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The New Chautauqua Game: Designing the Renewable City and Region Using E[m]ergy Accounting

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Abstract

This paper presents the results of a simplified method for reconfiguring a small city and rural county to support its current population on the environmental energies available within the boundaries of the county. It is configured as a game, based on the simplifying assumption that the collection and concentration of renewable energies is almost entirely a matter of surface or land area, so that a renewable economy becomes a matter of competing land uses, of tradeoffs between land used for the production of food, fuel, electricity, and so on. Emergy accounting was used to translate different forms of consumption into equivalent land areas, while the many forms of production and consumption were reduced to 29 parameters that can be varied to test alternate scenarios for the county. The results have been coded into a web site for playing the game.

1 Introduction

The growth and operation of our massive metropolitan system relies as much on the quality of its energy supplies as on their sheer quantities. The fuels and electricity that power our economy are more portable and of higher density than the environmental energies of sun and wind. Just as it takes work (and unavoidable waste) to concentrate fuels into electricity, environmental energies require substantial land areas to capture and concentrate them into usable fuels, electricity, or other services. We use the energy systems language developed by H.T. Odum and his collaborators for the evaluation of ecosystems to consider the difference between an economy based on high-quality fuels and one based on renewable, environmental energies (Odum, 1996).

In particular, this paper uses the techniques of "emergy" synthesis that Odum developed to evaluate the quality and value of resources. It is a more comprehensive form of embodied energy assessment that includes all forms of environmental work, not just purchased fuels and power. As he defined it in 1996, "EMERGY is the available energy of one kind previously used up directly and indirectly to make a service or product." The "m" indicates energy "memory," but since the term is so easily confused with energy (especially by auto-correction), we have adopted the more legible form e[m]ergy. E[m]ergy synthesis is an accounting technique that considers all the upstream work and resources involved in a product or process, and we have used it to

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help understand the radical urban and economic reorganization that will be necessary to shift to a renewable economy. Much of the current activity on the sustainable design of cities is dedicated to incremental improvements, to making cities smarter and more efficient, or of beginning a transition to renewable resources. More ambitious proposals for converting primary energy supplies entirely to renewable sources largely approach it as a question of substitution, unplugging coal and plugging in solar for example, without appreciating the scale of the changes involved or the role of energy quality in the growth and organization of cities.

As Odum (1983), Brown (1980, 2003), Huang et al. (2001), Ascione et al. (2009), and others have demonstrated, urban agglomerations and energy quality are mutually dependent and reinforcing. The larger the city and the denser its population, the greater the concentration of high-quality resources it commands. Conversely, the use of renewable resources is largely a matter of competing land uses—of land used for concentrating diffuse energies into food, biofuels, electricity, or manufactured products. The stark choice between using land to grow corn for ethanol or for food was recently played out in in price spikes, which illustrate the largely exclusive use of land. In general, low density environmental resources are captured in large areas and concentrated into higher quality products and services for use in smaller, developed land areas. Though there can be some overlapping land uses—photovoltaics on building roofs for example—when considered at scale, the development of a renewable economy will involve a considerable re-allocation of land uses.

It is worth remembering that any city before about 1750 was based almost entirely on the capture and concentration of renewable resources in the familiar arrangements of an agricultural economy. The few large cities of the pre-modern world arose as the centers of empires that gathered and concentrated those resources from much larger regions, mostly by conquest. Today's mega-cities have been built instead by extracting and mobilizing high-quality fuels with very modest land-use demands. We are not proposing a return to the agricultural patterns of the past, but considering how to maintain the health, education, and prosperity of contemporary metropolitan life as we navigate the transition to a renewable economy. We think it valuable to explore the shape of that all-renewable city as a design goal, whether the transition takes decades or centuries.

To explore that condition, this paper uses an e[m]ergy analysis of Chautauqua County, New York, USA, to ask what form of reorganization it would take to support the current population on the renewable income of the County itself. To keep the study simple, we sought to balance the supply and demand of the county, so that the total energy available from renewable sources is both the limiting factor and ultimate goal. Of course, any real economy can only exist in cooperation (and competition) with its neighbors, so it would need to produce surpluses with which to trade, but exploring the principle of balancing consumption and renewable income clarifies the challenge that we face. The results are a series of speculations, not fully realized solutions, offered as a contribution to the design of future human settlements.

2 Scenario Planning as a Land Use Design Tool

The use of maps to visualize the allocation of space has a rich history and sits alongside the allocation of metrics to these maps to assist in how we perceive concepts external to our typical (human) scale of understanding and interaction. Arguably the most important development in this field in the last fifty years was the "McHarg Method" (McHarg, 1971) that demonstrated how urban planners could take a more environmentally conscious approach to evaluating and implementing development. With the proliferation of big data, a new "intelligent terrain" (Dunn, 2013) is emerging wherein open-source data, provided by governments and private institutions, is linked to geospatial information, creating the opportunity for new, cross platform scenario planning tools. These new digital platforms have the potential to reach more citizens and help them understand the challenges of the transition we face, which was part of the motivation of framing this simple tool as a game. A more comprehensive version of the tool that can be used by designers and policy-makers is currently under development.

For any individual actively involved in shaping a 'renewable' future it can be difficult to comprehend the consequences (both positive and negative) that their decisions will have. Scenario planning is one tool that can help determine the extents of this indeterminacy, although it cannot predict the future it helps establish both limitations and possibilities. Tools such as this are needed to contextualize and visualize the dynamic tradeoffs that must take place and it is within this framework that the New Chautauqua Game has been developed, providing a simulated environment where the implications of calibrating a region around twenty-nine parameters can be played out, reviewed, debated and re-tested. Design professionals (and citizens) can determine the correct point to step away from analyzing a situation (whether through mapping or otherwise) and augment that situation with their design skills.

To demonstrate the viability of a large scale scenario planning tool The New Chautauqua Game uses a real county in upstate New York as a case study and site for investigation. Nonetheless, the principals are general enough to accommodate other, similar sized spatial regions.

2.1 Primary and Support Land Areas

E[m]ergy accounting can be used to make the imported resources and upstream costs used for even the simplest activity visible as areas of land. In an economy based purely on renewable resources, any product or service can be traced to the capture of environmental energies such as sun, wind, and rain, and their progressive conversion and concentration into useful forms. For example, the energies converted to edible crops are fed to animals and people who perform work of different kinds, which are used to gather, build, transport, or process materials into useful forms, all the way up to the sophisticated devices concentrating those original energies into electricity or information. The same principle applies to an economy based on high-quality fuels, with the important distinction that the energy potential stored in their molecules was actually captured over large areas by algae and green plants back in the Jurassic or Cretaceous, and conveniently tucked away underground.

The work and resources needed for food, transportation, electricity, and so on can be traced back to the areas of land needed for the original capture using Unit E[m]ergy Values (UEV) from the scientific literature. UEVs combine all the inputs used for a particular process and normalize them into equivalent units of solar e[m]ergy, which are designated as "solar em-Joules" (abbreviated as sej). These are most often reported as normalized intensities or densities, such as sej/J, sej/kg, sej/$, sej/ha for use in synthetic accounts (see Brown & Ulgiati, 2004). As a first order estimate of the land areas required for a service or product, the total e[m]ergy involved can be divided by the average e[m]ergy intensity of the renewable resources available in that region, expressed as sej/ha.

To make the distinction visible in the New Chautauqua Game we distinguish between the primary and support land involved in each product or service. Primary land is the actual area required for a productive activity—the amount of agricultural land needed to provide a specific quantity of crops or the area of photovoltaic panels to provide a quantity of electricity. For resource flows involving modest or non-exclusive land use—fossil fuels (modest) or fresh water (non-exclusive)—no primary land was allocated, though support land area was determined.

Support land is determined by dividing the total e[m]ergy (sej) attributed to each area of land use by the average e[m]ergy intensity of renewable inputs to the county, which is 2.97E15 sej/ha. It is the area that would be needed to gather an amount of renewable resources equivalent to the imported inputs for that activity, which are currently derived mostly from fossil fuels. For example, each hectare of forest used to provide harvested wood requires an additional 0.05 hectares to capture the energies needed for harvesting and transporting the wood (1.77E14 J biomass / 1.69E9 J/ha = 1.05E5 ha primary, 1.77E14 J biomass * 8.90E4 sej/J = 1.57E19 sej, 1.57E19 sej / 2.97E15 sej/ha renew = 5.30E3 ha support, 5.30E3 ha support / 1.05E5 ha primary = 0.05 ha/ha). In contrast, each hectare of photovoltaic panels would require an additional 188 hectares of land to capture and concentrate the resources needed to provide new panels at the end of their useful life (1.77E14 J PV elec / 8.48E12 J/ha = 21 ha primary land, 1.77E14 J PV elec * 6.59E4 sej/J = 1.17E19 sej, 1.17E19 sej / 2.97E15 sej/ha renew= 3.92E4 ha support, 3.94E3 ha support / 21 ha primary = 188 ha/ha), illustrating the tremendous cost (and value) of concentrating sunlight into electricity. However, the e[m]ergy of photovoltaics is mostly a result of the photoactive materials (Brown et al., 2012), so that amount of support land would be required to harvest the energy needed to concentrate those materials from background levels, which no one would ever do. A more accurate estimate for a completely renewable economy would be based on the costs of recycling those materials.

Nonetheless, the calculation of support land highlights the particular value of fossil fuels and the unacknowledged land use consequences of the transition to renewables. Taking the amount of biofuel that could be produced from one hectare of corn, we can estimate from V. Smil's work that it would only take .0009 hectares of primary land to extract the same amount of fuel from an oil well. As he has established, fossil fuels have a very high energy density (J/ha) in terms of current land use (Smil, 2010). For both the oil and biofuel, the amount of equivalent support land needed to achieve the concentration of the fuel is about 2.8 hectares. However the areas of land used to 'capture' the solar energy embedded in the fossil fuels are conveniently located in the distant past.

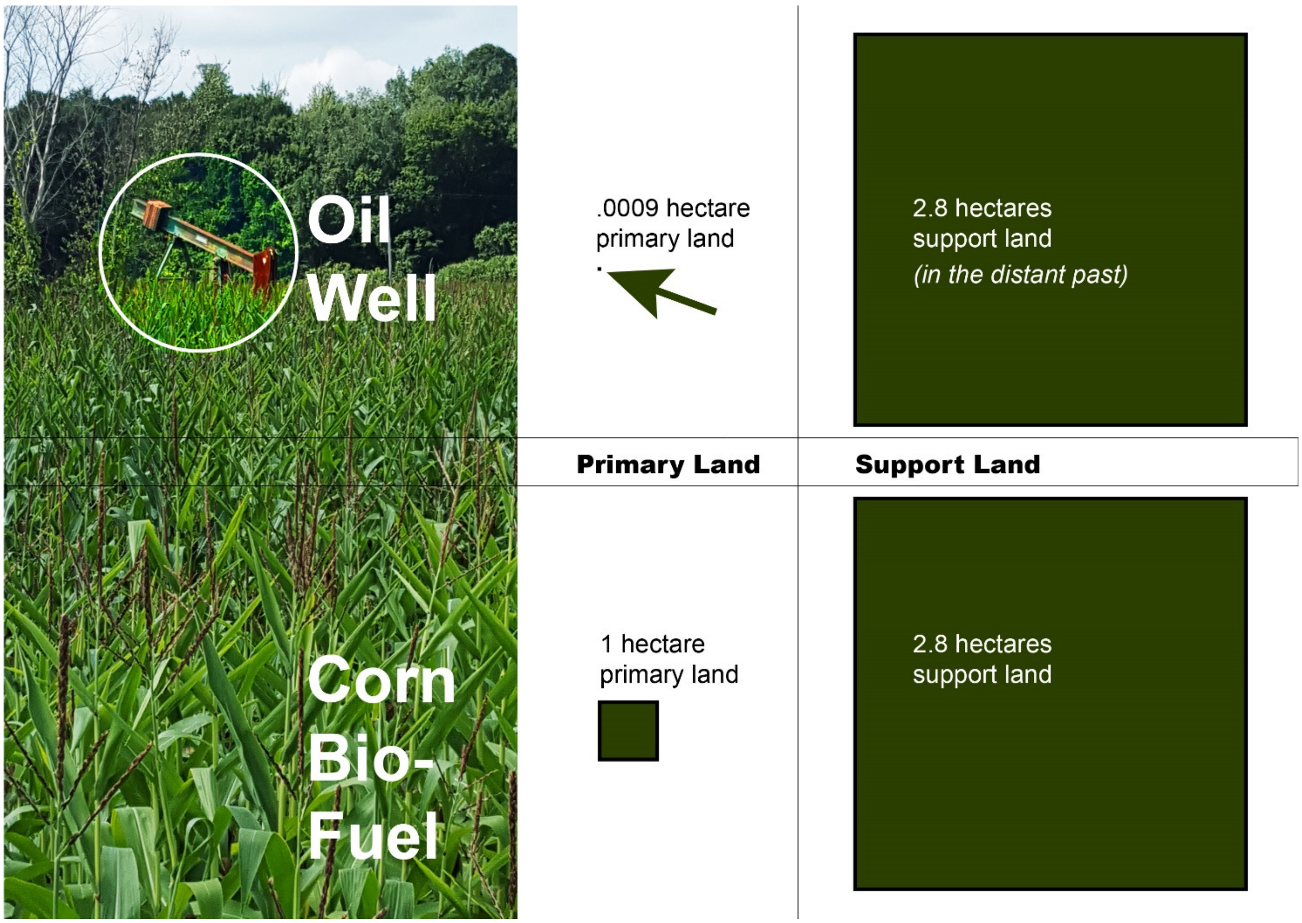

Fig.1 Oil well in a cornfield in Chautauqua County, with illustrations of the primary and support land required to produce the same amount of energy as a hectare of corn for biofuel.

2.2 Scenario Builder: Design Parameters

To explore the scenarios for a redesigned county based only on renewable inputs, a simplified model was developed using twenty-nine parameters to describe those aspects of human consumption, transportation and settlement that can be adjusted or modified. This sacrifices many of the complexities of a real county or region, for example combining local and imported resources, reducing energy production to four types, and keeping the proportion among some categories fixed to simplify the number of variables. The parameters as implemented in the scenario planning tool are shown in Figure 2, and the tool allows participants to adjust them and quickly evaluate whether the scenario fits within the spatial confines of the region. The most significant simplification in this model is the effect of transportation distances, which are not directly connected to density. Incorporating a more nuanced calculation of commuting distances for different settlement patterns would add significantly to the accuracy of the model.

Fig.2 Twenty-nine parameter sliders in the New Chautauqua scenario builder

2.3 Land Allocation

In order to test the impact of the effect of the lifestyle and efficiency parameters that were implemented, a scenario mapping tool has been constructed that provides a graphic output of the changes in land allocation for different combinations of parameters. A base map was established with current land use allocation based on GIS land cover data. In the Chautauqua County case study each pixel equates to 64.53 hectares. Increasing or decreasing the number of pixels on the map would result in differing levels of granularity to the scenario maps generated. Superimposed on this map are major settlement points, 17 in the case of Chautauqua County, ranging in scale from Jamestown (population 31,146) to Sunset Bay (population 637). It is from this baseline position that the impact of changing the twenty-nine parameters can be investigated.

For each settlement point a land "demand" is calculated based on the population of that settlement point, with the total population in the region determined by current census data. The distribution of the population across the identified settlement points can be adjusted to fit four scenarios: "Baseline Distribution", the population at each point is equal to the current population living there; "Even Distribution", the total population is distributed evenly across the settlement points; "Two Centers", the population is shared equally between the two largest existing settlement points in the county; and "One Center", all population is allocated to the largest current settlement. Adjusting the population in this manner allows the participant to investigate the impact of settlement hierarchies on land distribution.

To remap the region two "passes" take place, based on the land type demand. The first finds the nearest available pixels of each land type required to supply the settlements with what they need, without taking any from a neighboring settlement. If there is a shortfall identified at this stage (where available land has been distributed equally based on population demand) a second pass takes place wherein the nearest unallocated point is identified and that pixel is reallocated to a new land use, based on any shortfall in demand for that settlement point. There is a further hierarchy embedded during this phase that first looks at natural, then forest, then agriculture, and then developed land, based on the "ease" with which these land uses can be converted to other uses. For example, if Settlement A requires 10 pixels of agriculture land (or 645.3 hectares) it first looks for the 10 nearest available agriculture pixels on the baseline map. If, after the demand of Settlement B and Settlement C are taken into account, only 8 pixels are available it will then look for the nearest 2 unallocated pixel and convert that to agricultural land. If a shortfall still exists after this then it is clear that the settlement cannot be supported within the current limits of the spatial region.

It is this reallocation, or remapping, of the region that creates the changed map and it is this map, in combination with the revised inputs, that can be used as a tool in the decision making processes that shape the future of our cities and regions. Variable testing can be undertaken wherein the impact of changing each parameter can be measured. Furthermore, analysis can take place about the impact of changing population distribution across the county, for example what happens if the population of Settlement A increases by 50,000, is that sustainable in the long term given a particular lifestyle? Further questions can be asked about whether or not the location of existing settlements is correct, should new settlements be built?

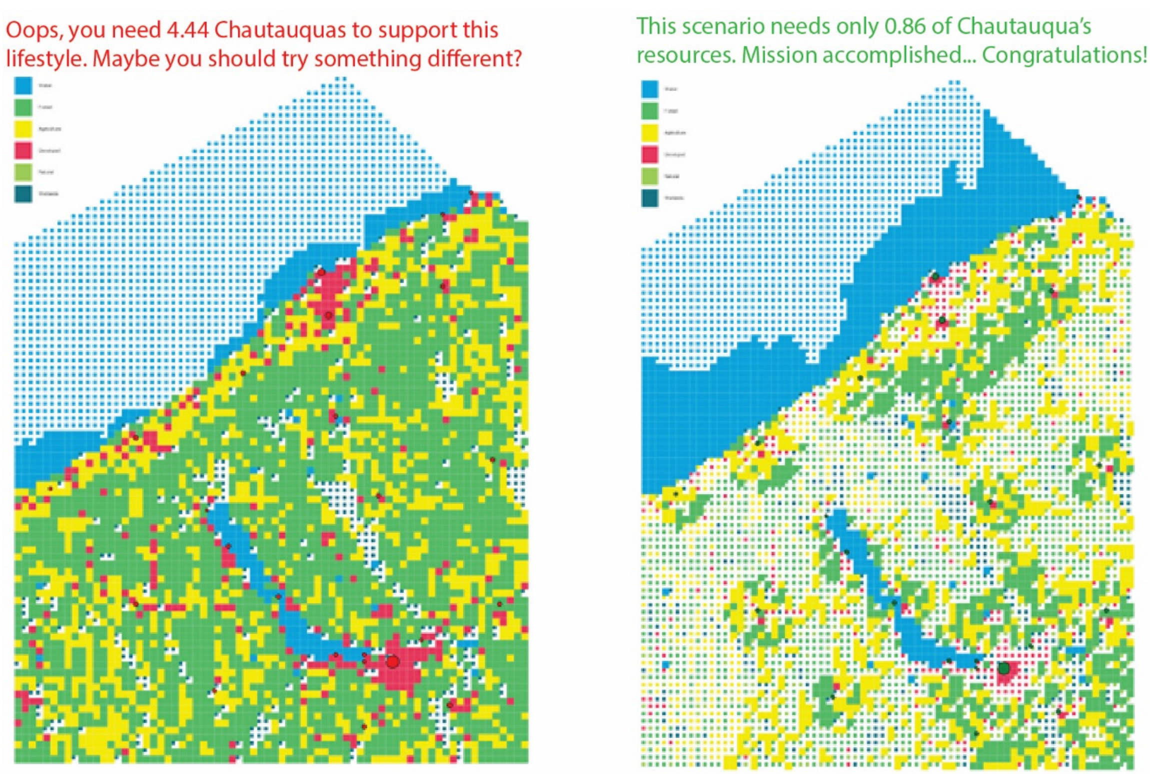

Fig.3 New Chautauqua Game scenarios maps for Chautauqua County, NY: Current county and changed, renewable county.

3 Chautauqua County E[m]ergy Accounting

Chautauqua is a largely rural county of 388,545 hectares (including water area) in the western part of New York State, bordering Lake Erie and largely defined around Lake Chautauqua, a freshwater lake of about 5,260 hectares situated 213m above Lake Erie and draining into a separate watershed that ultimately empties into the Gulf of Mexico. Its principal industries are agriculture, tourism, and manufacturing, though it is located in the heart of the so-called "rust-belt," so its industrial capacity has declined significantly in recent decades.

An e[m]ergy diagram and accounting were prepared of the annual resource flows in the county, and summarized in Figure 4 and Table 1. Although the county maintains a useful GIS database, much of the resource information needed for a comprehensive accounting is not tracked at the county level, so data was assembled from a mixture of the National Land Cover Database (NLCD), Census Data, EPA eGrid, normative data for household consumption, and inspection of aerial photographs of the urban areas. The information was indexed to land area, to facilitate the exploration of land-use changes.

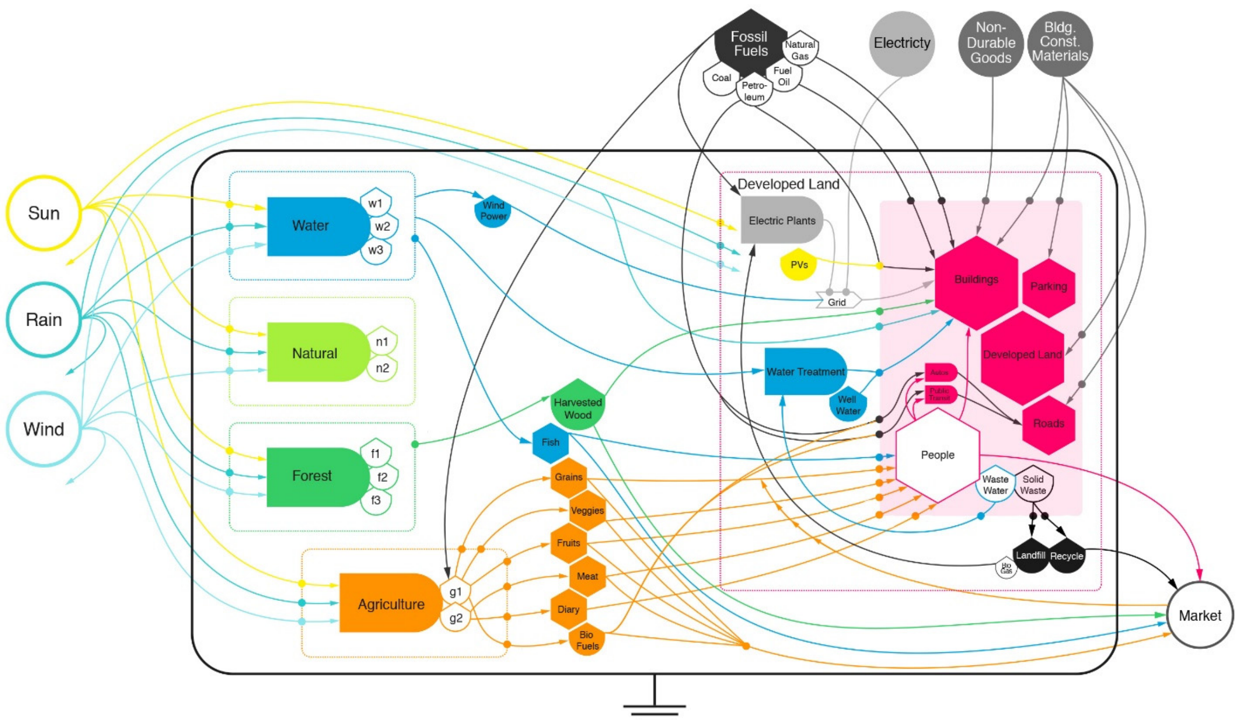

Fig. 4 Energy-e[m]ergy diagram of Chautauqua County based on land use.

For this model, four sources of renewable resource inputs were evaluated, sunlight, wind, and the chemical and geopotential of rain, though only the largest was included in the e[m]ergy accounting to avoid double counting of inputs from planetary systems. Figure 4. There is some potential in the area for both wave power on Lake Erie and deep geothermal heat, but the focus of the game was limited to the sources that involved tradeoffs in land area. For the e[m]ergy analysis of the existing county five basic land uses were considered: forest (35.3%), water and wetlands (33.7%), agriculture (21.9%), developed land (5.2%), and natural or unallocated land (3.9%). The total e[m]ergy inputs to the current county total 6.68 E+21 sej/yr, of which 1.02 E+21 are renewable inputs and 5.66 E+21 are imported inputs.

In e[m]ergy analysis, the ratio of the total to the imported e[m]ergy inputs is called the E[m]ergy Yield Ratio (EYR), which gives a measure of how much economic value the region or activity provides. Odum estimated that Middle East Oil had an EYR of about 13, compared to about 6 for domestic oil fields (1996). The EYR of Chautauqua County is about 1.2, reflecting its agricultural character, which is based on crops concentrating sunlight into products. Another useful metric is the Environmental Loading Ratio (ELR), which compares the e[m]ergy of the imported and non-renewable inputs to that of the renewable ones, and serves as an indicator of the dependence of the region on non-renewable resources. Ascione et al determined that the ELR of Rome was about 60, while that of Italy overall was close to 16, illustrating the resource intensity of urban areas (2009). The ELR of Chautauqua County is 5.5, again highlighting its rural nature.

Table 1 E[m]ergy Evaluation of Chautauqua County

LAND USE TYPE		Data	Unit E[m]ergy Value (UEV)*		E[m]ergy	Primary Land	Support Land
Inputs	Item, units	Units/yr	sej/unit		E14 sej/year	hectares	hectares
WATER & WETLANDS						**131,110**	**6,881**
Renewable	Rain, Chemical, J	1.66E+16	2.35E+04	*a*	3,897,463		
Imported	Harvested Fish, J	8.05E+12	2.54E+06	*a*	204,539		
NATURAL LAND						**14,999**	
Renewable	Rain, Chemical, J	1.71E+15	2.35E+04	*a*	401,272		
FOREST LAND						**137,091**	**3,694**
Renewable	Rain, Chemical, J	1.56E+16	1.81E+04	*a*	2,824,919		
Imported	Harvested Wood, J	1.23E+14	7.00E+04	*a*	109,822		
AGRICULTURE LAND						**85,172**	**149,834**
Renewable	Rain, Chemical, J	9.70E+15	2.35E+04	*a*	2,278,679		
Imported	Grains, harvested, J	7.84E+14	5.22E+05	*a,b*	4,094,284		
	Vegetables, harvested, J	2.30E+11	1.80E+05	*a,b*	414		
	Fruits, harvested, J	3.55E+14	3.84E+03	*c,d*	13,646		
	Meat, harvested, J	6.44E+12	6.75E+05	*a,b*	43,463		
	Milk, harvested, J	2.00E+13	6.49E+05	*a,b*	129,739		
	Biofuels, J	1.21E+14	1.43E+05	*e*	172,506		
DEVELOPED LAND						**20,174**	**1,743,011**
Renewable	Rain, Chemical, J	2.55E+15	2.35E+04	*a*	599,691		
Imported	Building Constr., m^2	9.26E+07	1.80E+13	*f*	507,506		
	Parking Constr. m^2	5.08E+06	2.33E+13	*g*	59,262		
	Other Developed Land, m^2	1.41E+08	4.97E+11	*g*	697,653		
	Road Constr., m^2	3.89E+07	2.33E+13	*g*	454,459		
	Potable Water, L	2.88E+10	2.38E+08	*h*	68,523		
	Waste Water, L	1.98E+10	2.37E+10	*i*	4,691,132		
	Grains, imported, J	1.84E+14	5.60E+05	*j*	1,031,783		
	Vegetables, imported, J	4.33E+13	4.91E+05	*j*	45,616		
	Fruits, imported, J	3.73E+13	4.84E+05	*j*	180,613		
	Meat, imported, J	9.42E+13	7.13E+05	*j*	671,773		
	Dairy, imported, J	2.00E+13	6.49E+05	*j*	129,739		
	Fish, imported, J	2.05E+13	2.54E+06	*j*	520,246		
	Elec. Prod. InCounty, J	2.59E+15	2.19E+05	*k*	5,658,900		
	Elec. Imported, J	5.82E+15	2.19E+05	*k*	12,753,804		
	Natural Gas, J	7.70E+15	1.41E+05	*l*	10,821,639		
	Fuel Oil, J	9.97E+14	1.37E+05	*l*	1,366,518		
	Biomass, J	1.46E+14	8.90E+04	*a*	129,870		
	Other Fuels	4.82E+14	2.31E+05	*m*	1,113,357		
	Vehicle Gasoline, g	1.76E+08	2.25E+08	*l*	7,317,543		
	Public Transit Gasoline, g	2.78E+06	6.55E+09	*l*	182		
	Nondurable goods, $	1.81E+08	1.97E+12	*n*	3,568,019		
	Solid Waste, g	1.76E+08	2.25E+08	*o*	395		
	Recycled Content, g	9.24E+07	2.72E+10	*p,q*	25,169		
				Renewable Inputs	10,206,563		
				Imported Inputs	56,582,113		
				Totals	66,788,676	**388,545**	**1,903,420**

* All UEV converted to new baseline, 1.2E+25 seJ/yr (Brown et al., 2016). a. Campbell and Ohrt, 2009. b. USDA, 2012 Census of Agriculture, USDA Nutrient Database. c. Francescatto, 2008 d. Marchettini, 2003. e. Giampietro, 2005. f. Kurtz, Lehigh Valley, 2014. g. Brown and Vivas, 2007. h. River Source: Buenfil, 2001. i. Bjorkland, 2001. j. Johansson, 2000. k. EIA 2010 Mix: Brown, 2002, Hayha et al., 2011, Brown et al., 2012. l. Brown et al., 2011. m. average of sources. n. Bureau of Labor Statistics, 2014, NEAD, 2012. o. Brown and Buranakarn, 2001. p. Buranakarn, 1998. q. La Rosa, 2009.

Using this approach, the current county would require an additional 4.90 “counties” of land area to operate solely on renewable resources (Table 1). This is a rough and conservative simplification, since the forms of the renewable resources, dominated by the e[m]ergy content of rain, don’t directly match the forms of consumption, and the available resources can't be wholly diverted to human uses. Despite the simplification, the land area calculation makes visible the tremendous value of the concentrated fuels currently used to drive the county economy.

3.1 Chautauqua County: Scenarios

For the simplified version of the original county with which the game begins, it reports "Oops! You need 4.44 Chautauquas to support this lifestyle. Maybe you should try something different?" The slight difference from the number of "counties" estimated in the full baseline accounting derives from the simplifications used in the game used to reduce the number of parameters, for example, the use of averaged e[m]ergy intensities and the allocation of primary land based on the consumption requirements of the population. The game is a pure translation of human consumption into land area, and so omits any land area not related to those forms of production. That unallocated land only appears in scenarios that require less than one county of land and is listed in Table 3 as Natural, but it is not included in the land totals used to determine the balance of consumption and production in the scenario. The renewable inputs associated with the unallocated Natural land are also omitted from the totals, but would be needed in order to calculate standard e[m]ergy metrics like EYR. In short, the game has been constructed entirely to demonstrate the land use consequences of the 29 parameters.

Broadly speaking there are two kinds of parameters that were included in the simplified model, efficiencies of production and efficiencies (or reductions) of consumption. Both are needed to achieve the necessary reduction in land area, but two scenarios are presented below which emphasize one or the other. Table 2. Scenario 1 assumes a radical reduction in current levels of consumption, 10% of current rates of power consumption, miles driven, goods purchased, etc., but otherwise assumes current levels of production efficiency. Scenario 2 assumes increased efficiencies of production of food, construction, energy, biofuel, etc., which allows slightly higher levels of consumption at 20% of current norms.

Table 2 Game parameters of Original County and Scenarios

Parameter	Original	Scenario 1	Scenario 2
Developed Land Density, % base	100	1000	1000
Building Construction - Efficiency, % base	100	100	200
Deprecation of Buildings, yrs	50	50	100
Energy Demand - per capita, % base	100	10	20
Production Efficiency - Solar PV, % base	100	100	200
Production Efficiency - Biomass, % base	100	100	200
Production Efficiency - Wind Power, % base	100	100	200
Energy Mix - Solar PV, %	1	5	5
Energy Mix - Biomass, %	1	5	5
Energy Mix - Wind Power, %	0	90	90
Energy Mix - Fossil Fuel, %	98	0	0
Food Demand, % base	100	90	90
Food Production Efficiency, % base	100	100	200
Diet Mix - Vegetable, %	15	22	22
Diet Mix - Fruit, %	10	9	9
Diet Mix - Meat, %	20	2	2
Diet MIx - Dairy, %	5	2	2
Diet Mix - Fish, %	5	10	10
Diet Mix - Grain, %	45	55	55
Vehicle miles - per capita, % base	100	10	20
Vehicle efficiency - MPG, % base	100	100	200
Biofuel Production Efficiency, % base	100	100	200
Vehicle Fuel Mix - Biofuels, %	11	100	100
Vehicle Fuel Mix - Electricty, %	0	0	0

Vehicle Fuel Mix - Fossil Fuel, %	89	0	0
Goods Purchased, % base	100	10	20
Waste Produced, % base	100	30	30
Waste Recycling - diversion rate, %	55	95	95
Water Usage - per capita, % base	100	30	30

The result of the two scenarios are tabulated in Table 3, and both reduce the total land needed to less than the area of the county, allowing for natural areas and the kinds of surplus needed for trade. The simplifications of the game model include a number of implicit biases in the design strategies. Fish and wind power are allocated to the Lake Erie water area (there is substantial wind potential just off shore), which can't be used for other purposes. So unlike photovoltaics, for example, which displace other land uses, wind power becomes a key part of any winning land use strategy in the county.

Table 3 E[m]ergy Evaluation of Original County, Scenario 1, and Scenario 2

	Original County			**Scenario 1 (Consumption)**			**Scenario 2 (Production)**		
Land Use Type	**E[m]ergy**	**Primary Land**	**Support Land**	**E[m]ergy**	**Primary Land**	**Support Land**	**E[m]ergy**	**Primary Land**	**Support Land**
Inputs, notes	*sej / year*	*hectares*	*hectares*	*sej / year*	*hectares*	*hectares*	*sej / year*	*hectares*	*hectares*
WATER									
Renewable Inputs	5.99E+19			1.10E+20			5.63E+19		
Imported Inputs	4.97E+19	20,146	16,723	9.01E+19	37,074	30,305	9.01E+19	18,943	30.305
Wind – Power, a				6.02E+17	812		6.02E+17	812	
Fish, b	4.97E+19	20,146		8.95E+19	36,262		8.95E+19	18,131	
NATURAL									
Renewable Inputs				1.61E+20	54,115		2.44E+20	82,081	
FOREST									
Renewable Inputs	3.12E+20			1.61E+20			1.56E+20		
Imported Inputs	1.57E+19	104,789	5,298	7.87E+18	52,395	2,649	1.57E+19	52,395	5,298
Biomass, b	1.57E+19			7.87E+18	52,395		1.57E+19	52,395	
AGRICULTURE									
Renewable Inputs	4.18E+20			2.16E+20			1.44E+20		
Imported Inputs	1.66E+20	140,553	74,364	1.12E+20	72,808	57,447	1.21E+20	48,336	57,447
Biofuels, c	5.48E+19	5,660		4.98E+19	5,145		4.98E+19	2,573	
Vegetables, a,d	2.88E+19	36,120		3.80E+19	47,678		3.80E+19	23,839	
Fruit, a, d	1.89E+19	867		1.53E+19	702		1.53E+19	1,405	
Meat, a,d	5.28E+19	80,583		4.76E+18	7,252		4.76E+18	14,505	
Dairy, a,d	1.27E+19	9,495		4.57E+18	3,418		4.57E+18	1,709	
Grains, a,d	5.29E+19	7,828		5.82E+19	8,611		5.82E+19	4,305	
DEVELOPED									
Renewable Inputs	5.99E+19			6.02E+18			6.02E+18		
Imported Inputs	4.06E+21	20,166	1,363,266	2.41E+20	2,027	79,727	2.81E+20	2,027	91,715
Built Env. e	2.97E+19	20,145		8.83E+18	2,015		2.75E+18	2,015	
Solar PV, f	2.03E+19	21		1.01E+19	13		2.03E+19	13	
Other Fuels, g	2.38E+21			0.00E+00			0.00E+00		
Gasoline, h	6.50E+20			0.00E+00			0.00E+00		
Water, i	6.21E+20			1.86E+20			1.86E+20		
Goods, j	3.59E+20			3.59E+19			7.18E+19		
Solid Waste, k	9.91E+15			3.30E+14			3.30E+14		
Recycled Waste, l	3.43E+17			1.78E+17			1.78E+17		
SUMMARY									
Primary Land	285,654	hectares		164,302	hectares		121,699	hectares	

Support Land	1,459,651	hectares	170,128	hectares	184,765	hectares
Total Land	1,745,305	hectares	334,429	hectares	306,464	hectares
In-County Land	388,545	hectares	334,429	hectares	306,464	hectares
Out-of-County	1,356,760	hectares	0	hectares	0	hectares
Multiples of County	4.49		0.86		0.79	

Notes. a. Dolan et al., 2009. b. Campbell and Ohrt, 2009. c. Giampietro, 2005. d. Average of vegetables in county. USDA 2012 Census of Agriculture, USDA Nutrient Database. e. Brown, 2003. f. Brown et al., 2012. g. EIA, 2010 Elec. Mix, Brown, 2002, Hayha et al., 2011, Brown et al., 2012. h. Brown et al., 2012. i. River Source: Buenfil, 2001. j. Bureau of Labor Statistics, 2014, NEAD, 2012. k. Brown and Buranakarn, 2001. l. Buranakarn, 1998.

The primary land areas and their e[m]ergy intensities (sej/ha) of the baseline analysis and the 3 scenarios are plotted in Figure 5, which illustrates the hierarchy of land use intensity that has been shown to emerge in human development (Brown, 1980, 2003; Huang et al, 2001). In general the greater the intensity, the smaller the land area, but the ranges of intensity are revealing. The differences between the baseline and the simplified original county scenario are visible in the slopes of their respective trendlines, largely caused by the different accounting for natural land. More informative are the spectrum of intensities of the two successful scenarios, which are shifted down and to the left, driven by the greater density of developed land and the lower levels of consumption.

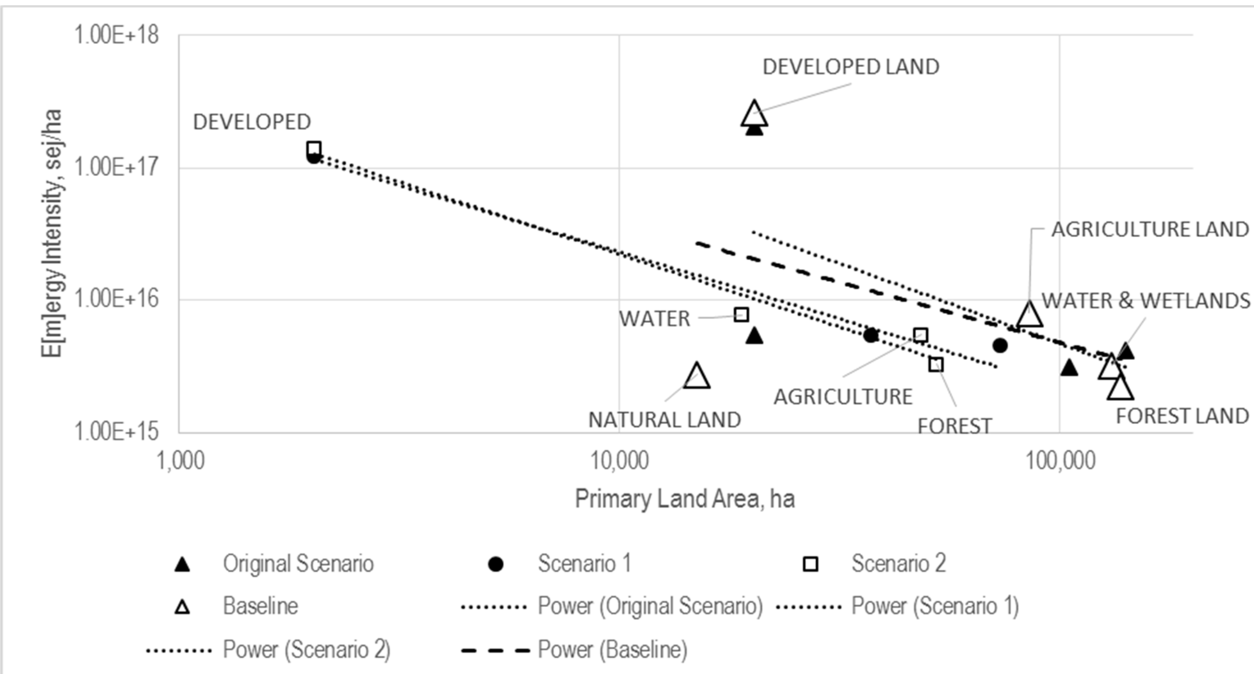

Fig. 5. Chart of land area (ha) vs. e[m]ergy intensity (sej/ha) for baseline accounting and 3 game scenarios: original, 1, and 2.

4. Conclusion

The ambition to build a renewable city is a complex and difficult task, especially as the cities and the citizens tasked with designing and living in it have to understand the rich ecosystems upon which they depend. E[m]ergy accounting provides a method with which to account for the high quality of the energy currently supporting these systems and the New Chautauqua Game provides an accessible platform within which the land use consequences of changing these flows can be understood. The use of e[m]ergy accounting in a scenario planning tool provides a methodology for understanding the total flows of resources involved, this model does not account for the full sociocultural or political and economic processes that shape human settlement.

Even in its simple form, it is a powerful demonstration of the trade-offs between an economy based on fuels and one based on environmental energies. Students that have played it quickly grasp the principles and understand the limitations. The game could be improved by refining the data on which is based. In the current form each pixel on the maps equates to 64.5 hectares in the real County. Given greater computing power and more data the resolution could be increased so that one pixel was equal to one hectare or less, so that decisions could be planned on a more readily understandable (and accessible) scale, shrinking the point of analysis from the region to the city. Scenario testing allows the built environment to be quantified into a series of inputs and outputs that can be checked against original intentions, afford better tracking of information, and ultimately lead to be more informed decisions being taken.

This method reveals the strengths and limitations of e[m]ergy accounting as a projective tool. Its great power is to make explicit the tremendous concentration of upstream work and resources in our current patterns of living. Conversely, true redesign means that the many forms of production and concentration embedded in e[m]ergy intensities have to be unpacked. In all the UEVs used in this analysis, some of the inputs are readily replaced by renewable resources, while others require specific materials that can only be obtained by mining (or recycling), and so would demand redesign at many scales. The complexity of the increased specificity would turn this into a design tool, rather than tool for teaching or raising awareness.

The scenarios explored by users of the New Chautauqua Game, through the twenty-nine parameters, raise challenging questions about what form future human settlement could take. Questions that quickly move beyond ones about power sources—wind, solar, fossil fuels—to questions about what people should eat, how freely should be able to move between settlements, or how close should they live to one. A vegan diet may use less land than the mixed diet of today, but is this a realistic strategy? If a mixed diet is more important to the wider population, then what other tradeoffs must be made to live within the means of a region's renewable resources? Translating the vast flow of modern living into the equivalent land areas needed to shift to renewable resources quickly changes the debate about a sustainable future from questions about waste and morality to the more immediate questions of supply, demand, and land use.

To play the game visit: http://www.mebd-penndesign.info/New-Chautauqua-Game or http://mostapharoudsari.github.io/SettlementEmerge/

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