intervention at this time. Some of this – such as the repurposing of waste cooking fuel – is already happening without new government policy. Biogas from waste processes could also be a promising complement, particularly given its long and successful history in other countries. In the UAE, biogas could require government alignment of different state-owned entities that currently do not interface or plan or invest jointly. An economic and governance study would be a precursor.

As for biofuels, the Masdar Institute of Science and Technology consortium for bio jet fuels is a potentially useful example, given its staged, exploratory approach and recognition of the scant available resources in the country for sustainable aviation jet fuels. Government support (in the form of land access or RDD&D support) for such initiatives could be appropriate. The UAE could also investigate the lifecycle impacts of importing biofuels from other countries.

REFERENCES

ADB (Abu Dhabi Metro) (2013), "Abu Dhabi Metro." ADB, Abu Dhabi. *http://abu-dhabi-metro.com/.*

ADRSB (Abu Dhabi Regulation and Supervision Bureau) (2013), "Water and Electricity Sector Overview," ADRSB, Abu Dhabi.

ADWEA (2014), (Abu Dhabi Water & Electricity Authority), " Abu Dhabi Water & Electricity Authority and Emirates Aluminium Sign a Memorandum of Co-operation" ADWEA, Abu Dhabi. *http://www.adwea.ae/en/press/press-releases/abu-dhabi-water-electricity-authority-and-emirates-aluminium.aspx.*

ADWEC (Abu Dhabi Water and Electricity Company) (2011), "ADWEC Winter 2011 / 2012 Electricity & Water Demand Forecasts," Abu Dhabi.

ADWEC (Abu Dhabi Water and Electricity Company) (2012), "ADWEC Winter 2012 / 2013 Electricity & Water Demand Forecasts," Abu Dhabi.

AEA Technology Environment (2005), "Damages per Tonne Emissions of PM2.5, NH3, SO2, Nox and VOCs from Each EU25 Member State (Excluding Cyprus) and Surrounding Seas", AEA Technology Environment, Didcot.

Al-Hadhrami, M. (2013), "Feasibility Assessment of Electric Vehicles in Abu Dhabi: Socioeconomic Feasibility and Policy Implications," Master of Science Thesis, Masdar Institute of Science and Technology, Abu Dhabi.

Ali, M.T. *et al*. (2011), "A cooling change-point model of community-aggregate electrical load," Energy Build., vol. 43, no. 1, pp. 28–37.

Alnaser W.E., and Alnaser, N.W. (2011), "The status of renewable energy in the GCC countries," Renew. Sustain. Energy Rev., vol. 15, no. 6, pp. 3074–3098.

Al-Sharfan, M. (2013), "Effect of Public Transportation on Private Cars Ridership in Car Dominant Societies," Master of Science Thesis, Masdar Institute of Science and Technology, Abu Dhabi.

Arnold, T. (2008), "Dubai Metro 'will cut traffic by 17%,'" Arabian Business, 30 July 2008.

Atkinson, E. (2013), "Abu Dhabi Waste to Energy Opportunities and Challenges" May 2013, TAQA, Abu Dhabi. *http://wastetoenergy.rethinkevents.com/wp-content/uploads/2013/05/Ed-Atkinson.pdf.*

BP (British Petroleum) (2012), "BP Statistical Review of World Energy," June 2012. BP, London.

Chedid R. and Chaaban, F. (2003), "Renewable-energy developments in Arab countries: a regional perspective," Appl. Energy, vol. 74, no. 1–2, pp. 211–220.

Chinery, L.E., (2010) "Modeling Transportation in Abu Dhabi: A 25-year Projection of Emissions Under Alternative Scenarios of The Passenger Vehicle Fleet," Master of Science Thesis, University of North Carolina, Chapel Hill, NC.

El-Katiri, L. (2011), "Interlinking the Arab Gulf: Opportunities and Challenges of GCC Electricity Market Cooperation." July 2011. Oxford Institute for Energy Studies, Oxford.

El-Katiri, L. (2012), "Opportunities and Challenges of GCC Electricity Market Cooperation," Oxford Institute for Energy Studies, Oxford.

Etihad Rail (2012), "The Etihad Rail story," November 2012. Etihad Rail, Abu Dhabi. *http://www.etihadrail.ae/en/about/etihadstory.*

Etihad Rail (2013), "Etihad Rail Factsheet." Etihad Rail, Abu Dhabi. *http://www.etihadrail.ae/sites/default/files/pdf/factsheets.pdf.*

FEWA (Federal Electricity & Water Authority) (2010), "FEWA Water Production 2009-2012 for MED & RO." FEWA, Dubai. *http://www.fewaonline.gov.ae/white/_uploads/stat_water_en2010.pdf.*

Fichtner (2011), "MENA Regional Water Outlook Part II Desalination Using Renewable Energy," March 2011, Fichtner, Stuttgart.

GAN (Global Arab Network) (2009), UAE to bolster power infrastructure in Ras Al Khaimah. GAN, London. *http://www.english.globalarabnetwork.com/200912164045/Energy/uae-to-bolster-power-infrastructure-in-ras-al-khaimah.html.*

IEA (International Energy Agency) (2013), "United Arab Emirates Balance for 2011". OECD/IEA, Paris. http://www.iea.org/statistics/statisticssearch/report/?&country=UAE&year=2011&product=Balances.

IEA-ETSAP/IRENA (2012), "Water Desalination Using Renewable Energy Technology Brief," March 2012, IEA-ETSAP/IRENA, Paris/Abu Dhabi.

IIASA (2014), "GAINS GLOBAL (Greenhouse Gas – Air Pollution Interactions and Synergies)", IIASA, Laxenburg.

IPCC (2007), "Summary for Policymakers", in: B. Metz *et al*. (eds.), Climate Change 2007: Mitigation, Fourth Assessment Report, Cambridge and New York.

IPCC (Intergovernmental Panel on Climate Change) (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programmes, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). IGES, Kanagawa.

IRENA (2014a), REmap 2030: A Renewable Energy Roadmap, June 2014.

IRENA, Abu Dhabi. http://www.irena.org/remap/REmap_Report_June_2014.pdf.

IRENA (2014b) Rethinking Energy: Towards a new power system. September 2014. IRENA, Abu Dhabi. http://www.irena.org/rethinking/Rethinking_FullReport_web.pdf.

Lahn, G. and Stevens, P. (2011), Burning oil to keep cool: the hidden energy crisis in Saudi Arabia. December 2011. Chatham House, London. http://www.chathamhouse.org/publications/papers/view/180825.

Lin, P., *et al*. (2011), "Sensitivity of CO_2 Emissions to Renewable Energy Penetration for Regions Utilizing Power and Water Cogeneration." In Advances in Sustainable Manufacturing, edited by Günther Seliger, Marwan M. K. Khraisheh, and I. S. Jawahir, 287–92. Springer Berlin Heidelberg.

MOENR (United Arab Emirates Ministry of Energy) (2013), "Statistical Annual Report Electricity and Water 2008-2012". MOENR, Abu Dhabi. http://www.moenr.gov.ae/assets/ce34dc91/annual-report-2013.aspx.

Mokhtar, M. *et al*. (2010), "Systematic comprehensive techno-economic assessment of solar cooling technologies using location-specific climate data," Appl. Energy, vol. 87, no. 12, pp. 3766–3778.

Reiche, D. (2010), "Energy Policies of Gulf Cooperation Council (GCC) countries—possibilities and limitations of ecological modernization in rentier states," Energy Policy, vol. 38, no. 5, pp. 2395–2403.

RSB (Regulation & Supervision Bureau) (2012), "RSB Customer Tariffs & Charges." RSB, Abu Dhabi. http://www.rsb.gov.ae/En/PrimaryMenu/index.aspx?PriMenu_ID=177&CatMenu_ID=67&SubCatMenu_ID=152.

Sgouridis, S. *et al*. (2013), "A sustainable energy transition strategy for the United Arab Emirates: Evaluation of options using an Integrated Energy Model," Energy Strategy Rev., vol. 2, no. 1, pp. 8–18.

Smith, B. (2012), "Demand Side Management – Plans and Challenges in Abu Dhabi," ADWEA, Abu Dhabi.

UAENBS (United Arab Emirates National Bureau of Statistics) (2012), "Energy 2010," UAENBS, Abu Dhabi.

UN DESA (UN Department of Economic and Social Affairs) (2012), "World Population Prospects: The 2012 Revision". UN DESA, New York, NY. http://esa.un.org/unpd/wpp/unpp/panel_indcators.htm.

UN ESCWA (UN Economic and Social Commission for Western Asia) (2012), "The demographic profile of the United Arab Emirates". UN ESCWA, Beirut. http://www.escwa.un.org/popin/members/uae.pdf.

US EIA (U.S. Energy Information Administration) (2012), "UAE Country Analysis Brief,". US EIA, Washington, DC. http://www.eia.gov/countries/country-data.cfm?fips=TC&trk=p1.

US EIA (2014), "International Energy Outlook 2014". US EIA, Washington, DC. http://www.eia.gov/forecasts/ieo.

US EIA (2013), " United Arab Emirates". US EIA, Washington, DC. http://www.eia.gov/countries/country-data.cfm?fips=tc.

WHO (World Health Organization) (2013), "Road Safety Status Country Profiles: United Arab Emirates". WHO, Geneva.

LIST OF ABBREVIATIONS

A/C	air condition
AC	absorption chillers
ADWEA	Abu Dhabi Water and Electricity Authority
ADWEC	Abu Dhabi's Water and Electricity Company
AED	Arab Emirates Dirham
BNEF	Bloombergy New Energy Finance
bscf/d	billion standard cubic feet per day
CNG	compressed natural gas
CO_2	Carbon dioxide
COP	coefficient of performance
CSP	concentrated solar power
DEWA	Dubai Electricity and Water Authority
DIES	Dubai Integrated Energy Strategy
DNI	direct normal irradiation
EJ	exajoule
EOR	Enhanced oil recovery
EPC	engineering, procurement and construction
EU	European Union
FEWA	Federal Electricity and Water Authority
FLH	full load hours
GCC	Gulf Cooperation Council
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
GW	gigawatt
GWh	gigawatt-hour
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KIZAD	Khalifa Industrial Zone Abu Dhabi
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelised cost of electricity
LNG	liquefied natural gas
MED	multiple effect distillation
MIGD	million imperial gallons per day
MBtu	million british thermal units
MOFA	Ministry of Foreign Affairs
MSF	multi-stage flash
Mt	megatonne
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt-hour
NOX	mono-nitrogen oxide
OPEC	Organization of the Petroleum Exporting Countries
PJ	petajoule
$PM_{2.5}$	particulate matter of less than 2.5 micrometres
PV	photovoltaic
PWR	power-to-heat ratio
RFID	radio frequency identification
RO	reverse osmosis
SBRC	Sustainable Biofuels Research Consortium
SE4ALL	Sustainable Energy for All
SEWA	Sharjah Electricity and Water Authority
SO_2	sulphur dioxide
TWh	terawatt-hour
UAE	United Arab Emirates
USD	US Dollars
VC	vapour compression

ANNEX A:

Energy price assumptions for the UAE REmap analysis

Commodity prices in 2010 USD	Business		Government	
	2010	2030	2010	2030
Crude oil (USD/GJ) Crude oil (USD/bbl)	14 90	14.6 90	14.6 90	21.3 130
Household electricity (USD/kWh)	0.04	0.09	0.1	0.12
Industrial electricity (USD/kWh)	0.04	0.07	0.1	0.09
Natural gas (USD/GJ)	3	8	5	14
Petroleum products (USD/GJ)	12	20	12	20
Gasoline (USD/GJ) Gasoline (USD/litre)	15 0.47	19 0.60	24 0.77	34 0.93
Municipal waste (USD/GJ)	1	3	1	3

ANNEX B:

Technology portfolio

Sector	Renewable energy deployment in Reference Case in 2030	
Power sector (incl. CHP) (TWh/year)	Total electricity production	233
	Hydro	0
	Geothermal	0
	Solar PV	4
	CSP	2
	Wind	0.16
	Solid biomass	1
	Liquid & gaseous biofuels	0
Industry (PJ/year)	Total consumption	1962
	Electricity consumption	103
	Solid biomass	0
	Liquid & gaseous biofuels	0
	Solar thermal	0
Transport (PJ/year)	Total consumption	755
	Electricity consumption	11
	Liquid & gaseous biofuels	0
Buildings (PJ/year)	Total consumption	725
	Electricity consumption	709
	Solid biomass	0
	Liquid & gaseous biofuels	0
	Solar thermal	2

ANNEX C:

Production costs of renewable and fossil energy technologies, from the business perspective, in 2030

	Renewable Energy Technologies	USD/GJ_{th}	Conventional Technologies	USD/GJ_{th}
Industry Sector	Solar thermal	9.5	Natural gas (furnace)	8.8
	Geothermal	9.5		
Buildings Sector	Cooking electricity	27.5	Cooking LPG/kerosene	40.4
	Water heating: Solar with electric backup	17.5	Space cooling: electricity	17.7
	Space Cooling: Solar	40.4	Water heating: electricity	37.1
		USD/p or t-km		**USD/p or t-km**
Transport Sector	Plug-in hybrid (passenger road vehicles)	0.34	Petroleum products (passenger road vehicles)	0.34
	Battery electric (passenger road vehicles)	0.35	Petroleum products (freight rail)	0.12
	City tram for passenger road vehicles	0.33		
	Long range train for freight road	0.12		
		USD/GJ_{e}		USD/GJ_{e}
Power Sector	Wind onshore	24.2	Natural gas	26.7
	Solar PV (Residential/Commercial)	27.6		
	Solar PV (Utility)	16.3		
	RO Desalination/Solar PV	25.8		
	Solar CSP PT storage	28.3		
	Landfill gas ICE	21.6		

ANNEX D:

Detailed roadmap table

Total primary energy supply (PJ/year)	2010	Reference 2030	REmap 2030
Coal	30	137	137
Oil	440	811	742
Gas	2 080	3 558	2 947
Nuclear	0	482	482
Hydro	0	0	0
Traditional biomass	0	0	0
Modern bioenergy (incl. biogas, biofuels)	0	20	42
Solar thermal	0	27	164
Solar PV	0	13	166
Wind	0	1	5
Geothermal	0	0	33
Ocean / Tide / Wave / Other	0	0	0
Total	2 550	5 049	4 718
Total final energy consumption (PJ/year)			
Coal	30	73	73
Oil	417	811	754
Gas	1 064	1 734	1 569
Traditional biomass	0	0	0
Modern biomass (incl. biogas)	0	0	0
Modern biomass (liquid)	0	0	0
Solar thermal	0	2	122
Geothermal	0	0	16
Other renewables	0	0	0
Electricity	241	823	785
District Heat	0	0	0
Total	1 753	3 443	3 319
Gross electricity generation (TWh/year)			
Coal	0	8	8
Natural gas	97	173	123
Oil	1	0	0
Nuclear	0	44	44
Hydro	0	0	0
Biomass	0	1	3
Solar PV	0	4	46
CSP	0	3	9
Wind onshore	0	0	1
Wind offshore	0	0	0
Geothermal	0	0	0
Ocean / Tide / Wave	0	0	0
Total	98	233	234

Electricity capacity (GW)			
Coal	0	1	1
Natural gas	23	42	35
Oil	<1	0	0
Nuclear	0	6	6
Hydro (excl. pumped hydro)	0	0	0
Biomass	0	0	1
Solar PV (utility)	0	2	17
Solar PV (rooftop)	0	0	4
CSP	0	1	6
Wind onshore	0	0	1
Wind offshore	0	0	0
Geothermal	0	0	0
Ocean / Tide / Wave	0	0	0
Total	23	52	70
CO_2 emissions (Mt CO_2)			
Total emissions from fossil fuel combustion	152	272	238
Renewable energy indicators (%)			
Renewable energy share electricity – generation	0%	3%	25%
VRE share electricity – generation	0%	3%	20%
Renewable energy share electricity – capacity	0%	5%	41%
VRE share electricity – capacity	0%	5%	31%
District heat	0%	0%	0.0%
Industry	0%	0%	4.6%
incl. RE electricity and DH	0%	0%	5.5%
Transport	0%	0%	0.0%
incl. RE electricity and DH	0%	0%	1.1%
Buildings	0%	11%	79.5%
incl. RE electricity and DH	0%	4%	29.0%
TFEC	0%	0.9%	10.4%
TPES	0%	1%	9%
Financial indicators (in USD_{2010})			
Substitution Cost – Business Perspective (USD/GJ)			0.4
Substitution Cost – Government Perspective (USD/GJ)			-6.3
Incremental system cost (bln USD/year)			-1.9
Reduced human health externalities (bln USD/year)			-0.2 to -0.6
Reduced CO_2 externalities (bln USD/year)			-0.8 to -3.1
Incremental subsidy needs in 2030 (bln USD/year)			2.6
Incremental investment needs (bln USD/year)			4.9
Investment needs Reference Case (bln USD/year)			2.3
Investment needs REmap Options (bln USD/year)			5.0
Total investment needs RE (bln USD/year)			7.3
Biomass supply (PJ/year)			
Total supply potential			<50
Total demand			42

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