SUSTAINABLE ENERGY TRANSITION:
PROPERTIES AND CONSTRAINTS OF REGENERATIVE ENERGY SYSTEMS WITH RESPECT TO SPATIAL PLANNING AND DESIGN

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Abstract

Spatial organization of the built environment affects energy consumption and provision significantly. Transition from fossil-fuels to sustainable energy thus presents many challenges for architects, engineers, spatial planners and landscape architects. Energy neutral buildings exist and self-sufficient neighborhoods are being constructed. At larger scales, however, possible synergies between different processes and functions remain unexplored. Can we envision entire regions that are self-sufficient and run on renewable sources?

Before transforming the built environment, one must understand the characteristic of regenerative systems. The aim of this study was is to compare fossil-fuel energy systems with regenerative systems. It explores key properties and constraints of regenerative energy systems with respect to spatial organization and design of the built environment. The findings of this comparative analysis are illustrated with the help of a regional case-study in South Limburg, the Netherlands.

Preliminary results suggest that some similarities exist between fossil-fuel and regenerative systems. Yet, some properties differ significantly and may affect the organization of the built environment at large. Energy sources, temporal availability, rate of utilization, energy density and system size all differ and represent constraints which can not be solved by conventional spatial design.

Integrated solutions can only be rendered on the basis of understanding regenerative energy systems. This way, spatial planning and design disciplines can contribute to the mitigation of climate change and the adaptation of human environments to renewable energy sources.

1. Introduction

1.1 Energy trends and consequences

Examining recent developments in the European energy system, three major trends can be observed: Firstly, energy consumption has been rising more than 20 percent since the oil crisis in the late 1980's. Secondly, extraction of primary energy resources in Europe has been decreasing significantly (EIA, 2006). Thirdly, the amount of energy provided by renewable means remains limited in comparison to conventional energies. Across Europe, renewable sources contribute only 6.8 percent to the energy provision (CBS, 2007). In order to bridge the widening gap between energy supply and demand, Europe is importing more and more energy. Consequently, the share of imported resources has risen to almost 50% of the total consumption and is expected to increase in the future (EIA, 2006). For many reasons, this situation can not be considered sustainable; neither in economical nor ecological terms. The importing of energy from outside of Europe increases dependency on foreign economies. Above all, scientific studies have revealed a significant correlation between the excessive combustion of fossil fuels and global warming, leading to changing climate and precipitation patterns as well as rising sea levels (e.g. IPCC, 2007).

1.2 Energy transition

Sustainable development represents a paradigm shift, also in the "energy world". The Royal Netherlands Academy of Arts and Sciences emphasizes in one of their latest publications on energy transition that "research must focus on a system approach to the entire [energy] chain, from primary sources of energy to end-user" (KNAW, 2007, p.xiii). Cambridge University Professor Susan E. Owens emphasizes that spatial organization of the built environment affects more than half of the total energy consumption (1990). Energy-conscious transformation of the built environment requires planners, architects and engineers to collaborate with each other and other disciplines. Spatial planning and design can contribute significantly towards sustainable energy transition.

The transition to sustainable energy systems is by no means limited to the provision of renewable energy; improving energy efficiency is just as important. Both aspects, efficiency (step one) and renewables (step two), have been described in the three-step-strategy referred to as 'Trias Energetica' (Lyssen, 1998). Step three, using fossil-fuels as "cleanly" as possible, is not being considered for two reasons. Fossil fuels, which have accumulated over hundreds of millions of years, can not be replaced at the same pace as they are consumed. The combustion of fossil-fuels continues to release greenhouse gases which contribute to climate change and environmental degradation. Therefore, the third strategy of the 'Trias Energetica' may be beneficial during the transition from one energy regime to another but not as a long-term option for a sustainable energy regime that is both regenerative and self-sufficient.

It is important to note that the discussion on sustainable energy transition is not a new one. In the aftermath of the first and second oil crisis, Howard and Elisabeth Odum, among other scholars, argued for a "steady-state economy" where "inflows of energy balance the outflows" (1976, p.241). Energy transition, however, remains a rather vague objective with regard to spatial planning and design.

1.3 State-of-affairs

Transition to renewable energy sources has been studied for more many years. Increasing efficiencies in energy conversion and assimilation of renewables have become key concerns of sustainable development; many ideas circulate and newspapers discuss energy issues regularly. Yet, we are still depending, to a large part, on fossil-fuels and the appetite for energy continues growing across the globe. Disciplines concerned with the planning and design of the built environment are only beginning to understand the magnitude of sustainable energy transition. This study investigates the properties of regenerative energy systems in the natural world with a special focus on possible implications to energy-conscious planning and design. It is self-evident that planners, architects and engineers, first of all, have to understand the characteristics of flow-based energy systems before the built environment can be transformed accordingly.

As indicated above, organization of the built environment influences the energy system at large. Assimilation, conversion, transportation, storage and use of energy are affected by the physical environment in which we live. Access to inexpensive fossil-fuels has not only suppressed renewable energy provision but also manipulated the built environment in many aspects favorable to the use of non-renewable energy sources. The majority of today's built environment reflects the belief in almost inexhaustible resources. The assumptions that energy costs will remain low and sources of fossil fuels will continue to be discovered have been proven incorrect; energy prices fluctuate greatly and are expected to increase in the future. Meanwhile, we were told that non-renewable resources are indeed limited and will be exhausted within a century. In the physical reality, however, one can still recognize energy-excessive patterns of function separation and cost-benefit analysis. Suburbia, excessive highway networks and conventional power plants manifest human faith in inexhaustible (fossil-fuel) resources at our disposal. Fossil-fuels have indeed shaped the 20th century human environments. The discussion on transition from fossil-fuel to regenerative energy systems must acknowledge the physical environment in which we live today and which will continue influencing energy systems of future generations. That is why, in Europe, we need to discuss *improving* existing built environments rather than designing new cities with *ideal conditions* for regenerative systems.

Sustainable energy transition is constrained by a number of aspects; occasionally, issues surface in public discussions. For instance, how to store wind energy so it becomes available in times of need. It is suggested that planners, architects and engineers use the system approach to adapt the built environment (Lovins, 2002). Similar to life cycle analysis (LCA), which investigates the entire life cycle of a product, we must consider the flow of renewable energy from when it enters the Atmosphere until no exergy remains. The paper centers on the key differences between resource-based (fossil-fuels) and flow-based (regenerative) energy systems. This way, we hope to contribute to the integration of energy aspects in spatial planning and design. Experiences from a case-study will help to illustrate the characteristics of both energy regimes.

"Humans not only submit and adapt; they transform in accordance with a preconceived plan. That is, before transforming, they do something extraordinary; namely "see" what is not there" (Tuan, 1998, p.6).

2. Method of Inquiry

This paper presents findings of a multidisciplinary research project conducted by spatial planners, landscape architects and engineers investigating potential synergies between spatial planning and exergy. One objective is to investigate whether entire regions in the Netherlands can be self-sufficient on the basis of renewable energy. Throughout the research project, case-studies help to identify and test energy-conscious design guidelines. While envisioning adaptation of the built environment to renewable energy sources, we have encountered a number of constraints. It appears that many of these constraints can not be solved by mere spatial allocation of land-uses such as housing areas, industries and greenhouses. That is why this paper discusses the fundamental differences between the two energy regimes.

2.1 The case-study method: Research-driven design

During the case-study design, a method referred to as 'research-driven design' was employed. According to Ina T. Klaasen, Professor at the Delft University of Technology, research-driven design involves the creation of a localized design based in part on the results of scientific research (2004). In 2007, we were asked to envision possible pathways for energy transition in South Limburg. Scenario approaches and system science influenced regional energy visions. While composing proposals for the year 2040, a number of uncertainties such as energy prices and population numbers emerged. Such autonomous developments have great impact on regional development, especially when planning 30 years ahead. Incorporating context scenarios studies allowed accounting for some critical uncertainties. Working with ecological concepts, on the other hand, enabled the exploration of energy-conscious design, based on the understanding of natural processes. Research-driven design facilitates the integration of scientific knowledge with creative spatial thinking.

2.2 The area: Case-study South Limburg

South Limburg is located in the South of the Netherlands and comprises an area of approximately 660 square kilometres with a population of about 617.000 inhabitants. The region has a long history as an energy provider to the entire Netherlands. With the closing of the coal mines in the early 1960's, however, the region not only suffered thousands of job losses but also became highly dependant on energy imports from other parts of the Netherlands and abroad. At present, about 98 percent of the energy demand in South Limburg is provided from outside the region. Remaining two percent of energy is renewable; primarily second generation biomass and heat-cold exchange with the shallow underground (CBS, 2006).

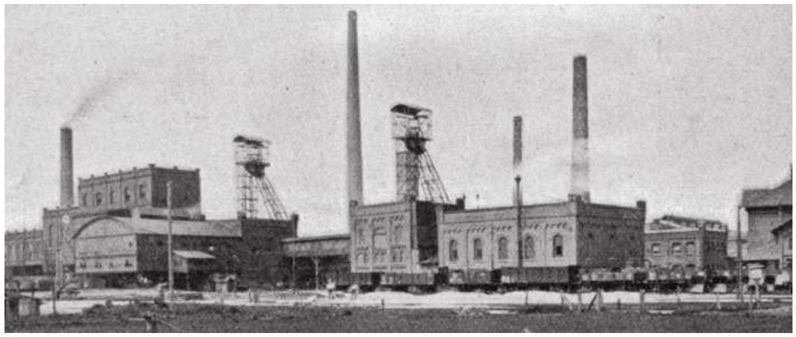

Figure 1: 'Oranje Nassau' mines, South Limburg, 1920's (photographer unknown)

2.3 The team: Regional Atelier 2007

In January 2007, a group of international master students was invited to render a sustainable future for this unique region in the south of the Netherlands. The mission drivers were depletion of fossil fuels, greenhouse gas emission, dependency on energy import and economic shortfall of the region. The assignment was to design sustainable landscapes increasing the regional self-sufficiency in terms of energy. The scope-of-work included a wide range of energy related issues ranging from potential energy savings, assimilation, storage, transportation, consumption and re-use of energy to the exploration of added values on a regional scale; for example preservation of cultural landscapes and improved flood control. During the design process, the group split up into smaller working units investigating the *Maasvallei*, *Heuvelland* and *Parkstad* in-depth.

Figures 2 and 3: The Heuvelland (left) and Maasvallei (right) in South Limburg (NL)

Based upon the system approach, the understanding of ecological concepts and human activities, each of the 'sub-regional' teams composed strategic landscape visions supported by a set of strategies and guidelines for sustainable energy transition. Strategies and design guidelines were than visualized and presented to the public (Etteger and Stremke, 2007). Based upon literature study, inventory, analysis, interviews, and experiences throughout the design process, a number of constraints of regenerative energy systems have been identified which will be explored in the subsequent section.

3. Properties and Constraints of Regenerative Energy Systems

Energy sources and the built environment influence each other in many ways. Available resources and conversion techniques shape urban and rural landscapes (e.g. Ruhr area in Germany). Conversely, physical realities of the environment may suppress or support certain energy sources (e.g. Hoover dam in the Black Canyon, United States). Present-day human energy systems are primarily resource-based and differ in many aspects from regenerative energy systems. The differences between the two energy regimes are of major importance to spatial planning and design of the built environment. Energy sources, temporal availability, energy balance and efficiency, energy density, system boundaries and adaptation to change are discussed subsequently.

3.1 Energy source

As the name indicates, *resource-based systems* depend on accumulated resources such as crude oil, coal and natural gas. These resources have accumulated over hundreds of millions of years; they are considered non-renewable and stocks are limited. The extent of remaining resources, or better, the amount of years they will last, is being debated heavily. However, the rate of resource utilization exceeds the rate of accumulation; it is only a matter of time before they are fully depleted.

Flow-based systems are powered by the influx of renewable energy - that is primarily solar radiation. The Royal Netherlands Academy of Art and Sciences, stresses that "solar energy is the most important sustainable source of energy" (KNAW, 2007, p.xv). In doing so, they emphasize the importance of a sustainable energy system based on direct and indirect solar energy. It has been estimated that the Earth receives about 1.94 calories of solar energy per minute and square centimeter (Blair, 2007). The global solar radiation of one day exceeds about half the energy stored in remaining fossil-fuel stocks. Whereas fossil-fuels have accumulated in certain areas of the world, regenerative sources are distributed more homogeneously across the Earth. Within a nation state, coal may be present but must be transported to the consumer. Renewables, in contrast, can be assimilated close to where they are required.

South Limburg: Fossil-fuels in the region are not depleted yet; low quality coal is still present in the 'Mijnstreek' Limburg; an area that extends from Parkstad Limburg all the way to Sittard-Geleen near the Belgium border. Mining was stopped when natural gas and oil were found in the Northern part of the Netherlands. Although limited to a short period of time, mining has left its footprints in Limburg. *Parkstad* reflects the extent of the coal mines since every mining company established their own settlements near their own shaft. Today, the provincial government focuses on biomass as energy source.

3.2 Temporal availability

One of the advantages of accumulated resources is that they are accessible 24/7 and throughout different seasons. *Resource-based systems* are capable of influencing the rate of primary resource extraction as well as energy conversion; for instance, natural gas production and power plant capacities. Therefore, temporal availability of energy is considered continues or aperiodic. Price variations, political unrest or extreme weather conditions (e.g. hurricanes in the Gulf of Mexico) may influence resource extraction to some degree. However, they result only in minor fluctuations (on the global scale).

Periodic changes in the environment constrain the transition to *flow-based energy system*. Renewables are indeed available for an indefinite period of time; the 'supply' of most sources, however, is not constant. Inorganic (sun, wind and water) or organic renewable sources (biomass) become available only during certain periods of time. The supply may fluctuate between day and night, between summer and winter, rainy seasons and dry seasons. Solar radiation fluctuates more and more as one moves away from the equator.

But not only the 'supply side' fluctuates; the human energy demand also changes throughout the day and between seasons. Energy transition thus requires matching renewable energy supply with energy demand. Human adaptive behaviour plays a major role in this process. The integration of renewable sources (e.g. wind turbines) into multi source-multi product energy (MSMP) systems (KNAW, 2007) is another strategy.

South Limburg: If the region is to rely on renewable sources, temporal availability must be addressed. Due to the elevated topography in South Limburg, hydro power plants on the plateaus could cope with peak loads in electricity demand. Seasonal storage can be accomplished by means of biomass or biomass derivates such as biogas, bio-ethanol and biodiesel.

3.3 Energy balance and efficiency

Resource-based systems can flourish (for a limited period of time) based upon fossil-fuels stored underground. Due to the exploitation of accumulated resources, system output can exceed system input; a reversed situation, compared with flow-based systems.

Flow-based systems only appropriate as much energy as is being assimilated; the system input exceeds the output. Solar energy, the main source of regenerative energy, is available abundantly. A major constraint of *flow-based systems* is their limited capacity to capture and store inorganic energy, also referred to as primary production. If present human societies would have to rely on renewable sources exclusively, relative inefficiencies in energy conversion would lead to increased land-use pressure; large areas would be needed to assimilate sufficient renewable energy.

Another key difference between the two energy regimes can be found on the 'consumer side'. Proponents of the *resource-based system* considered the stock of fossil-fuels almost inexhaustible. Consequently, efforts to improve efficiencies remained limited.

South Limburg: Potential regional self-sufficiency has been estimated on the basis of land-use characteristics and energy conversion rates. This approximation of renewable energy supply has then been compared with current energy consumption in the region. The deficit between potential supply and present demand in South Limburg is approximately 50% (Stremke, 2007). The degree of self-sufficiency, however, relies heavily on the criteria established for the potential utilization of renewable sources. In South Limburg, the objective was to design *sustainable* energy landscapes without compromising distinct qualities of the cultural-heritage landscapes, nor food production or biodiversity.

3.4 Energy density

Energy density - that is the amount of energy stored in a given unit of mass - varies considerably between different energy carriers. Gasoline, for example, has an energy density of 47 MJ/kg. Bulky biomass, in contrast, has a density of as little as 10 MJ/kg.

Flow-based systems appropriate diverse regenerative energy sources and carriers, each with a different energy density (e.g. solar radiation, geothermal heat and biomass). Generally, fossil-fuels have a significantly higher energy density, compared with regenerative energy carriers. This is because fossil-fuels have been exposed to high pressure and heat over millions of years. Density of bulky biomass is low due to the large water content in fresh plant material. It is possible to increase energy density; such “upgrading” is energy intensive.

Assimilation of renewable energy, for instance through photosynthesis or photovoltaic cells, requires space and time. It is imperative to consider rates of energy conversion in spatial planning and design because it influences the amount of space necessary to assimilate energy (e.g. how many wind turbines). Apart from that, energy density influences the spatial distribution of energy carriers. Cascading of residual heat, for example, is a function of monetary and material investments. Laws of physics, however, prevent cascading of warm water and air over longer distances.

South Limburg: Different strategies can be employed to cope with low densities of renewable energy carriers such as biomass. The first option is to minimize distances between assimilation and use. In other words, the spatial extent of energy systems should reflect the energy density of the carrier under consideration. Bulky biomass, for instance, should be used within the region. The number and location of conversion plants in the region, e.g. fermentation tanks, is then a function of available (second-generation) biomass and organic waste. One alternative is to “pre-treat” energy carriers. In the case of organic waste, that would mean drying the waste before transportation. Increasing energy density is, to some degree, also beneficial for seasonal storage as it reduces the volume of energy carriers.

3.5 System boundaries

Resource-based systems are relatively closed systems; they run on accumulated resources. Obviously, the question of system boundary is also one of time. When considering long time-spans, for instance millions of years, fossil-fuels are simply a conversion step. From a human perspective, however, we appropriate resources which are already present in the system (the Earth). The relative closeness of the system Earth is insofar a problem as the energy accumulated over of millions of years is converted and emitted into the atmosphere over short period of time.

Flow-based systems, in contrast, are open to the environment. The inflow of renewable energy is utilized. Photosynthesis, the conversion of inorganic to organic matter, relies entirely on solar radiation. In both systems, however, exergy is lost and entropy created. While energy continues to enter the system (Earth), entropy remains within the system and accumulates.

System boundary represents another key difference between resource and flow-based systems. This aspect is discussed extensively in the ecological literature. Throughout the last three decades, a major shift from an ‘equilibrium point of view’ to a ‘disequilibrium point of view’ has occurred. Ecologists initially believed that populations and ecosystems are in balance with local resources and conditions. In other words, systems were considered relatively closed or autonomous. Later studies, however, have shown that ecosystems must be considered open; they are strongly influenced by the input and output of materials, individuals and energy across system boundaries (Pulliam and Johnson, 2002).

South Limburg: Open system theory requires acknowledging global developments while acting locally or regionally. Depletion of coal in Australia, for instance, will affect provision of electricity from power plants in the Northern Netherlands. The system boundary of South Limburg is primarily a political boundary; the region represents one of the Dutch planning regions. The optimum extent of regions for effective spatial planning has been discussed extensively (e.g. Steiner, 2002). It appears that regions with unifying culture, similar landscape typologies and ecosystems have a strong potential to address energy transition effectively. That is partly due to the fact that the size of such regions is still at human scale; inhabitants know their way and feel attached to “their” region. At the same time, regional focus allows for integrated solutions; the effectiveness or which goes beyond possibilities at smaller scales (e.g. building scale).

3.6 Adaptation

Resource-based systems are capable of balancing fluctuations in energy supply. Adaptation to changes in the system environment is postponed until feedback is experienced. Some advanced ancient civilizations in the Mediterranean basin, in particular the Greek and Roman Empire, have failed to adapt to the depletion of resources; for instance, wood for ship building. The lack of ships for the transport of goods and establishment of control, among other reasons, eventually resulted in the collapse of these civilizations. The same would have been true for England, only that large coal deposits were found before wood became a scarce resource. Coal then led to the industrial revolution coinciding with the expansion of the British Empire (Sieferle, 2001).

The history of flow-based systems, in contrary, is more balanced and stretches over much longer time spans. Regenerative systems rely on energy-flows rather than stored resources. That is why flow-based systems are more flexible; they respond to feedback, adapt and optimize the utilization of available energy sources. Cascading of energy between consumers is one of the most prominent strategies to increase overall system efficiency (Odum, 1983). Adaptation allows the system to be sustainable on the basis of renewables, to grow in (bio)mass and biodiversity. The combination of increasing efficiencies and regenerative sources renders flow-based energy systems more sustainable, compared with their resource-based counterparts.

South Limburg: If energy efficiency can be further increased, the region can transform into a regenerative and nearly self-sufficient part of the Netherlands. Great potentials have been mapped in the region, reaching from rivers and streams, wind exposed plateaus, agriculture and forestry providing second generation biomass and geothermal heat to densely populated cities which allow for heat cascading and advanced public transportation. Transition from fossil-fuels to regenerative energy system, however, presupposes adaptation of large parts of the human environment.

4. Conclusion

The discovery of fossil-fuels, in conjunction with the invention of the combustion engine, not only stimulated unprecedented economic growth but also resulted in spatial patterns which are highly dependant on vast amounts of energy: energy needed for construction and maintenance of the built environment, energy for transport of people and goods. One of the pressing questions of sustainable development is how to adapt the built environment to a regenerative energy regime. Energy-conscious organization principles are needed to guide the transformation of the human environment. Before articulating such guidelines, however, the characteristics of regenerative energy system must be explored. This paper discussed key differences between (human) fossil-fuel and (natural) regenerative energy systems with respect to spatial planning and design.

Research into the characteristics of both energy regimes has shown that they indeed differ significantly. Some aspects, however, have proven to be less relevant for spatial planning and design than others. *System boundaries* of both energy regimes are more or less permeable. Resource-based and flow-based systems differ insofar as that system output (e.g. greenhouse gas emission) is of major concern in the first regime whereas input (e.g. assimilation of solar radiation) limits the latter one. Finally, both energy regimes are capable of adapting to changing conditions in the system environment. The capacity and pace of *adaptation*, however, varies. In resource-based systems, feedback is delayed. Flow-based systems are exposed to immediate feedback; they continuously adapt and optimize resource utilization. Whereas energy density, system boundaries, and adaptation are important aspects of a comparative system analysis, other system properties are more relevant to spatial planning and design.

Spatial distribution of *energy sources* differs significantly with great implications to the built environment. The homogeneous distribution of renewable energy does not present a constraint but rather an opportunity to minimize energy loss in transportation and transmission. *Temporal fluctuations* in energy supply present one constraint of flow-based energy systems. Special attention is required to balance energy supply (e.g. through storage) and demand (e.g. adaptive behaviour) in space and time. The final characteristic that was examined concerns the way in which *energy is utilized* in both regimes. Fossil-fuels can only “feed” a system for a limited amount of time. Industrial agriculture, for example, consumes more energy than it provides; fossil-fuels are turned into biomass. The energy input of flow-based systems, in contrast, is always larger than the output. The limited capacity of natural systems to utilize primary energy sources has led to the evolution of many energy-effective strategies. Cascading of energy in food-chains is only one example that has inspired heat cascading in the built environment.

In conclusion, the two energy regimes differ in many aspects from each other. In spite of many advantages of regenerative energy systems, a number of constraints need to be addressed while discussing transition from one energy system to another. Through research and case-study design, both chances and constraints of sustainable energy transition have been identified. Energy transition has more implications to design and planning of the built environment than has been assumed. Each energy regime has distinct characteristics which influence the environment and vice versa. The properties and constraints of regenerative energy systems which have been discussed in this paper illustrate the manifold relations between spatial planning and sustainable energy transition. We invite architects, planers and engineers to join in the dissemination of fundamental scientific knowledge which can inform energy-conscious planning and design of the built environment. In doing so, spatial design disciplines can remain relevant and face their responsibility for other places as well as for future generations.

“The success or failure of a transition process comes down to a complex set of factors involving more than purely technological efforts” (KNAW, 2007, p.xvii).

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