DESIGNING SUSTAINABLE ENERGY LANDSCAPES

CONCEPTS PRINCIPLES AND PROCEDURES

SVEN STREMKE

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Concepts, Principles and Procedures

Sven Stremke

Thesis

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Introduction

1

Energy is indispensable for life. The vast majority of life on Earth obtains energy directly from solar irradiation through photosynthesis, or indirectly via other life forms. What is the relation between energy and the design of sustainable landscapes? In this thesis, landscape is conceptualized as that part of the physical environment that is influenced by humans to provide food and energy, among other landscape services. Up until the discovery of fossil fuels, farmland provided food, grasslands provided fodder for working animals, forests and bushes provided fuels. There existed a clear correlation between 'land' and 'energy'. Energy was scarce because space was limited (Pimentel and Pimentel, 2008). The term 'energy', as we understand it today, only emerged during the industrial revolution when technological innovation allowed the conversion of fossil fuels from one form to another (Sieferle, 1997). Open cast mines, oil and gas fields is what one may call 'fossil fuel energy landscapes'. Edward Burtynsky (2009) is one of the photographers who have captured the nature of fossil fuel energy landscapes that are a result of industrial resource extraction, conversion and consumption. Discussing fossil fuel energy landscapes is, however, not the scope of this thesis. This thesis is concerned with the fact that, in the near future, landscapes again will have to provide renewable energies. The assimilation of renewable energy requires space (Sijmons et al, 2008) and affects both the spatial organization and appearance of our physical environment (Koh, 2005a). The research presented in this thesis is motivated by the need to develop *sustainable energy landscapes* - landscapes that are well adapted to renewable energy sources without compromising other landscape services, landscape quality or biodiversity.

1.1 Problem description

Well-recognized institutions such as the United Nations, the World Wildlife Foundation and Intergovernmental Panel on Climate Change (IPCC) have studied the present-day "fossil fuel economy" (Droege, 2002, p.87). They point to (partly irreversible) effects such as climate change, loss of biodiversity, environmental pollution, social inequity, and unhealthy living conditions. These effects, combined with growing concerns about energy security, drive the transition to renewables. As a consequence, competition between energy crops and food production is increasing. In addition, renewable energy sources can have adverse effects on biodiversity and landscape quality. Two key objectives have emerged from the recent discussion on energy transition. Firstly, reduction of energy consumption to decrease greenhouse gas emissions and land-use pressure (Dernbach and Brown, 2009; Rees and Wackernagel, 1994; Rees, 1996; Ros et al, 2000).[1] Secondly, replacement of fossil fuels by renewable energies. In order to contribute to sustainable development, renewable energy provision must not harm social equity, biodiversity and landscape quality (Pasqualetti, 2001; Gamboa et al, 2005; Stremke, 2007; Van der Horst and Evans, 2010). The question that is of special interest to me as landscape architect is how to transform present-day fossil fuel depending landscapes into sustainable energy landscapes? What are the principles by which sustainable energy landscapes can be designed, and how to organize the design process? The former question relates to *substantive knowledge* and the latter to *procedural knowledge* (see e.g. Ryle, 1949; Schön, 1983; Lang, 1994).

1.2 Literature discussion

The research presented in this thesis benefited both from literature from landscape architecture and from other disciplines. The literature discussion below is divided into the following three topics: (1) energy in engineering and environmental design[2], (2) energy-related concepts, strategies and precedent cases, and (3) long-term transformation of large territorial systems.

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1 Other co-benefits of reducing energy consumption include reduced demand pressure on energy prices, strengthened local and national economies, job creation and technology development, protection of low-income households, and reduction of air pollutants (Dernbach and Brown, 2009).

2 Environmental design refers to the disciplines concerned with the design and spatial organization of the built environment; for instance, architecture, urban planning, spatial planning and landscape architecture.

1.2.1 Energy in engineering and environmental design

Various fields of engineering are concerned with the transition to sustainable energy systems and engaged with improving energy technologies[3] and infrastructure[4]. Until recently, the performance analysis of energy systems was limited to energy efficiency. Nowadays, the concept of exergy[5] is embraced by *thermodynamic engineers* and others in order to identify and minimize losses in energy conversion, assimilation, storage, and transport (e.g. Bejan, 2002; Cornelissen, 1997; Çomakli et al, 2004; Hepbasli, 2008). The so-called 'heat-cascade' is one energy-conscious intervention that is discussed extensively by thermodynamic engineers (Akisawa et al, 1999). The theoretical energy savings of cascading heat has been estimated between 5% (Matsuhashi et al, 2000) and 60% (Groscurth et al, 1989). Studies have shown that the impact of such energy-conscious interventions is influenced largely by site-specific factors (see e.g. Hepbasli, 2008).

About 37% of the global greenhouse gas (GHG) emissions derive from industry of which more than 80% is caused by energy use (Worrell et al, 2009). Efforts to reduce energy consumption in the industrial sector have intensified in recent years, leading to the emergence of a discipline called *Industrial Ecology* (IE) (Connelly and Koshland, 2001; Jelinski et al, 1992). IE principles have been put into practice in 'eco-industrial parks', an environmentally friendly version of industrial parks (e.g. Kalundborg, Denmark). Yet, IE strategies are not integrated across the entire industrial sector (Connelly and Koshland, 1997), and many industries hesitate to break new grounds (Rosen, 2002).

Considerable progress has been made in the domain of *building engineering and architecture*. More and more, renewable energy is considered in building design and orientation (e.g. Wines and Jodidio, 2000; Santamouris, 2006; Torio et al, 2009). Some of the energy-conscious design principles that have been published are derived from vernacular architecture (e.g. Knowles, 1974; Raydan and Steemers, 2006). Since the 1990s, the concept of exergy has been applied in the design of several buildings (e.g. Schmidt, 2004, 2006 and 2009). In Switzerland, exergy has been introduced into local building legislation (Favrat et al, 2008). Recently, exergy analysis is also employed by architects to study energy

3 Energy technologies are technical devices that can assimilate, convert, and store energy. The range of renewable energy technologies reaches from small heat exchangers to large wind turbines and is described in depth (see e.g. Twidell and Weir, 2006; Randolph and Masters, 2008).

4 Energy infrastructure refers to the networks that can transport and transmit energy, for instance district heat networks, gas grids, and power lines.

5 Exergy is defined as the maximum amount of work which can be produced by a stream of matter, heat, or work as the medium comes into equilibrium with a reference environment (Dincer, 2000).

losses in the built environment (e.g. Jansen et al, 2009; Jansen and Woudstra, 2010).

In *urban planning* too renewable energies are more and more considered (e.g. Balocco and Grazzini, 2000; Droege, 2006; Herzog et al, 1996). Energy-conscious urban design principles have been formulated in pursuit of more sustainable development (Boelen et al, 1995; Elkin et al, 1991; Frey 1999; Meier, 1974). Urban planning practice has embraced energy-conscious principles to varying degrees. Proponents of the 'solar cities' project, for example, advocate energy self-sufficiency and energy-conscious land-use planning (Droege, 2002). In his book 'synergy city', Wood proposes a contemporary approach to a high density and super-symbiotic society (2007). Comprehensive analysis of urban energy systems has been conducted only recently (e.g. Ascione et al, 2009; Girardin et al, 2010).

Energy is also addressed in *landscape planning and design*. Historically, energy conservation was somewhat limited to the selection of plant material and site planning (e.g. Robinette and McClenon, 1983; Brown and Gillespie, 1995; Thompson and Sorvig, 2000). Recently, renewable energy assimilation has become a scope to landscape planner and designer (Motloch, 2001; Reinke, 2008). The location and lay-out of energy crop plantations[6], the design of wind parks[7] and other energy technologies[8] have turned into an important area of activity both in landscape architecture practice and research. The need for energy-conscious (re)organization of landscapes and transportation networks has been emphasized by several designers (e.g. Thayer, 2008; Thün and Velikov, 2009; Van Hoorn et al, 2010).

At the *regional scale*, inquiry focuses on the analysis of energy flows. For the metropolitan area of Taipei (Taiwan), six energetic zones have been described (Huang et al, 2001). In the province of Siena (Italy), seven exergy destroying sectors have been identified (Sciubba et al, 2008). The mapping of renewable energy potentials at the regional scale has been studied and operationalized (Dobbelsteen et al, 2007a and 2007b; Ramachandra and Shruthi, 2007). By including both renewable and residual energy such as waste heat from power plants, the so-called 'extended energy potential mapping' approach has emerged (Broersma et al, 2009).

Energy gradually receives more and more attention among environmental designers. The German professional magazine *Garten und Landschaft* [Garden and Landscape] devoted one issue to energy landscapes (03/2009). Harvard University journal *New Geographies* too addressed

6 See for instance Bell and McIntosh (2001), De Vries et al. (2008), Eker et al. (1999), Galdon et al. (2007), Kloen (2002), Van Dooren and Dubbeldam (1999).
7 See for instance Leeuwen (2006), Pasqualetti et al. (2002), Schöbel (2008 and 2009).
8 See for instance Sijmons et al. (2008).

the relations between energy and space (2/2009). The *International Review of Landscape Architecture and Urban Design* devoted one recent issue to 'sustainability' with special attention to energy landscapes (TOPOS 1/2010). The *Landscape Research Journal* too published a special issue that explores the relationship between landscape and energy (2/2010). Despite this growing attention to energy landscapes, only few environmental designers discuss principles and guidelines that can help designing sustainable energy landscapes (e.g. Dittrich and Schöbel, 2010).

1.2.2 Energy-related concepts, strategies and precedent cases

Due to the many similarities between natural and human ecosystems (see e.g. Nielsen, 2006; Korevaar, 2007), nature presents a source of inspiration for energy-conscious design (Stremke and Koh, 2010). Nature is described through ecological concepts; some of which reveal how renewable energy is assimilated and energy flows optimized. The Second Law of Thermodynamics presents another source of insight for the design of sustainable energy landscapes (Stremke et al, 2010). Several existing renewable energy landscapes[9] provided a third source of inspiration. The bio-energy village Jühnde in Germany (Degenhardt and Karpenstein-Machan, 2002), the rural municipality Güssing in Austria (Koch et al, 2006), and the renewable energy island Samsø in Denmark (Jørgensen et al, 2007) were studied. In the following, key publications both from ecology and thermodynamics are reviewed.

Several descriptive *ecological concepts*[10] have been translated into prescriptive landscape design principles.[11] Landscape-ecological design principles, for example, can help preserving biodiversity.[12] Ecological engineers apply ecosystem knowledge for instance in the design of waste water treatment plants (e.g. Mitsch and Jørgensen, 2003; Todd et al, 2003; Van Bohemen, 2005; Van Leeuwen, 1981). The relationship between resource utilization and landscape pattern, studied by landscape ecologists, is of particular importance to the design of sustainable landscapes (see e.g. O'Neil et al, 1988; Ryszkowski and Kdziora, 1987). In the context of resource depletion and environmental pollution, ecological systems can serve as models for sustainable design.[13] The value of ecology as 'agent of creativity' is debated within the environmental design community (e.g.

9 I am using the term 'renewable energy landscapes' because our studies have shown that these landscapes utilize renewable sources but can not (yet) be considered sustainable energy landscapes.
10 For instance Cherrett (1988), Odum (1969, 1983, 1992), and Patten (1978, 1998).
11 See for instance Forman and Godron (1986), Forman (1995), Makhzoumi and Pungetti (1999).
12 For instance Cook and Hirschman (1991), Dramstad et al. (1996), Farina (1998), Botequilha-Leitão and Ahern (2002), Opdam et al. (2002), Nassauer and Opdam (2008).
13 See for instance Alberti (2000), Golley (1996), Hough (1984), Koh (1978 and 1982), Lyle (1994), Moffatt and Kohler (2008), Newman and Jennings (2008), Newman (1975), Pulliam and Johnson (2002), Steiner (2002).

Bradshaw and Handley, 1982; Corner, 1997; Karr, 2002). Yet, it remains difficult (if not impossible) to find any better model for environmentally sound development, other than nature.

The *concept of exergy* is increasingly employed to minimize losses in energy conversion (e.g. Bejan, 1996 and 2002). The concept of exergy is also applied, to different degrees, in environmental impact assessment and ecosystem studies (see Dewulf et al, 2008). Since the 1990s, exergy and entropy[14] are increasingly used to measure ecosystem maturity (e.g. Bastianoni and Marchettini, 1997; Ludovisi et al, 2005; Schneider and Kay, 1994). Living plants are understood as "thermodynamic machines" which produce work (Svirezhev and Steinborn, 2001, p.101). The concept of exergy is also useful to estimate irreversibility of human actions both at the regional and national scale (Sciubba et al, 2008; Wall, 1978 and 1987). Some consider exergy as one of the indicators for sustainable development (see e.g. Dincer, 2000 and 2002; Dincer and Rosen, 2007; Jørgensen, 2006).

1.2.3 Long-term transformation of large territorial systems

The transition to renewable energy is expected to require (at least) several decennia (Sieferle, 1997 and 2001; Smil 2003 and 2008). Transition needs to occur across the different spatial scales of the physical environment all the way to large territorial systems such as regions (Dobbelsteen et al, 2008; Kratochvil, 2004; Koh, 2005a; Van Dam and Noorman, 2005). Both the long-term character of energy transition and spatial complexity of regions present key challenges to environmental designers.

Proponents of *strategic spatial planning* emphasize the importance of long-term visions (Albrechts, 2004, 2006a and 2006b) and community participation (Healey, 1997 and 2009). They stress the need to localize visions so they can encourage and promote public debates (Cartwright and Wilbur, 2005; Friedmann, 2004). To the proponents of *transition management* too, visions must be appealing and imaginative to gain support by a broad range of actors (Van der Brugge and Rotmans, 2007; Kemp et al, 2007; Rotmans et al, 2001). How far strategic spatial planning and transition management can gain momentum in the energy-conscious transformation of regions remains to be seen. Forty years ago, energy security issues persuaded a group of corporate planners working for Royal Dutch Shell to embrace scenario thinking (Kleiner, 1996). Today, it appears that scenarios, strategic planning and energy meet once again (Vamelis and Sumrell, 2009).

14 The Second Law of Thermodynamics states that spontaneous processes will occur always in the direction of increasing entropy. Entropy is a measure of the state of disorder of a system.

Landscape planners and designers too study how to transform large territorial systems (e.g. Sijmons, 1990). Steinitz's 'design-framework' (1990 and 2002) has been employed to envision alternative futures for many regions across the world. 'Planning by design' is an approach that integrates possible scenarios and desirable futures in the development of alternative futures (Weller, 2008). Nassauer and Opdam describe yet another approach. To them "design was explicitly both a research activity and a product of the research. The final landscape designs, or alternative futures, were expressed as replicable design rules by which the present landscape could be transformed into each of those futures" (2008, p.639). Each of those approaches can be employed for long-term transformation of large territorial systems. The literature review, however, also revealed several issues that deserve further attention.

1.3 Knowledge gaps

Design, in general, requires a thorough understanding of the design process itself and sound design principles. For the design of sustainable energy landscapes, both procedural and substantive knowledge are lacking. The following four knowledge gaps were identified:

The first knowledge gap concerns energy-conscious design principles. Natural ecosystems present sustainable patterns but "designers, planners, and local actors fail to use ecological knowledge properly […] There is a need for knowledge systems that simplify this complex variety so that it can be understood and handled by local planners, and designers" (Opdam and Steingröver, 2008, p.1). Translational research[15] is one means to formulate energy-conscious design principles.

The second knowledge gap concerns the absence of 'second-law thinking' in spatial planning and landscape design. In spite of the great relevance of the Second Law of Thermodynamics to sustainable development, there are few environmental designers which embrace second-law thinking (e.g. Gommans, 2009; Thayer, 2008; Vries et al, 2008). The study of second-law thinking and its application in other disciplines can contribute in formulating additional principles for the design of sustainable energy landscapes.

The third knowledge gap relates to the scale of energy-conscious design. There are calls to pursue sustainable energy transition at the

15 Musacchio defines translational research as "collaborative learning process between scientists, designers, planners, and engineers who seek to solve complex environmental problems by connecting scientific theory, concepts and principles to the design and planning of the built environment" (2008, p.3).

regional scale (Benner et al, 2009; Dobbelsteen et al, 2008; Koh, 2005; MO-RO-MLV, 2008). Whether or not the regional scale can facilitate the development of sustainable energy landscapes, however, remains open. There is little research on energy-conscious regional planning and design.

The fourth knowledge gap, finally, relates to the design procedures. Planning and design practice is complex and challenging, especially at the regional scale (Van der Valk and Van Dijk, 2009). There is a strong necessity for long-term visions when it comes to sustainable development in general (Mintzberg, 1994; Kunzmann, 2000) and sustainable energy landscapes in particular (Van Hoorn et al, 2010). In spite of the different approaches to spatial planning and landscape design that have been discussed before, a knowledge gap persists on how to incorporate current trends and critical uncertainties in the process of composing regional visions.

1.4 Goal and research questions

The goal of this thesis is to advance the knowledge basis for planning and design of sustainable energy landscapes at the regional scale. The two sub goals are to investigate (a) principles by which sustainable energy landscapes can be designed, and (b) procedures by which the design process can be structured. On the basis of the described problems, the literature review and the goals of this research, the following research questions were formulated:

1. What can we learn from natural ecosystems in order to develop sustainable energy landscapes?
2. How can the Second Law of Thermodynamics inform the design of sustainable energy landscapes?
3. How can we conceptualize the region in the context of energy-conscious spatial planning and landscape design?
4. How to incorporate current trends and critical uncertainties in long-term regional planning and landscape design?

1.5 Definition of terms

The key terms that were of capital importance during my research are defined as follows.

Region refers to an area of a country or the world having definable characteristics but not always fixed boundaries. Region can also refer to an administrative district of a city or country (Oxford dictionary, 2010). Commonly, a region consists of several landscapes.

Landscapes are areas, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors (Council-of-Europe, 2000). In this thesis, the concept of landscape embraces both urban and rural areas.

Landscape architecture is the discipline concerned with the conscious shaping of the human environment. It involves planning, design and management of the landscape to create, maintain, protect and enhance places so as to be functional, beautiful and sustainable, and appropriate to diverse human and ecological needs (ECLAS, 2009).

Landscape planning is described as a forward-looking action to enhance, restore and create landscapes (Council-of-Europe, 2000). Landscape planning addresses the question of how to solve land-use conflicts between different interest groups and proposes strategies for future development and organization of a landscape (Tress et al, 2006).

Spatial planning aims to create rational territorial organization of land uses and the linkages between them, in order to balance the demands for development with the need to protect the environment, and to achieve social and economic objectives (ESPON, 2004).

Environmental design refers to the disciplines concerned with the design and spatial organization of the built environment; for instance, architecture, civil engineering, urban planning, spatial planning and landscape architecture.

Sustainable development is defined as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

A *sustainable energy system* is a “cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks” (Hepbasli, 2008, p.598). In this thesis, the focus lies on renewable and residual energy.

A *sustainable landscape* comprises and is part of several energy systems that effectively utilize renewable energy and networks. The energy demand of sustainable landscapes can be met by local renewable sources.[16]

16 In this thesis, I use the term ‘sustainable energy landscape’ to emphasize on sustainable energy as the thematic scope of my research. Landscape design, of course, is by no means limited to energetics but needs to address a broad range of landscape services.

1.6 Organization of the thesis

This thesis consists of nine chapters (see figure 1-1). Chapter 1 contains the problem description, the literature review, a list of knowledge gaps and research questions. In chapter 2, the research design for this thesis is presented. The main body of the thesis contains six articles that deal with energy-conscious regional planning and landscape design. All six articles were written as independent publications for different journals. That is why some overlap between the different chapters, especially in the introductions could not be avoided. The main body of the thesis can be further divided into two parts.

Part 1 focuses on the exploration of substantive issues. In chapter 3, I identify and discuss a number of descriptive ecological concepts and ecosystem strategies which help formulating energy-conscious design principles. In chapter 4, I discuss how the concept of exergy can inform the design of sustainable energy landscapes. In chapter 5, I illustrate how these concepts and principles have been applied in the design of several sustainable energy landscapes. In chapter 6, I discuss how to conceptualize the 'region' in the context of energy-conscious planning and design. The theoretical discussion is supplemented by figures and facts from a regional case-study in Southeast Drenthe, the Netherlands.

Part 2 of this thesis focuses on procedural issues. In chapter 7, I advance a framework for composing integrated visions; a five-step approach through which current trends and critical uncertainties can be integrated in the design process. Chapter 8 illustrates how this approach has been applied to compose a set of integrated energy visions for Margraten, in the South of the Netherlands.

In chapter 9, I discuss the findings of this thesis with respect to the four central research questions. In the final chapter, I also reflect on the state-of-the-art of energy-conscious landscape design and discuss some implications of my research.

Chapter 1

Introduction

Chapter 2

Research Design

Part 1: Substantive issues

Chapter 3

Energy and the Biosphere
Ecological concepts and strategies with relevance to energy-conscious spatial planning and design

Chapter 4

Energy and the Technosphere
Exergy landscapes: Exploration of second-law thinking towards sustainable landscape design

Chapter 5

Energy-conscious Environmental Design
Energy landscapes: Integration of ecological concepts and thermodynamic laws in environmental design

Chapter 6

Energy and the Regional Scale
Exploring the region as scale for energy-conscious spatial planning and design

Part 2: Procedural issues

Chapter 7

Energy Visions at the Regional Scale
Integrated visions (I): Methodological framework

Chapter 8

Energy Visions for Margraten
Integrated visions (II): Envisioning sustainable energy landscapes

Chapter 9

General Discussion

Figure 1-1 Overview thesis.

Fossil fuel energy landscape: Open-cast mine near Leipzig, Germany (courtesy LaNaServ, D. Stremke)

Fossil fuel energy landscape, Gulf of Mexico, May 2010 (Flickr, J. D. Davidson)

Research design

2

The research presented in this thesis was conducted as part of my contribution to a multidisciplinary research project entitled ‘Synergies between Regional planning and EXergy’ (SREX). The research path has been nonlinear; research questions, exploration, discussion and reflection alternated continuously. In a certain way, each article included in this thesis has its own itinerary. Different people were involved in the research process which stretched from several months to years. Nevertheless, the research presented in this thesis followed a certain “research design” to speak with the words of Creswell (2009, p.3). In this chapter, I discuss the nature of the problem(s) studied, the worldview of the researcher[1], the chosen methodology[2] and methods[3].

1 Philosophical worldview (or epistemology) describes the position that is taken on the theory of knowledge.
2 Methodology refers to the strategy that underpins the way research is carried out.
3 Method refers to the operational techniques and procedures that are used to conduct the research.

2.1 Introduction

Many environmental design problems are so ill-defined that they are called *wicked problems* (Churchman, 1967; Rittel, 1972; Bazjanac, 1974). For wicked problems, there exists no explicit basis for the termination of problem-solving activity; any time a solution is proposed, it can be developed still further (Rowe, 1987). This thesis is motivated by a set of interrelated wicked problems - resource depletion and climate change - which had several implications for my research: Firstly, research methods were not predetermined; they had to be defined successively. Secondly, design principles and procedures rendered in this thesis contribute to a growing body of knowledge that is ‘under construction’.

Whereas all designers, in one way or another, engage in creative exploration in the process of designing, there is a clear difference between design that is simply design and design that serves as research. If designers address both a particular design and a larger set of questions, they are, according to Laurel, conducting research (Laurel, 2003). This is an important notion because this thesis presents the research conducted by a landscape designer. To me, design research is a form of ‘heuristic’; a means to contribute to reduction in the search for a problem solution (after Newell et al, 1976, p.78).

The ultimate test of a design, of course, is to realize it and to test inherent hypotheses empirically. However, “it is easier to test an experiment in the technical or natural sciences because it can be considered as replicable, closed system” (Steenbergen et al, 2002, p.25). Ethical and financial considerations as well as the time factor make it virtually impossible to test a regional plan under controlled, repeatable conditions. In such cases we “have to draw plausible conclusions on the basis of a series of applications, regarding the necessary conditions and effects that arise” (Klaasen, 2004, p.199). Conclusions not only have to be plausible and explicit, but also have to be published for critical discussion.

2.2 Worldview

The terms ‘philosophical worldview’ (Creswell, 2009), ‘paradigm’ (Lincoln and Guba, 2000), ‘epistemology’ and ‘ontology’ (Crotty, 1998) all stand for a “basic set of beliefs that guide action” (Guba, 1990, p.17). Although the worldview remains largely hidden in research, it influences the practice of research and should therefore be identified (Creswell, 2009). This thesis is influenced both by the personal and the disciplinary background of the author. Our knowledge about 'reality' is a result of interplay between reality and the person who perceives reality. In my opinion, reality cannot be known objectively.

2.3 Methodology

Environmental designers, according to Rowe, have three modes of inquiry at their disposal; they are deduction, induction and abduction (Rowe, 1987, pp.101-102). The first mode of inquiry, *logical deduction*, is considered most valid in situations with a clear expression of ends. Appropriate means can be deduced by using available rules and principles, for instance building codes. *Inductive reasoning*, the second mode of inquiry, can help as one moves from the particularities of a situation to a more comprehensive conclusion. *Abduction* is a third mode of inquiry. Natural laws, just to name one example, are adduced in order to explain natural phenomena. Abduction, according to Rowe, "is an appropriation from outside the immediate context of the problem space [...] It must show promise in facilitating problem-solving activity" (Rowe, 1987, p.102-103). Abduction is a common mode of inquiry in design research (ibid.). Several environmental designers have successfully combined the three modes of inquiry (e.g. Schöbel, 2006). This thesis too adopted logical deduction (e.g. applying energy-conscious urban design principles), inductive reasoning (e.g. formulating generally applicable design guidelines on the basis of case-studies), and abduction (e.g. translating knowledge from ecology and thermodynamics).[4]

The European Council of Landscape Architecture Schools has described three types of research practiced by landscape architects (LeNotre, 2008). They are closely related to the three modes of inquiry discussed heretofore.

(a) *Research for planning and design*: Research including ecology and other disciplines in order to apply knowledge to landscape planning and design.
(b) *Research of planning and design*: Research aiming to improve landscape architecture theory and methods such as planning and design processes.
(c) *Research by planning and design*: The analysis of complex spatial strategies by, for example, producing, applying and evaluating scenarios.

In this thesis, all three types of research have been practiced (see figure 2-2 and 2-3). The research findings were then used to design several

4 This approach might be comparable to what Creswell (2009) defines as 'mixed method strategy'.

sustainable energy landscapes. Klaasen described this approach to design as *research-driven design* (2004, p.126). For this thesis, the interplay between the different types of research and design can be described as following (see figure 2-1). *Research-by-design* is considered an overarching approach to research in Landscape Architecture which consists of the following three actions: *research for design*, for instance the study of ecology and thermodynamics; *research of design*, for instance the study of existing methodological frameworks, and *research-driven design*, the application of design principles and procedures in several cases.

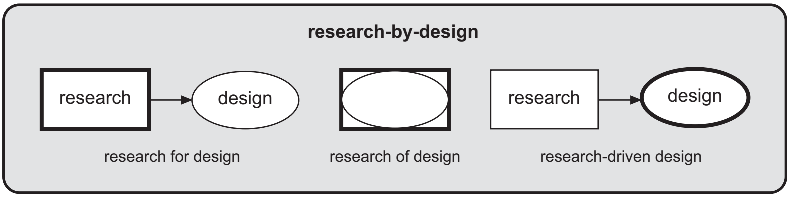

Figure 2-1. Research-by-design as conceptualized in this thesis.

2.4 Methods

As noted earlier, two kinds of knowledge gaps exist with regard to the design of sustainable energy landscapes. They are of substantive and procedural nature. The framework by which both design principles and procedures have been studied can be illustrated by a 'double-loop'. Although the two conceptual research frameworks are similar in structure, the operational methods differ significantly as discussed below.

2.4.1 Substantive knowledge

In this thesis, design principles are formulated partly on the basis of descriptive concepts from ecology and thermodynamics (chapter 3 and 4). Emerging design principles were treated as hypotheses and explored through application in energy-conscious regional design (chapter 5). The effects of possible interventions on the energy economy and on landscape quality were studied in order to further advance the planning and design of sustainable energy landscapes. The research-by-design framework consists of eight phases. Step 1 through 4 can be characterized as research for design; step 5 through 8 as research-driven design (figure 2-2).

Over the past years, we went through this 'double-loop' several times; to articulate generally applicable design principles and to apply and refine them in the design of sustainable energy landscapes (see chapters 3, 4, 5 and 6).

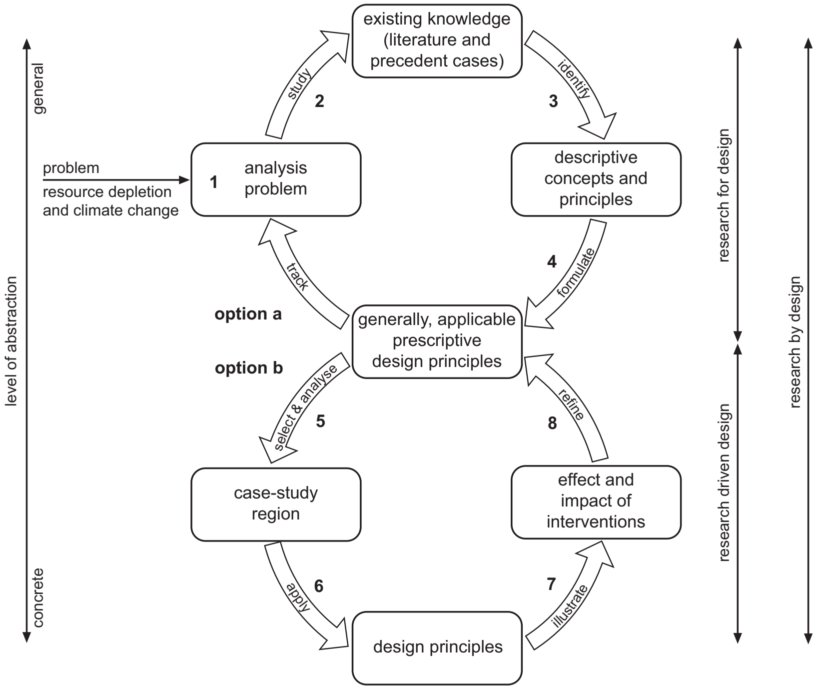

Figure 2-2. Conceptual framework for research on energy-conscious design principles.[5]

2.4.2 Procedural knowledge

The process by which sustainable energy landscapes can be designed is treated as hypotheses too. Through the study of existing planning and design approaches, we have identified building blocks and synthesized a new approach for the composition of integrated energy visions. The 'five-step approach' enables designers to incorporate current trends and critical uncertainties in the composition of long-term visions (chapter 7). The approach has been applied in several case-studies and checked against a number of criteria discussed in the strategic planning and landscape design literature (chapter 8). Step 1 through 4 of the research on procedural knowledge can be characterized as *research of design*; step 5 through 8 as *research-driven design* (figure 2-3).

5 Step 1: Problem analysis: resource depletion and climate change.
Step 2: Study of existing knowledge i.e. literature and precedent cases.
Step 3: Identify descriptive concepts and principles that are relevant to the problem.
Step 4: Formulate generally, applicable prescriptive design principles.
Step 5: Select and analyse case-study region(s) to test and refine design principles.
Step 6: Apply design principles in the design of sustainable energy landscape.
Step 7: Illustrate effects and impact of energy-conscious interventions in case-study region.
Step 8: Check design principles and (if necessary) refine generally, applicable design principles.
Option a: Track developments in case-study region and (if needed) search for additional principles.
Option b: Conduct another case-study to further test and refine design principles.

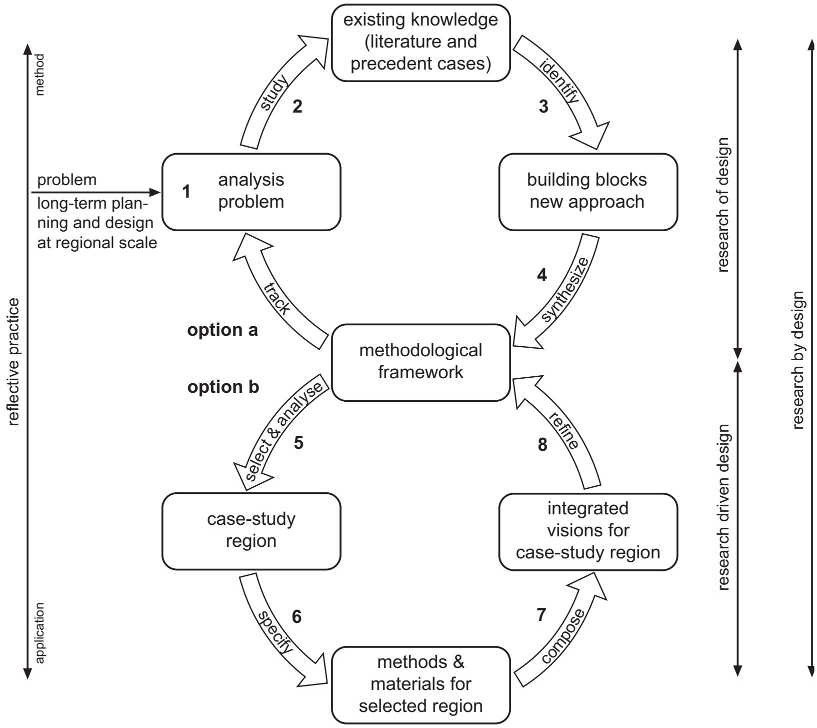

Figure 2-3. Conceptual framework for research on the regional design process.[6]

2.5 Strategies research quality

The research presented in this thesis aimed to advance both substantive and procedural knowledge. Design principles and procedures were formulated as hypothesis, applied in a number of cases, and continuously refined. Since no actual construction took place (yet), it is rather difficult to corroborate hypotheses. Working on long-term transformation of the physical environment at the regional scale, Klaasen notes, one must rely on predictive theories and sound argumentation (2004). The design of a garden, which presents a hypothesis at a smaller scale, can be tested empirically with the help of, for example, post occupancy evaluation. At the regional scale this is difficult if not impossible. The effectiveness of many of the principles presented in this thesis is however being studied by my colleagues from the SREX project. The reduction of GHG emissions, for example through heat cascading, has been calculated (Gommans and Leduc, 2009). The following strategies have been pursued to safeguard research quality.[7]

6 Step 1: Analysis of design issue: long-term planning and design at the regional scale.
Step 2: Study of existing knowledge i.e. literature review.
Step 3: Identify building blocks for new approach for the composition of integrated visions.
Step 4: Synthesize building blocks into new methodological framework.
Step 5: Select and analyse case-study region(s) to test approach.
Step 6: Specify particular methods and materials for selected case-study region.
Step 7: Compose set of integrated energy visions for the case-study region.
Step 8: Compare case-study process with theoretical framework and (if necessary) refine framework.
Option a: Track impact of energy visions and continue improving the framework.
Option b: Conduct another case-study to further test methodological framework.

7 For further information see Stake (1995), Francis (2001), Yin (2003), Flyvbjerg (2006), and Zeisel (2006).

Triangulation of data: One strategy was to gather data from multiple sources. Both literature and maps were triangulated to make sure they were reliable. During the analysis phase of the case studies, for example, we consulted both national and provincial planning documents as well as local decision-makers in order to verify data.

Comparison of findings: We also tried to make our findings robust by comparing them with other studies. The findings of our case studies in the Netherlands were compared with each other. Another common strategy is to compare findings with similar studies by other researchers. Yet, to the best knowledge of the author, no comparable studies exist on energy-conscious design at the regional scale.

Interdisciplinary approach: All researchers participating in the SREX project have different backgrounds, for instance in architecture, urban management, spatial planning, and landscape architecture. This setting allowed me, from the beginning on, to discuss research questions, methods, and results with colleagues from other disciplines.

Explicit process: Conclusions are more convincing if the research process is clear and logical. Explicitness has been secured by rendering design processes as transparent as possible. In all case studies, we have presented and discussed our approach with the stakeholders, and tried to provide empirical data wherever possible.

Informant check: Insights from research should correspond with the reality in the study region. In both regions, a group of stakeholders was formed and continuous interaction facilitated. During a number of workshops, we discussed the regional analysis and checked whether our maps correspond with the physical reality. Following each workshop, results where gathered in a report and shared with the stakeholders.

Expert check: Another strategy to improve my research involved the dissemination of results with experts from the case-study regions and the commissioner of the SREX project (Agency NL). Project reports where composed biyearly and shared with Agency NL. In addition, reports and papers were made accessible via the project website.[8]

Peer review: To maintain scientific standards, various levels of peer review were established. Firstly, methods and results were discussed during the monthly researchers meeting. Secondly, project reports and manuscripts were reviewed by senior researchers and the members of the SREX advisory board. Finally, research papers were submitted to scientific journals and conferences where they received rigorous peer review. The following six chapters each hold one paper that has been submitted to a peer-reviewed journal. The status of each paper is indicated on the first page of the respective chapter.

8 http://www.exergieplanning.nl

Global energy systems: LNG tanker Arctic Discoverer near Hammerfest, Norway (Flickr, T. Rønning)

Symbiotic relationship in nature: Ants and Peonies (Flickr, Full Spectrumphoto)

Energy and the Biosphere

3

Ecological concepts and strategies with relevance to energy-conscious spatial planning and design[1]

Abstract. Sustainable systems utilise renewable energy sources and recycle materials effectively. In theory, solar radiation provides abundant energy to sustain humanity. Our capacity to utilise available sources, however, is limited and competition for resources is expected to increase in the future. Spatial organisation and design of the physical environment influences two aspects of sustainable energy transition: assimilation of renewables and energy consumption. How can spatial planning and design support the transition from fossil fuels to a sustainable energy regime? Natural ecosystems constitute one source of inspiration. They are described with the help of ecological concepts; some of which reveal how energy flow is optimised in nature. Ecological concepts and ecosystem strategies are not limited to the description of natural phenomena; they can also inform energy-conscious planning and design of neighbourhoods, cities, and entire regions. We identify and discuss nine ecological concepts with relevance to energy-conscious spatial planning and design.

Keywords. System thinking; sustainable energy transition; landscape architecture; regional design; sustainable energy landscapes; eco-mimetic design

1 Published as: Stremke S, Koh J (2010) “Ecological concepts and strategies with relevance to energy-conscious spatial planning and design” *Environment and Planning B: Planning and Design* **37**(3) 518-532

3.1 Introduction

The provision of clean, affordable, and reliable energy represents one of the greatest challenges of sustainable development. From a spatial planning perspective, it is interesting that more than half of the energy consumption in the developed world is related to the distribution of land uses (Owens, 1990). Energy-conscious design criteria have been articulated for the physical environment (see, for example, Edwards, 1999; Elkin et al, 1991; Frey, 1999). In practice, however, application is often limited to building scale (Williams, 2007) and neighbourhood scale (Witberg and Zinger, 1999). A number of municipalities, such as Kalundborg and Samsø (both in Denmark), and Güssing (Austria), have practiced energy-conscious planning and design at larger scales. Yet, it appears that projects focus on either urban or rural environments missing some of the potential benefits when these two complementary realms merge at the regional scale. Knowledge gaps exist in energy-conscious spatial planning and design, in particular at the regional scale. Existing knowledge on energy flow in natural ecosystems has not yet been explored fully in spatial planning and design. Natural ecosystems are described with the help of so-called ecological concepts, some of which reveal how energy flow is optimised in nature. We identify and discuss ecological concepts and strategies with respect to energy-conscious spatial planning and design at the regional scale. The hypothesis is that ecological concepts and strategies can inform energy-conscious spatial planning and design and thus support the development of a sustainable physical environment.

3.2 Present state of affairs

The integration of system thinking into energy-conscious planning and design has proved to be successful. Energy-efficient dwellings and office buildings have been constructed, such as the ING Bank in Amsterdam and the WWF headquarters in Zeist (both in the Netherlands). A number of synergetic industrial networks such as at Kalundborg indicate the potential benefits of scaling up and pursuing system innovation on a bigger scale. Energy-conscious (and material-conscious) design principles have been articulated and applied successfully (Ehrenfeld and Gertler, 1997). Urban and regional planners, however, have only recently begun to address energy transition as a key element of sustainable development (e.g. see van Dam and Noorman, 2005). 'Sustainable energy transition' refers to the transition from fossil fuels to self-sufficient energy systems based entirely on renewable-energy sources.

The amount of solar radiation is enormous; the influx of renewable energy exceeds global energy demand several fold (Smil, 2008; Willet, 1977). Human capacity to capture and use this energy source, however, is limited. If we are to rely on renewable energy, which is distributed fairly and remains economically feasible, we must increase assimilation as well as reduce demand. Because assimilation and consumption of renewable energy has not yet been fully addressed in spatial planning, great potentials exist for optimisation, in particular at landscape level and regional scale (see also Stremke, 2007).

3.3 Learning from nature

Ecology is a relevant natural science revealing pathways towards a self-sustaining world. This is not only because ecology deals with the environment, energy, and resources, but because of its integrative and dynamic character, which is reflected in system thinking and process ordering. During millions of years of evolution, nature has developed into highly effective ecosystems with optimised energy flows, material cycles, and spatial organization. Ecosystems continuously optimise energy flows and thus increase their resilience against disturbances; many ecosystem strategies provide inspiration for the design of sustainable human environments. At the beginning of the 21st century, we can not only learn *about* natural systems but also *from* natural processes and the spatial organisation of ecosystems.

Natural ecosystems and human systems have many similarities. Niches exist, competition takes place, and systems adapt to changing conditions in the system environment. Similarities between the natural and the human world are being discussed by many scholars. Steinitz (cited by Johnson et al, 2002), for instance, compares the structure of cities [described by Lynch (1960)] with that of natural ecosystems [described by Forman and Godron (1986)] and concludes that substantial similarities exist between the two systems. Due to the many analogies, Johnson and his colleagues (2002) call for a joint approach and shared theories between ecology, design, and planning. The value of ecosystem thinking to spatial planning and design has also been discussed by Hough (1984), Lyle (1994), McHarg (1969), and Newman (1975). Steiner observes a 'convergence' of ecologists and social scientists and states that "ecologists have addressed human communities, and planners and designers have attempted to provide syntheses to shape human communities" (2002, page 3).

In spite of the many similarities between natural and human ecosystems (Stremke and Koh, 2009), a number of crucial differences exist, some of which are to the advantage of sustainable development. In nature no goal-oriented planning exists. Humans, in contrast, have the capacity to plan for the future and to communicate ideas to each other. Steiner also says "it is tempting to think that all principles from ecology apply to humans, but people differ significantly from plants and animals ...humans possess culture, which perhaps only a few other species of animals have" (Steiner, 2002, page 19). Skilful design, awareness of the social context, and the wider political and planning ideologies, do indeed influence the success of spatial planning and design. Nonetheless, one must not underestimate the relevance of fundamental ecological concepts and strategies to the planning and design of sustainable human environments. What other model for a sustainable energy system do we have at our disposal, other than the natural world? Humans may choose to ignore energy-conscious strategies as long as we have sufficient resources at our disposal. Abundance of resources, very much a prerequisite of today's society, is, however, no longer a matter of course.

Although ecology has surfaced in the contemporary discourse on spatial planning and design, Corner states that a "culturally animate ecology, one that is distinct from a purely 'scientific' ecology, has yet to emerge" (1997, page 88). Corner not only pleads for intensified collaboration between ecologists, planners, and designers but also calls for 'translation' of fundamental ecological knowledge to inform meaningful and sustainable planning and design.

Let us now return to energy, and review some of the early publications addressing energy flow in natural ecosystems. Lotka (1925) introduced thermodynamics to ecology. His book Elements of Physical Biology, among others, inspired Odum to investigate the properties of energy flow in ecosystems. In many of his publications (for example, 1959, 1969, 1997), Odum emphasises the importance of thermodynamics governing ecological processes. The energy system of the Earth is governed by several laws of physics, among them the First and the Second Laws of Thermodynamics. The First Law of Thermodynamics states that energy cannot be created; it can only be transformed from one state to another. The Second Law reminds us that during each transformation, a certain amount of useful energy (i.e. exergy) is transformed to a less useful energy (i.e. entropy) (Dincer, 2000). Photosynthesis of inorganic energy into biomass, for example, releases energy in the form of heat dissipated into the environment (see figure 3-1).

The rate of efficiency in energy conversion has been an important subject, both in technological engineering and in system ecology. Jørgensen (2006) compared systems using the ratio of the work capacity of a system to the costs of creating that system. He concludes that the overall efficiency of natural systems is well beyond that of many human systems. He goes as far as saying that "nature is more effective than our attempts to construct useful systems" (2006, page 1). Karr likewise notes that the "efficiency of ecological systems is unparalleled. Recycling is standard in those closed systems; waste does not occur" (2002, page 134).

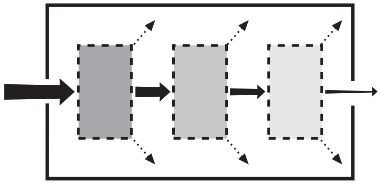

Figure 3-1. Earth receives energy from the sun (left arrow entering the system); during each conversion (smaller arrows) entropy (i.e. heat) is created and discharged into the environment (dashed arrows).

3.4 Ecological concepts and strategies

For more than a century, ecologists have been formulating concepts describing relationships between organisms and their environment. Energy-conscious design can apply what we have learned from these systems to the built environment.[2] The integration of ecological knowledge and creative spatial thinking forms the very basis of our proposed approach to energy-conscious spatial planning and design.

Innovation can be facilitated through translational research - translation and application of scientific knowledge in real-world problem solving (Musacchio, 2008). Translation of scientific knowledge, of course, is a key element of applied sciences. Using literature studies, interviews, commissioned research projects, and design studios, we have identified ecological concepts of special relevance for energy-conscious regional design. These concepts reveal how energy assimilation and energy flow are optimised in the natural world.

In this paper we explore five ecological concepts that are relevant to sustainable-energy transition: *energy flow, primary production, material cycling, system size*, and *sources and sinks*. We then discuss four ecosystem strategies which provide new insights towards energy-conscious spatial planning and design: *ecological succession, differentiation of niches, biorhythm*, and *mutual relationships*. Concepts and strategies are defined, and possible implications for spatial planning are discussed. 'Research questions' are stated in order to facilitate planning and design processes. 'Applications' illustrate possible interventions through examples. The

2 For a list of studied ecological concepts and principles please see appendix this paper.

list of concepts and strategies presented is by no means complete but provides a basis for the articulation of explicit energy-conscious design guidelines in following papers.

3.4.1 Energy flow

'Energy flow' refers to the transfer of energy between systems or system parts (Lindeman, 1942). The flow of energy leads to characteristic trophic structure and material cycles within ecosystems (Odum, 1969). It has been estimated that the Earth receives about 1.94 cal of solar energy per min per cm2 (Blair, 2007). The daily influx of solar radiation on Earth exceeds half the energy stored in all remaining fossil-fuel reserves.

The influx of solar energy is primarily determined by geographical location and exposure to the sun (for example, the orientation of terrain). Solar radiation is either intercepted in the landscape or reflected. Reflection represents the first control mechanism of energy flow. The rate of reflection (i.e. albedo) is influenced by surface moisture, texture, and colour. The limiting factor for assimilation of solar energy, however, is not so much the rate of influx but the capacity to capture and store available energy. The flow of energy is further influenced by landscape structure, the spatial configuration of landscape elements (Ryszkowski and Kdziora, 1987). Odum (1989) has highlighted that natural ecosystems are 'low powered', whereas humans depend on high-quality energy carriers such as fossil fuels. If we are to rely on (direct and indirect) solar energy, large areas are required to assimilate and transform the energy.

Research question: Where can we assimilate renewable energy without increasing land-use pressure, and how can spatial organisation help to optimise energy flow? *Application:* Identifying vacant (land or building) surfaces for the assimilation of renewable (see figure 3-2).

3.4.2 Primary production

The process of fixating solar energy in biomass is described as 'primary production', or photosynthesis. Photosynthesis is realised through energy influx, water, minerals, and nutrients which are provided by the breakdown of organic matter and the decomposition of other materials. The rate of primary production is therefore limited and cannot be increased indefinitely. Organisms can be grouped into trophic levels such as primary producers, primary consumers, and secondary consumers. Each trophic level feeds the one immediately below it. In every step of this energy cascade, parts of the energy are 'lost' due to respiration and heat transfer to the system environment. Consequently, the amount of energy declines with each successive trophic level, forming a pyramid-shaped distribution of energy among the trophic levels (Odum, 1983).

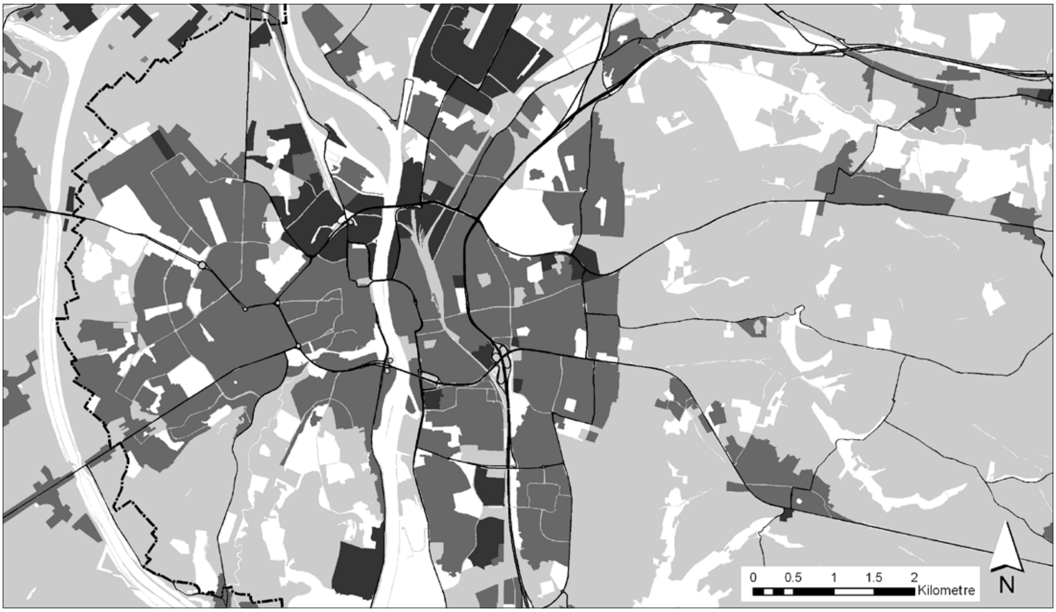

Figure 3-2. Potential locations for the assimilation of solar energy in the Maastricht area in the Netherlands. Dark grey indicates industrial areas and business parks, with high potential due to flat roofs. Mid-grey indicates residential areas where there is moderate potential. Light grey indicates open land where the potential is low. Pale grey areas are water, forest, and nature areas with restrictions for energy assimilation.

Energy loss between trophic levels reflects the working of the Second Law of Thermodynamics. Although conversion from one trophic level to another is relatively inefficient, the overall utilisation of energy is high due to the cascading of energy between organisms. Complex food chains with high species diversity and variety of energy qualities inspire alternatives to the monofunctional and technological optimisation of energy flow in the human world. Cascading of residual heat, for example, can improve overall efficiency of human energy systems by turning `waste' into an energy source. Such cascades require energy-conscious planning of the built environment (see figure 3-3).

Research question: What are the potentials to cascade heat in the case-study region? *Application:* Energy-conscious planning can facilitate the cascading of residual heat, for example, from industry to dwellings. Spatial distance, landscape relief, and the temperature of energy carriers need to be considered during the design process.

3.4.3 Material cycling

The cyclic process of plant growth (material composition), consumption (material conversion), and decomposition (dispersion) is described as the 'material cycle'. Each transformation of matter from one state to another requires energy. Looking at the Earth as a single biosphere, one can ascertain that the material cycles are relatively closed. Apart from some

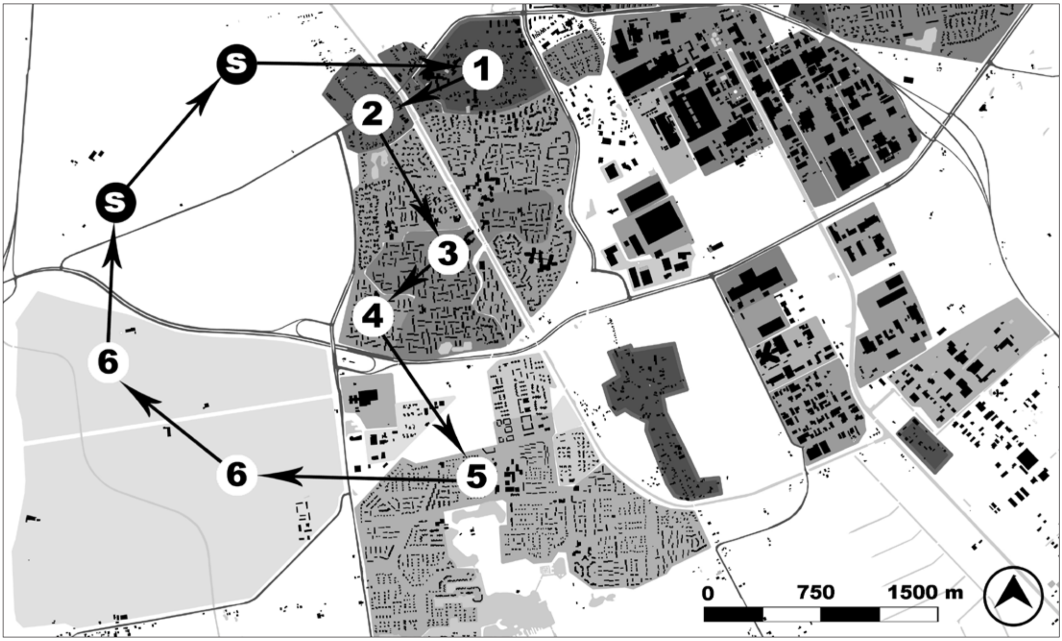

Figure 3-3. Proposed heat cascade in Emmen-Noordbarge (The Netherlands). Residual heat from gas processing units (S) is transported to the oldest neighbourhood (1) and further through more recent neighbourhoods with lower heat demand (2 - 5), to planned neighbourhoods with lowest heat demand (6).

marginal extraterrestrial dust and the occasional impact of meteorites, no matter enters or leaves the system. Every process on Earth thus not only depends on energy influx but also on the materials within that system (see figure 3-4).

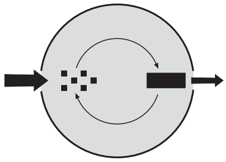

Figure 3-4. The Earth has relatively closed material cycles sustained by energy influx.

Many natural material cycles have been replaced by energy-intense technological processing. For example, the treatment of greywater and manure requires vast amounts of energy. Facilitating natural processes in material processing has great potential for reducing overall energy consumption (Todd et al, 2003). Eco-revelatory design aims to reveal and illustrate such natural processes (Helphand and Melnick, 1998).

Research question: What kind of energy-intensive material processing takes place in the case-study region and can technological processes be replaced by natural ones? *Application:* Parts of a conventional waste-water treatment system can be substituted by water basins with halophyte plants (see figure 3-5). Ecological waste-water treatment requires considerable space (three to four times more than conventional treatment) but consumption of fossil fuels can be reduced significantly.

Figure 3-5. Aerial photograph of an ecological waste-water treatment plant in Lallaing (France) designed by H20 Mosaic. Scale approximately 1:10 000 (photograph Google Earth).

3.4.4 System size

Communities of organisms and their physical environment are referred to as an ecosystem. ‘System size’ refers to the spatial extent of a system. As the size of any system exceeds its energetic optimum, an additional expenditure of energy is needed to maintain that systems (see figure 3-6). Optimum system size depends on the quantity and quality of the energy available (Odum and Odum, 1976).

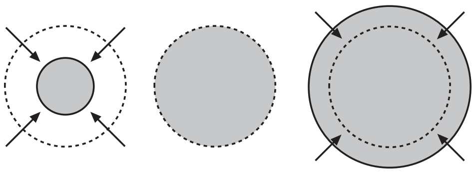

Figure 3-6. Deviation from optimum system size (indicated by dashed line) necessitates additional energy subsidies (arrows). The size of the left-hand system is smaller than its energetic optimum; the right-hand system is larger than its optimum system size.

In natural ecosystems a number of environmental conditions, such as the accessibility of energy, determine the optimum system size. In the human environment correlation also exists between system size and energy carriers. Transportation costs and the storage capacities of energy carriers differ greatly. Characteristics such as energy density influence how far an energy carrier can be transported effectively. In a postcarbon world, spatial planning and design must facilitate the utilisation of local energy potentials and account for the optimum system size of each energy carrier.

Research question: How much renewable energy of what quality is available in the case-study region and how can spatial planning help to minimise transportation and conversion losses? *Application:* Discriminate energy quality throughout the planning process. Electricity, for instance, can be transmitted over long distances without great loss. The transport of heat, however, is limited to a few kilometres (see figure 3-7).

Figure 3-7. Transportation distances (from the centre to the outside) for energy carriers originating in South Limburg (The Netherlands). Warm water should be transported a maximum of 10 km; solid biomass a maximum of 50 km. Liquid fuels can be transported over longer distances depending on the mode of transportation. Electricity can be transmitted with a loss of approximately 10% over 1000 km.

3.4.5 Sources and sinks

The concept of 'sources and sinks' relates to the flow of energy, material, and information between system components (Odum, 1992). In a source area the rate of 'production' exceeds local 'consumption'. Sinks consume more energy and resources than is provided locally; they depend on either storage or the import of resources (Pulliam, 1988). The concept originated as a demographic model describing the flow of organisms between different habitats.

Ecological footprint analysis (Rees and Wackernagel, 1994) shows that mankind appropriates a substantial part of the Earth's surface as a source area. More than 61% of the global land surface is said to have become source areas for mankind (Lyle, 1994).

Initially, we have used the source-sink concept to discriminate and map existing energy sources and sinks in the early design phase. However, the source-sink concept is not merely of special value for inventory and analysis. Landscape ecologists distinguish between landscape matrices, patches (for example, source and sink areas) and corridors through which exchange of energy, material, and information takes place (Forman, 1995). Increasing the connectivity of corridors and the spatial proximity of sources and sinks can optimise energy flows (Stremke and Koh, 2008). The clustering of residual energy sources and sinks can also potentially counteract the spatial fragmentation of human ecosystems discussed by Botequilha-Leitão and Ahern (2002).

Research question: Which energy sources and sinks exist in the case-study region and how can the flow between existing and planned sources and sinks be improved? *Application:* The planning of new energy sinks (for example, a new housing development) in proximity to an energy source such as geothermal heat (see figure 3-8).

Figure 3-8. Construction of new neighbourhoods (indicated by a dashed line) above an aquifer (dark grey) providing warm water for room heating. Energy-potential study Hoogezand-Soetermeer (The Netherlands).

3.4.6 Ecological succession

'Ecological succession' describes the gradual change in plant and animal communities in an area following a disturbance (Cooper cited in Molles, 2005). Disturbances are understood as being relatively discrete events in time that disrupt ecosystem development and change the availability of resources or the physical environment (White and Picket, 1985). Following a disturbance, plants and animals reinvade the area and a new ecosystem emerges.

Succession represents a dynamic response system of nature, allowing ecosystems to grow and mature. The development of ecosystems follows no predetermined path other than increasing resource utilisation, resulting in more complex and relatively stable systems (Golley, 1996; Odum, 1992). Studies into the energy economy of natural ecosystems have concluded that mature ecosystems appropriate more energy for maintenance and improvement compared with younger systems, which primarily invest in physical growth (Lotka, 1925; Odum, 1959). The disturbance of a plant community experiencing a severe drought is, in many aspects, comparable with humanity facing depletion of nonrenewable-energy resources. Resource scarcity is nothing but a (self-induced) disturbance to which humans (and the built environment) must adapt.

The implications of succession for spatial planning and design have been discussed by Newman (1975), Koh (1978), Hough (1984) and others. Newman states that “once the basic structures [in the human environment] are set up, energy and resources should be used more and more for the maintenance of structures and the development of interconnections within the community” (1975, page 262).

Research questions: Which renewable sources can help the case-study region to cope with depletion of fossil fuels and transform it into a self-sufficient entity? *Application:* Energy potential mapping (Dobbelsteen et al, 2007a) can help in identifying renewable-energy sources in the case-study region (see figure 3-9).

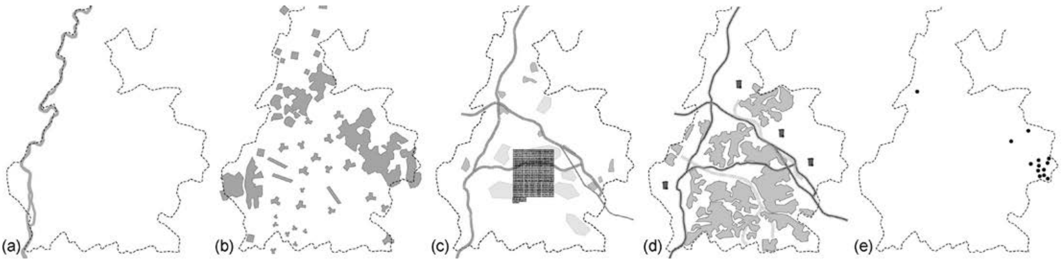

Figure 3-9. Quick-scan energy potential mapping at a regional scale in South Limburg (The Netherlands). Potential for (a) hydro power; (b) solar energy; (c) wind energy; (d) biomass; (e) geothermal energy.

3.4.7 Differentiation of niches

‘Niche’ describes how an organism or population responds to the distribution of energy and competitors; in other words how it makes its living (Molles, 2005). Differentiation of niches is another strategy in natural ecosystems for optimising energy utilisation. Ecosystems differentiated into niches by means of vertical stratification, horizontal zonation, and time zonation (Koh, 1978). Highly differentiated ecosystems are able to sustain a higher population density and species diversity compared with other, less differentiated, ecosystems (Pulliam and Johnson, 2002).

Differentiation of niches took place throughout the evolution of humankind. Man divided labour and, consequently, differentiated first into guilds and later into highly specialised professional groups. The members of each profession, for example, farmers, optimised resource utilisation and increased efficiency within their niche. Through differentiation, overall efficiency of resource utilisation increased so that more food, water, and energy became available (Sieferle, 1997). In the human world, however, differentiation is limited to a few aspects such as the division of labour. Other aspects, such as a more differentiated use of energy, have great potential and are currently being explored. The low-exergy approach, for example, aims at utilising low-valued and renewable energy sources for processes with low-quality energy demand such as room heating (Dobbelsteen et al, 2007b). The utilisation of, for example, residual and geothermal heat necessitates changes in the technological infrastructure and influences spatial configuration of land uses.

Research question: What kind of (spatial) niches can be differentiated in the case-study region with respect to energy provision? *Application:* Exploring possibilities for further differentiation of niches by means of vertical stratification (that is, three-dimensional planning and design) (see figure 3-10).

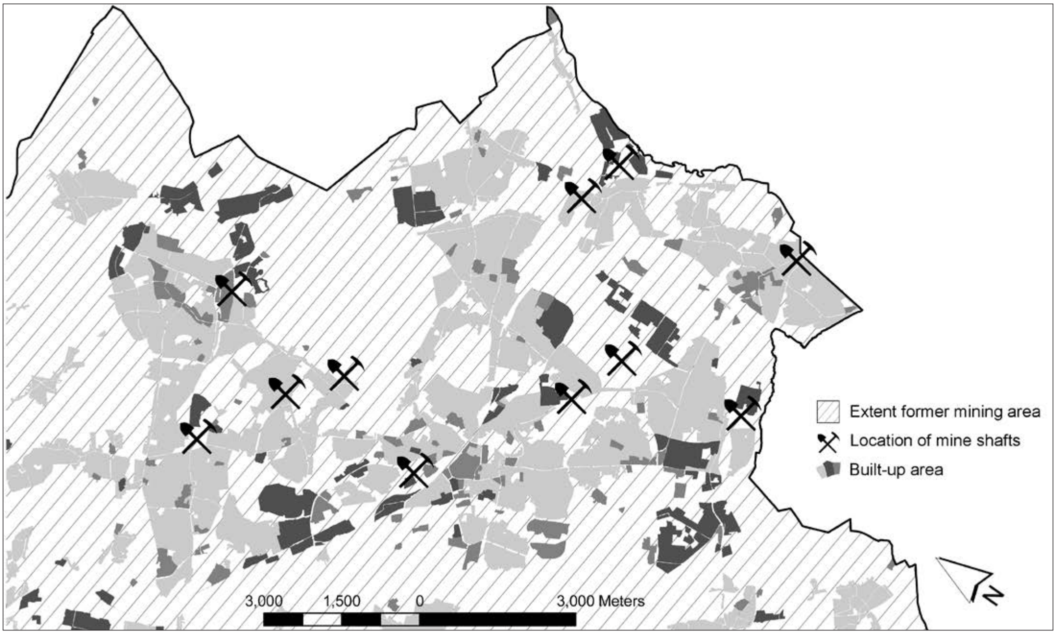

Figure 3-10. Map of the Parkstad region (The Netherlands). Potential for the vertical stratification of energy systems by means of heat (cold) storage in former coal mines.

3.4.8 Biorhythm and periodicity

'Biorhythm' is the pattern of physiological and behavioural responses to periodic changes in the physical environment (periodicity). Biorhythm allows organisms to survive through less favourable periods (Koh, 1978) and is especially pronounced in regions with distinct seasons. Growing seasons, periods of hibernation, and animal migration are just a few examples in nature. Organisms adapt to periodicity by different means.

In deciduous forests, for example, the growing seasons of vegetation layers tend to spread out over time, thereby reducing competition for energy and bringing about a better utilisation of light, moisture, and nutrients. Biorhythm allows natural ecosystems to increase the overall energy utilisation and the ecosystem's recuperation during 'inactive' periods.

Human organisation of life has gradually become aperiodic due to the advancement of technology, shelter, and clothing. This freedom from environmental periodicity enables the continuity of human activities around the clock, every day of the year. This aperiodic lifestyle, however, can only be sustained at the expense of vast amounts of energy. One of the challenges in designing sustainable environments is to synchronise energy supply and demand in time. Energy demand can be reduced by technological innovation, the adaptive behaviour of consumers (see e.g. Santamouris, 2006), and, as we advocate, advanced spatial planning. Increasing energy assimilation and storage capacity in the physical environment can help to synchronise the system from a supply perspective (see Stremke and Koh, 2008). Biomass (chemical energy), heat storage below ground (thermal energy), and water reservoirs (potential energy) can buffer periodic fluctuations in energy supply and demand; some of these necessitate spatial (re)organisation.

Research question: Where and how to store renewable energy above and below ground? *Application:* Cattle manure can be processed throughout the year; produced biogas can be stored locally or injected into the natural-gas grid (see figure 3-11).

3.4.9 Mutual relationships

'Mutual relationships' are interactions between species which are beneficial to all participants (Boucher et al, 1982). Organisms cooperate in mutual relationships because each one has a limited capacity for resource utilisation (see figure 3-12). The combined result of their cooperative behaviour exceeds the energy invested in the relationship. An example of a mutual relationship is nutrient exchange between fungi and certain plants. Utilisation of phosphate through mycorrhizal fungi living at the

Figure 3-11. Potentials for synchronising energy demand and supply in the rural community of Banholt (The Netherlands). Manure from cattle rearing can be stored on individual farm plots (indicated in black) or directly processed into biogas at the central conversion plant (white symbol). Biogas can be stored or injected into the existing natural-gas grid (courtesy of K. Neven).

plant roots can be 1000 times faster than by regular diffusion through soil. In exchange, fungi obtain organic products provided by the plant, in this case plant sugar (Chapin, 1980).

The opportunity (chance) for mutualism increases significantly when organisms experience resource scarcity (Odum, 1992). Not surprisingly, similar phenomena can be observed in the human world: if resources are inaccessible, scarce, or expensive it is more likely that they will be cascaded and recycled. Jørgensen (2006) predicts further system improvements when industries, energy utilities, farmers, and consumers cooperate with each other, forming so-called 'symbiotic networks'. He further notes that more complex relationships, involving a greater number of participants, have better possibilities to optimise their energy economy. The symbiotic network of Kalundborg (see figure 3-13) is perhaps the best example of mutual relationships which evolved over more than twenty years. Transport and conversion losses, however, limit the spatial extent of symbiotic networks and need to be accounted for in the planning and design process.

Research question: What spatial conditions are needed to evolve mutual relationships in the region? *Application:* Identify possible participants for mutual relationships, such as industries and energy utilities. In the near future, waste heat is expected to be considered thermal pollution. Spatial planning and design can help to identify possible heat sinks and establish mutual relationships with benefits to all participants.

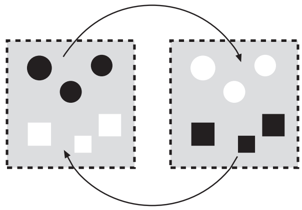

Figure 3-12. Mutual relationship between organisms increases overall resource utilisation. Black indicates a resource excess; white indicates resource scarcity.

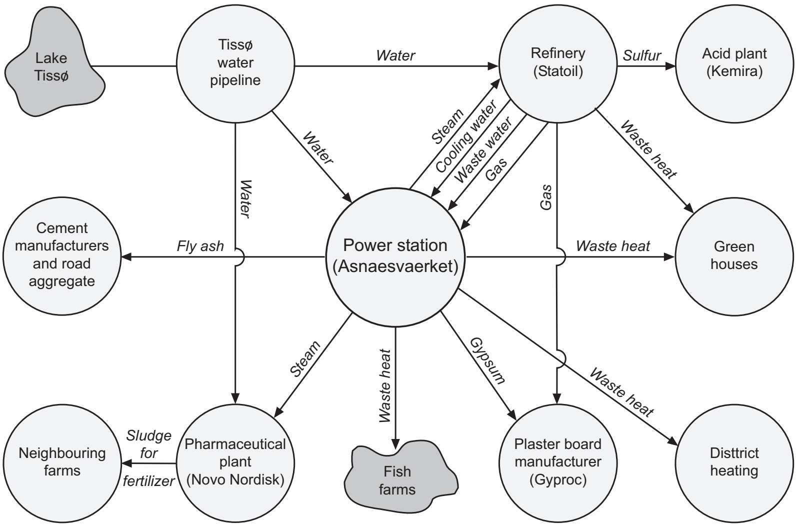

Figure 3-13. Overview of material cycles and energy flow of the symbiotic network in Kalundborg (based on Ehrenfeld and Gertler, 1997).

3.5 Conclusion

We have discussed ecological concepts and strategies that have great relevance to sustainable development in general and energy-conscious spatial planning in particular. They provide inspiration for how to devise a physical environment which can provide the right amount of energy, of adequate quality and at the correct moment in time.

In natural ecosystems, energy is cascaded from primary producers through complex trophic chains. Energy flow and material cycles are interrelated in many aspects. Materials (for example, minerals) are needed to assimilate energy, and energy is needed to drive processes (for example, material composition). The key difference between the two is that the Earth is open to the influx of solar energy whereas material cycles are relatively closed. In nature, system size is influenced by the quantity and quality of energy. As systems develop beyond their energetic optimum size, increasing amounts of energy are needed to maintain that system. Ecosystems exchange energy, materials, and information. Areas with surplus energy and material (sources) provide for others where consumption exceeds production (sinks). Depletion of fossil fuels constitutes a major disturbance for human ecosystems. In nature, many strategies have evolved which can help in adapting human environments to renewable-energy sources. Succession is one of nature's response systems to disturbances. During recovery, ecosystems are reestablished and, in time, become increasingly more energy efficient. The successive path, however, is not fully predetermined; niches differentiate and are occupied by chance. Biorhythm is a vital ecosystem strategy addressing periodic fluctuations in energy supply. Cooperative behaviour is yet another strategy of organisms exposed to resource scarcity. Mutual relationships create a win-win situation for all participants, increasing overall resource utilisation and reducing stress for organisms and their environment.

We have shown that ecological concepts and strategies inspire a great number of energy-conscious interventions in the physical environment. It is important to note, however, that not all strategies relate to every scale of intervention. Cascading of heat, for example, has to be realised on a much smaller scale than the generation of renewable electricity. Furthermore, concepts and strategies are not necessarily relevant for every design phase. Whereas some concepts are informative and help to reveal the complexity of natural and human ecosystems, others offer concrete strategies for energy-conscious spatial planning and design.

Ecological concepts and strategies discussed here have the capacity to expand the frame of reference in planning and design of the physical environment. Consideration of ecological knowledge in the planning and design of sustainable environments has many added values. Ecosystem strategies provide insights into how to adapt the human physical environment to renewable-energy sources. They should inform, and not determine, decision making. We suggest embracing ecological concepts and ecosystem strategies alongside state-of-the-art technologies and experiences from pilot projects.

Obviously, spatial planning is not limited to energy assimilation and conservation. Planning is directed towards balanced regional development and the physical organisation of space according to certain goals and objectives. However, we believe that proposals for long-term regional development which fail to address energy transition cannot be considered to be sustainable (Stremke, 2009). In this paper we have presented knowledge from (eco)system science and discussed possible implications for spatial planning and design. We will illustrate concrete guidelines and principles for energy-conscious regional planning and design in later papers.

Acknowledgements. This paper presents results of a multidisciplinary research project funded by Senter Novem, the Dutch agency for innovation and sustainable development. We would like to thank our project collaborators from Wageningen University, Delft University of Technology, and University of Groningen. In addition, we thank our colleagues and graduate students from the Landscape Architecture group at Wageningen University. We are grateful to our colleague Adrie van't Veer for helping us with the figures. Last but not least, we would like to thank the two anonymous referees for their comments.

Appendix[3]

Table 3-1. Selection of descriptive ecological concepts with implications to environmental design[4]

Survey on the importance of key ecological concepts among ecologists[5]	**Basic ecological concepts for future research and practice**
Cherrett (1988)	Odum (1992)
1 The ecosystem	**1 Open system**
2 Succession	**2 Source-sink concept**
3 Energy flow	**3 Hierarchical organization**
4 Conservation of resources	4 Environmental stress
5 Competition	5 Feedback in ecosystems
6 Niche	6 Natural selection
7 Material cycling	7a Competition
8 The community	**7b Mutualism**
11 Food webs	**8 Diversity in open systems**
12 Ecological adaptation	**9 Evolution of mutualism**
13 Heterogeneity	**10 Food webs**
14 Species diversity	11 Organism adaptation
16 Limiting factors	12 Heterotrophs and energy flow
17 Carrying capacity	13 Biodiversity: genetic & landscape diversity
18 Maximum sustainable yield	**14 Ecological succession**
24 Coevolution	**15 Carrying capacity**
26 Natural disturbance	16 Non-point pollution
31 Trophic level	**17 Second Law of Thermodynamics**
38 Parasite-host interactions	**18 Sustainable development**
29 Species-area relationship	19 Transition costs
41 Climax	20 Parasite-host relationship

Ecological concepts, with implications to environmentalism and ethics	**Concepts in ecology with implications to landscape planning and design**
Golley (1996)	Pulliam and Johnson (2002)
1 Ecosystem	**1 Open system**
2 Hierarchical organization	2 Keystone species
3 Biosphere	**3 Island biogeography**
4 Earth heat balance	**4 Disturbance**
5 Biospheric subdivision	5 Unpredictable events
6 Biome	**6 Hierarchy**
7 Landscape	**7 Scale (grain/extent)**
8 Structure of ecosystems	**8 Metapopulation**
9 Primary production and decomposition	**9 Source-Sin**k
10 Ecological succession	10 Landscape Memory
11 Life history adaptations	**11 Ecosystem Autonomy**
12 Individual organism	
13 Body size and climate space	
14 Mutualism	
15 Coevolution and niche	
16 Human ecology	

3 Supplementary material; not part of the original paper.
4 Concepts in bold were selected and studied in detail.
5 The original paper contains 50 concepts. Concepts are ranked according to the survey.

Table 3-2. Selection of principles and strategies with implications to sustainable development[6]

Principles for urban maturity (i.e. environmentally sound design)	**Principles and strategies for urban planning and design**
Newman (1975)	Hough(1984)
1 From growth to homeostasis (energy and resources more and more for system maintenance) **2 Increase in efficiency** (waste as energy source, recycling, reduced demand, process efficiency) **3 Industrial balance: symbiotic** (relationships between producers, manufacturers and consumers like trophic levels in nature) **4 Increase spatial efficiency** (compact city form with greater structural diversity) 5 Increase community diversity 6 Increase community interaction	**1 Dynamic processes** Landscapes are constantly shaped and highly dynamic, not static **2 Economy of means** (reach as much as possible with least financial and energy input) **3 Diversity** (high diversity for more health) 4 Environmental education 5 Enhancing the environment

Ecological principles and strategies for environmental design	**Ecological strategies relevant to sustainable energy transition**
Lyle (1994)	Koh (2005a)
1 Letting nature do the work **2 Nature as model and context** **3 Aggregation, not isolation** **4 Seeking opt. levels multiple functions** 5 Matching technology to need 6 Information to replace power **7 Multiple pathways, flexibility** 8 Common solutions to disparate problems **9 Storage, replenishment, & release** 10 Form to guide flow 11 Form to manifest process **12 Prioritization for sustainability**	**1 Hierarchical integration** **2 Differentiation of niche** **3 Localization** 4 Self-regulation 5 Cell as building block for growth 6 Interdependency of form, function, structure **7 Bio-rhythm** 8 Minimum volume or minimum surface/volume ratios

6 Principles and strategies in bold were studied in detail.

Lichen are a symbiotic association between fungus and green algae (Flickr,A. Elliott)

Heat is one form of exergy: Thermal exergy (Flickr, R. Smith)

Energy and the Technosphere

Exergy landscapes: Exploration of second-law thinking towards sustainable landscape design[1]

4

Abstract. Depletion of fossil fuels and climate change necessitate a transition to sustainable energy systems that make efficient use of renewable energy sources. Recently, the disciplines of building engineering, architecture and urban planning have begun embracing this 'second-law thinking' in order to reduce energy consumption in the built environment. Second-law thinking, however, is not yet a part of spatial planning and landscape design. This is especially problematic because the concepts of exergy and entropy are imperative to sustainable development. This paper explores the Laws of Thermodynamics and related concepts in order to advance the planning and design of sustainable landscapes. We propose a number of exergy-conscious design principles, each one supporting sustainable energy transition.

Keywords. engineering thermodynamics; industrial ecology; low-ex architecture; exergy-conscious; energy-conscious; planning; design; landscape architecture; regional scale; research by design

1 Published as: Stremke S, Dobbelsteen A van den, Koh J (2011) "Exergy landscapes: Exploration of second-law thinking towards sustainable landscape design" *International Journal of Exergy* **8**(2) 148-174

4.1 Introduction

Depletion of fossil fuels and climate change necessitate a transition to sustainable energy systems. Maurice Strong, former Secretary-General of the United Nations Conference on Environment and Development, stressed that “the whole concept of human settlements needs to be rethought, including [...] the broader issues of land use and urban planning” (Strong, 1992, p.493). Human settlements and landscapes are part of the physical environment, which is governed by the Laws of Thermodynamics. While the First Law of Thermodynamics (FLT) states that energy is always conserved, the Second Law (SLT) states that during any process, exergy (work capacity) is destroyed and entropy (disorder) is produced.

During recent decades, ‘second-law thinking’ has helped to increase efficiencies of energy conversion and material processing significantly (Sciubba and Wall, 2007). Industrial ecologists, inspired by highly effective natural ecosystems, have managed to design closed material cycles driven by renewable energy sources (Connelly and Koshland, 2001). A number of eco-industrial parks, such as Kalundborg (Denmark), illustrate that exergy destruction can be decreased in both material processing and energy conversion.

More recently, the Second Law of Thermodynamics has received considerable attention from other disciplines as well (Dewulf et al, 2008; Dincer, 2002). Building engineering (e.g. Torio et al, 2009), architecture (e.g. Shukuya, 2009a) and urban planning (e.g. Balocco and Grazzini, 2000; LowEx, 2009) have begun embracing second-law thinking and identifying means to decrease exergy consumption in the built environment. Exergetic optimization of thermodynamic processes, power plants and dwellings has been successfully realized, and low-exergy neighbourhoods are under construction (Schmidt, 2006).

Despite these achievements, the Second Law is not well understood in disciplines such as spatial planning and landscape design. This is especially problematic because the concepts of exergy and entropy are imperative to sustainable development (Dincer and Rosen, 2007), a common goal of contemporary environmental design. The key question is whether second-law thinking can advance the planning and design of sustainable landscapes[2] or, more specifically, whether spatial planning and design can help reduce exergy destruction in the built environment.

The objective of this paper is to discuss the Second Law of Thermodynamics in the context of regional planning and landscape

2 We define landscape as areas, perceived by people, whose character is the result of the action and interaction of natural and/or human factors (Council-of-Europe, 2000).

design. In doing so, we intend to advance second-law thinking in various environmental design disciplines[3]. Although the paper focuses on the reduction of energy consumption by means of spatial planning and landscape design, we would like to stress that exergy-conscious interventions must always be socially acceptable, economically feasible and not harmful to biodiversity.

Our research has been inspired by the ongoing multidisciplinary quest for sustainable energy systems[4]. The discussion in this paper is based on 'research-by-design'; a research approach that includes literature study, case-study research and design (in this case the design of several sustainable energy landscapes in the Netherlands). In this research, knowledge from outside the immediate context of environmental design was acquired by means of abduction. Our goal was to derive substantive knowledge about planning and design that could help mitigate the depletion of fossil fuels and climate change.

In this paper we first explore fundamental thermodynamic laws, concepts and implications. We then look at how second-law thinking has been applied in engineering thermodynamics, industrial ecology and architecture. Finally, we discuss whether second-law thinking can contribute to the planning and design of sustainable landscapes. We conclude the paper with a list of exergy-conscious design principles.

4.2 Thermodynamic concepts and implications

4.2.1 Laws of Thermodynamics, exergy and entropy

„The concept of energy is so familiar to us that it is intuitively obvious; yet we have difficulty in defining it exactly" (Dincer and Cengel, 2001, p. 119).

Laws of Thermodynamics

The First Law of Thermodynamics, also known as the law of conservation, states that energy cannot be produced or destroyed. Energy can only be converted from one state to another. The sun is the primary source of energy for the planet Earth; direct and indirect energy influx combined account for more than 99% of available energy (Twidell and Weir, 2006). The Second Law of Thermodynamics, or law of entropy, states that all spontaneous processes occur in the direction of decreasing

3 We define 'environmental design' as the disciplines concerned with the planning and design of the built environment, such as architecture, urban planning, spatial planning and landscape architecture.

4 Hepbasli (2008, p.598) defined a sustainable energy system "as cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks". In this paper, we have focused renewable energy sources.

energy quality (i.e. exergy) and increasing disorder (i.e. entropy). What we can learn from the Laws of Thermodynamics is that all processes on Earth consume 'useful' energy and release 'less useful' energy to the system environment. Energy is conserved, while exergy is destroyed and entropy is created.

Exergy

The concept of exergy was initially applied to heat engines only. The idea that only a fraction of energy content can be transformed into mechanical work was put forward by Gibbs and Maxwell. Although already known in the nineteenth century, this concept was not formalized until the mid-twentieth century (Rant, 1956). The term exergy originates from the Greek words *ex* and *ergon*, meaning *from* and *work*.[5]

Exergy is defined as the maximum amount of work that can be produced by a stream of matter, heat or work as the medium comes into equilibrium with a reference environment (Dincer, 2000) or into equilibrium with the surrounding environment (Connelly and Koshland, 1997). The work capacity of an energy carrier depends on the difference between the state of the carrier and its environment. Among the different gradients are temperature for thermal exergy, voltage for electrical exergy and altitude for potential exergy. Work capacity exists both in the form of 'hot' and 'cool' exergy (figure 4-1). The latter is available, for example, at LNG terminals where liquefied natural gas is regasified (Jansen and Woudstra, 2010). However, cool exergy is also available from the night sky, surface water and vegetation (Shukuya, 2009a) and can be influenced by exergy-conscious spatial planning and landscape design.

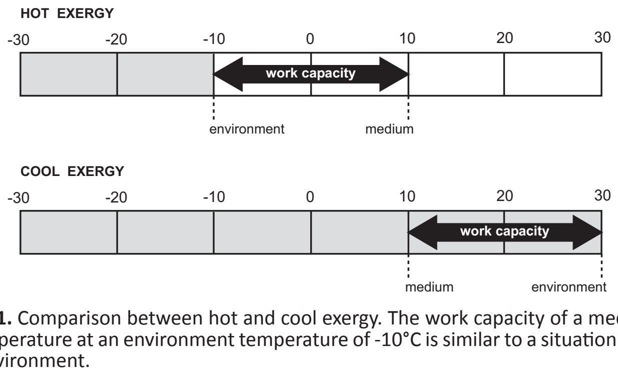

Figure 4-1. Comparison between hot and cool exergy. The work capacity of a medium with 10°C temperature at an environment temperature of -10°C is similar to a situation with 30°C in the environment.

5 Many writings from the early 20th century referred to thermodynamic functions of 'available energy' or 'work capacity'. For a comprehensive history of exergy, refer to Sciubba and Wall (2007).

In order to improve energy systems effectively, one cannot limit inquiry to the quality of energy sources; the presence and requirements of energy sinks are just as important (Hepbasli, 2008). Energy infrastructure is also important for optimization. A source of hot water near a district heating system has a higher work capacity compared to a situation without any energy infrastructure. Periodicity is yet another important aspect in second-law thinking (Stremke and Koh, 2010). During winter, hot water contains more exergy than during summer. Seasonal storage of hot and cool exergy can increase work capacity. The potential of energy to perform work thus depends on (a) the source, (b) the system environment, (c) the energy sink, (d) the energy infrastructure and (e) periodicity.

Entropy

The SLT states that spontaneous processes will always occur in the direction of increasing disorder or entropy. Entropy is a measure of the state of disorder of a system. The term entropy was first used by Clausius (around 1855) and originates from the words *en* and *trope*, meaning *in* and *transformation*.

The concept of entropy can be illustrated by the following example. If two systems with different temperatures are brought into contact, the higher temperature heat from one system will mix with that of the lower temperature system; exergy will decrease and entropy will increase (figure 4-2). Dincer and Cengel stated “there is less information about precisely where that energy resides, as it is now dispersed over the two systems” (2001, p.123). Hence, entropy also refers to the relative lack of information about energy at any point in time: its quantity, quality and location.

Figure 4-2. If two systems with different temperatures are brought into contact, the higher temperature heat from the one system will mix with that of the lower temperature system. Exergy is destroyed and entropy created.

Mixing of materials is another cause of entropy generation (figure 4-3). Mixing of animal manure with water, or paper with household waste, are just two examples. Additional exergy is required in order to separate materials again. Keeping residual material flows separated is an important means to minimize entropy production and preserve exergy.

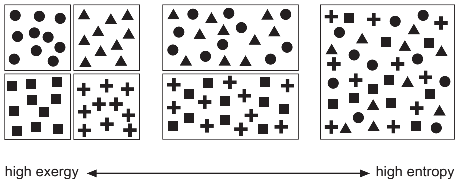

Figure 4-3. Mixing of materials reduces exergy and increases entropy. In the situation on the left hand side, all four materials are still separated and exergy is relatively high. On the right hand side, the four materials are mixed and entropy is relatively high.

Dispersion of materials in space also generates entropy (figure 4-4). Aluminium cans dispersed across a landfill are less 'useful' than the same cans in a recycling bin. Collecting the cans does require additional exergy (i.e. food for humans and fuel for machinery). Avoiding unnecessary dispersion of materials in space can help to preserve exergy. Accumulation of matter can even increase the specific exergy of a system. Photosynthesis is one natural process capable of increasing specific exergy: CO_2 is sequestered from the air and stored in the system.

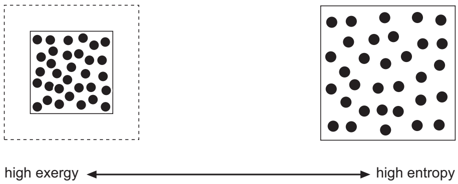

Figure 4-4. Dispersion of materials in space increases entropy. In the situation on the left hand side, all materials are concentrated on a relatively small area. On the right hand side, the same amount of materials is dispersed over a larger area and entropy is relatively high.

Comparison between energy and exergy

Energy, exergy and entropy are related, but differ significantly. Exergy is a measure of order and entropy is a measure of disorder. Exergy depends on the gradient between a system, a material or an energy carrier and its environment. Energy, in contrast, is always conserved (FLT). During all processes, exergy is destroyed and entropy produced (SLT); exergy efficiency can therefore never be 100%. Key characteristics of energy and exergy are compared in table 4-1.

Table 4-1. Comparison between energy and exergy (based on Dincer and Cengel, 2001)

Energy	Exergy
Is a measure of quantity only	Is a measure of quantity and quality (property)
Is governed by the FLT for all processes	Is governed by the SLT for all processes
Is always conserved in a process; cannot be destroyed or produced	Is always consumed during processes (exergy to entropy)
Is independent from environment parameters	Is dependent on environment parameters (e.g. temperature)
Has values different from zero	Can be equal to zero (equilibrium with environment)
Is motion or ability to produce work	Is motion or ability to produce work (useful energy)

Having presented a number of fundamental thermodynamic concepts, we can now examine how exergy relates to energy consumption - a key aspect of sustainable development.

4.2.2 Exergy destruction in human ecosystems

Since excessive amounts of exergy are lost during the combustion of non-renewables, Cornelissen (1997) rightfully argued that this exergy destruction has to be minimized in order to obtain sustainable development. We need to understand how exergy destruction differs between non-renewable and renewable energy sources. Moreover, in this section we discuss how exergy destruction can be estimated for territorial systems – a question that is of particular interest to exergy-conscious spatial planning and landscape design.

Non-renewable resources

The quality of energy can be expressed through the ‘energy grade’ function. Energy grade is defined by the ratio of exergy to energy. The energy grade of electricity, the highest quality energy carrier, is 1.0. Fossil fuels are generally considered high-grade energy sources. Natural gas, for example, has an energy grade of 0.913. Many renewables, are considered low-grade energy sources. Hot water, for example from a geothermal source, may have an energy grade as low as 0.00921 (table 4-2).

Table 4-2. Values of energy grade function for various energy sources and carriers. Temperature of the reference environment is 30°C (based on Dincer and Rosen, 2007)

Energy carrier	Energy grade function	
Electricity	1.0	High-grade
Natural gas	0.913	↑
Steam (100° C)	0.1385	↕
Hot water (66°C)	0.00921	↓
Hot air (66°C)	0.00596	Low-grade

The consumption of fossil fuels is considered to be the chief cause of exergy destruction (e.g. Cornelissen, 1997; Connelly and Koshland, 2001; Jørgensen, 2006). This is simply because fossil fuels are high-grade energy carriers. Over the past two centuries, mankind has managed to consume resources that had accumulated over hundreds of millions of years and released vast amounts of entropy into the environment – entropy in the form of heat and greenhouse gas emissions (GHG). Apart from the destruction of exergy present in fossil fuels, a large amount of exergy was used to ‘produce’ fossil fuels. Though the question of how much exergy was invested in producing fossil fuels is heavily debated, Sciubba and Ulgiati (2005) presented the following example. If one considers photosynthesis with an efficiency of 0.1%, about 1,000 Joules of solar exergy are needed for 1 Joule of biomass. To produce 1 Joule of crude oil, which is biomass converted with low efficiency over millions of years, about 54,000 Joules of solar exergy are needed. What we learn from this example is that the life-cycle of fossil fuels does not commence with their extraction; they have appropriated large amounts of solar exergy throughout their synthesis.

Renewable energy sources

Renewable energy is energy either from sources with essentially infinite availability (e.g. the sun) or from sources that can regenerate (e.g. biomass). In order to be considered a 'renewable source', the rate of consumption must not exceed the rate of replenishment. The discussion on work capacity of renewable energy has gone in two directions: (a) the technical boundary approach, and (b) the physical boundary approach (Torio et al, 2009). The technical boundary approach views solar energy as a high-exergy source (light can generate power). Biomass is also viewed as a high-exergy source, while warm water is a low-exergy source. This approach corresponds with the energy grade function discussed above. The physical boundary approach views direct solar irradiation as a low-exergy source, since about 90% of the available energy is converted into heat and dissipated into the environment. The difference depends on whether solar radiation is considered before or after its absorption into the environment.

In addition to the ongoing discussion on the exergetic quality of renewables, another question is whether the utilization of renewables results in additional entropy production. Connelly and Koshland (2001) argued that entropy will be produced regardless of whether or not the renewable source is utilized. We believe that the use of renewable energy does result in additional – albeit indirect – entropy production. This is due to the production, construction and operation of technical devices such as PV cells and wind turbines. Of course, the construction and maintenance of conventional power plants also results in entropy. However, there is another, more crucial difference between fossil fuels and renewables: the latter source appropriates disproportional amounts of space and consequently increases land-use pressure. We conclude that the efficiency of all energy flows must be improved in order to minimize entropy production and mitigate land-use pressure.

4

Exergy accounting for territorial systems

By investigating exergy changes of activities in a society, it is possible to obtain an expression for the exergy loss or gain in a territorial system. Extended Exergy Accounting (EEA) has been conducted both at the national (e.g. Wall, 1978 and 1987) and regional scales (e.g. Sciubba et al, 2008). According to Sciubba and Ulgiati (2005), EEA provides a more complete picture, compared to conventional exergy analysis, of how processes interact with their socio-economic environment and the biosphere at large. Territorial exergy accounting can reveal how much each sector of an economy contributes to exergy destruction and can specify the largest potential for improvements.

According to the EEA for the region of Siena (Italy), the largest exergy destructing sectors are commerce, industry and transportation (Sciubba et al, 2008). In this part of Tuscany, a large proportion of the electricity is generated from geothermal heat, which is a low-exergy source. Therefore, the energy sector contributes only 5% to the exergy destruction in Sienna (see table 4-3). In regions with conventional power plants, however, energy conversion contributes much more to exergy destruction. Power plants, oil refineries and gas processing plants represent ‘point sources of pollution’ (Odum, 1989) or ‘point sources of entropy production’ (see also Wall and Gong, 2001).

Table 4-3. Exergy destroying sectors in the region of Siena (Sciubba et al, 2008, altered)

Sector	Extended exergy destruction[6]	Relative exergy destruction
Resource extraction	1.76×10^{15} Joule/year	3 %
Energy conversion	3.46×10^{15} Joule/year	5 %
Industry	14.3×10^{15} Joule/year	20 %
Agriculture	8.33×10^{15} Joule/year	12 %
Commerce	17.8×10^{15} Joule/year	25 %
Transportation	12.5×10^{15} Joule/year	18 %
Domestic	12.3×10^{15} Joule/year	17 %

From a spatial perspective, it is interesting that EEA examines real-world systems. Exergy analysis is no longer limited to isolated thermodynamic processes; EEA quantifies exergy destruction in complex socio-ecological systems. We therefore suggest using EEA to assess the exergy destruction of any region *before* and *after* implementation of exergy-conscious interventions. Integrating the results of EEA in Geographical Information Systems (GIS) would allow pinpointing the location of exergy destruction in the physical environment. Girardin et al. (2010) developed a GIS model that can help to assess the possible integration of energy resources

6 Each entry is the difference between the total exergy input and output.

and demands in urban areas. Although their model focused on energy efficiency, it could provide a basis for integrating EEA and GIS.

4.2.3 Exergy and the development of natural ecosystems

"Entropy is fundamental for understanding thermodynamic aspects of self-organization, evolution of order and life that we see in nature" (Dincer and Cengel, 2001, p.122). A clear understanding of how natural ecosystems optimize energy flows is expected to contribute to exergy-conscious planning and design of human ecosystems.

Ecological succession

In recent decades, second-law thinking has contributed to the understanding of ecosystem development. In 1977, Prigogine received a Nobel price for illustrating how natural ecosystems defy the SLT (Prigogine et al , 1972). However, let us begin with Lotka, who introduced energetics to the study of natural ecosystems. In 1925, Lotka stated that "the systems that prevail are those that develop designs maximizing the flow of useful energy" (cited in Ludovisi et al, 2005, p.34). Forty years later, Odum argued that "ecological succession culminates in ecosystems in which maximum biomass and symbiotic functions between organisms are maintained per unit of energy flow" (1969, p.262). Although Odum did not refer to exergy at that time, he clearly stated that ecosystems improve energy flows throughout their succession.

In the 1990s, energetics once again became a focus of ecological studies. Schneider and Kay hypothesized "as ecosystems grow and develop, they should increase their total dissipation, develop more complex structures with more energy flow, increasing cycling activity, develop greater diversity and generate more hierarchical levels, all to abet energy degradation" (1994, p.25). By focusing on external inputs from other ecosystems, Bastianoni and Marchettini introduced another aspect to the discussion. They argued that ecosystems develop "towards an efficient use of available resources, reaching more complex forms of organization or diminishing the need for external inputs" (1997, p.40).

The concept of exergy was embraced by ecologists in order to study how natural ecosystems improve their energy economy (also see Svirezhev and Steinborn, 2001). For example, Jørgensen, stated "if there are offered more than one pathway to move away from thermodynamic equilibrium, the one yielding the most stored exergy will be selected" (Jørgensen, 1997, p.148). Jørgensen, among others, refers to exergy as a measure of ecosystem maturity - a relationship which will be discussed below.

Thermodynamic classification of ecosystems

Natural ecosystems tend to grow in biomass and complexity as they mature; they develop from near thermodynamic equilibrium towards highly structured and self-organising systems. Jelinski et al. (1992) classified three groups of ecosystems from a thermodynamic perspective (table 4-4). We added examples from human ecosystems to illustrate key differences between the three classes.

Table 4-4. Classification of ecosystems from a thermodynamic perspective (based on Jelinski et al, 1992)

Class	System inputs	Internal processes	System outputs	Example natural ecosystem	Example human ecosystem
Type 1 or pioneer ecosystem	Energy and materials (exergy non-renewed or not renewed within system)	Linear material flow (each component utilizes exergy individually and in linear manner)	Flow of waste material and waste energy (with reduced exergy)	Chemoautotrophic bacteria feeding off inorganic chemicals (archae in spring)	Paper mill depending on unsustainably produced wood and fossil fuels
Type 2 ecosystem	Limited flows of energy and materials (exergy from non-renewed and renewed sources)	Less linear material flow (components partially interact; limited forms of material cycling)	Limited flows of waste materials and waste energy (with reduced exergy)	Riparian ecosystem which depends on nutrient import from upstream or from the ocean	Paper mill using sustainably produced wood but fossil fuels
Type 3 or mature ecosystem	Energy (exergy from solar radiation)	Material cycles (components interact through e.g. symbiotic relationships)	Small flows of waste energy; no waste materials leave the system	Rainforest ecosystem	Paper mill using sustainably produced wood and renewable energy exclusively

Above classification can help to advance the discussion on exergy-conscious spatial planning and design; it reveals that mature ecosystems utilize energy sources effectively and cycle materials. Newman (1975), Hough (1984) and Lyle (1994), among others, have successfully integrated strategies of mature ecosystems into urban design, spatial planning and landscape architecture.

Exergy as measure for ecosystem maturity

Ecologists aim to estimate the maturity of ecosystems; several approaches employ exergy as a measure of ecosystem maturity (see e.g. Dewulf et al, 2008). A strict thermodynamic exergy analysis is apparently not useful because the reference environment would be an adjacent ecosystem. Jørgensen (2006) suggested using the studied ecosystem as reference environment, with the same pressure and temperature, but with dead organic matter as reference. He defined ‘eco-exergy’ as the exergy state of ecosystems with thermodynamic equilibrium as reference. Eco-exergy can be calculated based on the biomass present in an ecosystem and the information that is embedded in the biomass DNA. Jørgensen argued that “the more eco-exergy an ecosystem possesses the more resistance it has against changes" (2006, p.48). Similarly, Ludovisi et al. (2005) argued that specific dissipation (the ratio of biological entropy production to exergy stored in the living biomass) can serve as indicator of the development state of ecosystems.[7]

Despite the value of eco-exergy for estimating the maturity of natural ecosystems, exergy cannot account for all aspects of information. In the case of species extinction, a special form of information loss occurs. If the information stored in the species DNA is unknown, it cannot be recovered. Connelly and Koshland (2001) proposed to classify such exergy loss as 'irretrievable', as opposed to merely 'irreversible.' This discussion, however, shows that natural ecosystems tend to increase embodied biomass and information (i.e. eco-exergy), which in turn increases their resilience against disturbances. The fact that biomass can increase the exergy stored in ecosystems has direct implications for a number of exergy-conscious interventions presented in section 4.5.

4.2.4 Summary 'thermodynamic concepts and implications'

Section 4.2 introduced the First Law of Thermodynamics, stating that energy cannot be created nor destroyed anywhere in the landscape. The prime source of energy on Earth is the sun. The Second Law of Thermodynamics states that throughout the flow of energy, exergy is destroyed and entropy created. Solar energy enters the atmosphere and powers processes ranging from the global scale to the scale of individual buildings (see figure 4-5).

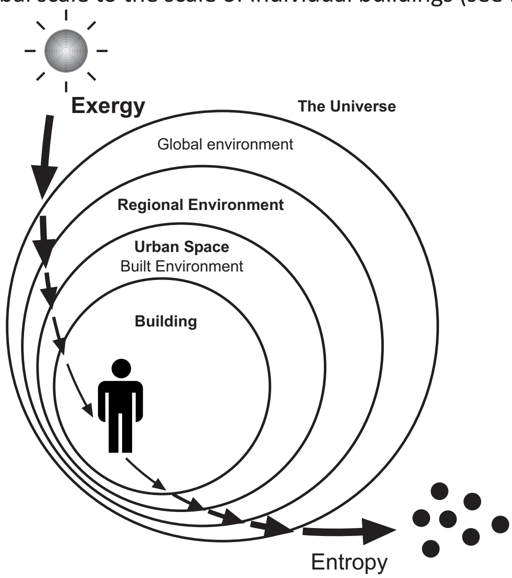

Figure 4-5. Conceptual illustration of global energy flows. Solar exergy enters the atmosphere and is gradually turned into entropy (based on Shukuya, 2009b).

7 For information on exergy as an indicator for ecosystem resilience and health see Jørgensen et al. (2010).

Combustion of fossil fuels represents the largest anthropogenic cause of entropy production. Mixing of materials and mixing of energy flows further contributes to entropy production. Entropy is also created as materials are dispersed into air, soil and water. To create exergetically sound landscapes, we conclude that energy flows must be optimized and material cycles closed.

Exergy destruction of territorial systems can be assessed. Energy conversion, industry and transportation are among the largest exergy destroying sectors. Renewables are not necessarily low-grade energy sources. Their quality varies from high-grade (e.g. biomass) to relatively low-grade (e.g. warm water from aquifers). It is exactly this qualitative diversity of renewables that provides many opportunities to match energy supply with demand. Even when energy originates from renewable sources, efficiencies must be increased in order to minimize exergy destruction and mitigate land-use pressure.

Natural ecosystems develop towards effective use of available resources. Mature (or class 3) ecosystems are considered sustainable because they maintain closed material cycles and utilize renewable energy sources effectively. The specific (or stored) exergy of a region can be increased through photosynthesis and subsequent biomass agglomeration. Nature development, for example, could potentially offset the exergy losses caused by industrial activities, and eventually contribute to a net exergy gain within regions.

We hypothesize that exergy-conscious spatial organization of the built environment can help decrease exergy destruction, and can ultimately increase their resilience. Moreover, we believe that the current dependency of many regions on imported fossil fuels can be reduced by using a broad mix of local, renewable energy sources. We therefore agree with Dincer (2002) that exergy is a key component in obtaining sustainable development. Whether or not, and to what extent second-law thinking can contribute to the planning and design of sustainable landscapes will be discussed in section 4.4. The following section focuses on the application of second-law thinking.

4.3 Application of second-law thinking

“Exergy related studies have received a tremendous amount of attention from various disciplines ranging from chemical engineering to mechanical engineering, from environmental engineering to ecology and so on” (Dincer, 2002, p.138). In this section we review the integration of second-law thinking in (1) engineering thermodynamics, (2) industrial ecology, and (3) architecture and spatial planning. The underlying question is: what can we learn from these disciplines in order to advance the planning and design of sustainable landscapes?

4.3.1 Engineering Thermodynamics

The global energy crisis of the 1970s and the more recent emphasis on resource depletion have led to a "complete overhaul of the way in which power systems are analyzed and improved thermodynamically" (Bejan, 2002, p.545).

Introduction to Engineering Thermodynamics

Engineering thermodynamics (ET) aims to minimize thermodynamic losses during energy conversion and during the construction and operation of energy systems (Bejan, 1996). Initially, thermodynamic engineers focused exclusively on the analysis of power plants. Only later were the true potentials of second-law thinking recognized. According to Slesser (1974), it was in 1974 when the concept of exergy was first introduced to the discussion on resource depletion. Today, exergy analysis (e.g. Szargut et al, 1988) and thermo-economic analysis (e.g. Lozano and Valero, 1993) are considered the most efficient tools for the design and optimization of energy conversion systems and energy policies (Susani et al, 2006).

Exergetic life-cycle analysis (ELCA) goes beyond conventional exergy analysis and estimates exergetic investments and exergetic pay back times for energy systems.[8] Both ELCA and EEA internalize energy, materials and labour invested in the construction of systems (see section 4.2.2). A drawback from a second-law perspective, however, is that EEA excludes, and ELCA accounts only partly, for the exergy required to return materials to their original state (e.g. after decommissioning wind turbines). McDonough and Braungart's (2002) 'cradle-to-cradle' approach may provide a theoretical framework that can help to further advance exergy accounting. However, the thermodynamic aspects of cradle-to-cradle are still unresolved, and research is ongoing.

Possible solutions from Engineering Thermodynamics

Bejan argued that "the physical result of global optimization of thermodynamic performances is structure" (2002, p. 561). He defined structure as configuration, topology, geometry, architecture and

8 Cornelissen (1997) estimated that it will take between 0.07 and 1.2 years to pay back the exergy investments of district heating grids. Pay back time depends primarily on the density of the heat distribution system.

pattern. He also argued that location[9], temperature[10] and time[11] are structure-generating principles that should be studied further. Location, energy quality, and time are not only relevant for the optimization of thermodynamic performance, but also for the planning and design of sustainable landscapes, and have resulted in a number of design principles listed in section 4.5.

Discussion on Engineering Thermodynamics

"Does industry embrace exergy?" is the question that Rosen (2002) discussed in a paper with the same title. He ascertained that exergy analysis has been a long-standing practice in electric utilities. Other industrial sectors, however, have not yet embraced exergetic thinking, for a number of reasons. Rosen suspected that exergy analysis is too complex for some users, and that results are too difficult to interpret. Moreover, the concept of exergy is, unfortunately, still unfamiliar to many – a situation we also experienced during expert workshops on sustainable energy and environmental design.

The proposition that further optimization of thermodynamic performance will lead to increased structure in energy systems (Bejan, 2002) coincides with the idea of increasing structure in natural ecosystems (e.g. Lotka, 1925; Odum, 1959 and 1992) as well as human ecosystems (e.g. Newman, 1975; Hough, 1984; Jørgensen, 2006). Bejan's (2002) perspective corresponds to a large extent with landscape architect Lyle's three modes of ecosystem order (1994), where 'structural order' refers to the composition of system components, 'functional order' refers to the flow of energy and materials, and 'locational patterns' is influenced by carrying capacity (see also Rees and Wackernagel, 1994).

4.3.2 Industrial Ecology

Industry accounts for almost 40% of the global energy consumption and contributes almost 37% to the global GHG emission[12] (Price at al. 2006). The energy intensity of most industrial processes is estimated to be at least 50% higher than the theoretical minimum (IEA, 2005). Copper, to cite only one example, is produced with an exergy efficiency as low as 4%

9 The efficiency of power plants is influenced by the rate at which residual heat can be transferred to the environment. Bejan (2002) refers to the location of power plants as criteria for exergetic efficiency.

10 The greater the temperature difference between energy source and sink, the greater the work capacity, but also the greater potential exergy destruction (Bejan, 2002).

11 A fast heat transfer between source and sink is more exergy efficient than a slow transfer (Bejan, 2002).

12 CO_2 emissions in the industrial sector arise from three sources (1) use of fossil fuels for energy, (2) use of fossil fuels in chemical processing and metal smelting, and (3) non-fossil fuel sources, for example cement and lime manufacture (Worrell et al, 2009).

(Hinderink, 1996). Efforts to reduce material and energy consumption in the industrial sector have intensified in recent years, ultimately leading to the emergence of a new discipline called Industrial Ecology (IE)[13].

Introduction to Industrial Ecology

The rationale of IE is to go beyond 'end-of-pipe treat and release approaches' in industrial processing. One objective of IE is to design industrial ecosystems with high exergetic efficiency (Connelly and Koshland, 2001). Natural ecosystems serve as models, because the exergetic efficiency of many ecosystem processes is high; for photosynthesis it varies between 48 and 81% (Lems, 2009). IE has been put into practice in 'eco-industrial parks', i.e. environmentally efficient industrial parks (PCSD, 1996). Even with substantial efforts in pollution prevention, single firms have only limited capacity to reduce waste (Pauli cited in Ehrenfeld and Gertler, 1997). Therefore, industries cooperate in eco-industrial parks.

Possible solutions from Industrial Ecology

Exergy destruction in the industrial sector can be reduced, for example, through symbiotic relationships between different industries (Jørgensen, 2006). Theoretical energy savings in heat generation alone can amount to 60% if waste heat from one industrial process is used to drive another process (Groscurth et al, 1989). The practical potential of so-called 'heat cascades', it has been argued, may be limited to 5% energy savings (Matsuhashi et al, 2000). Potential energy savings are influenced by site-specific factors, such as the spatial organization of different industries. 'Co-siting' of industries is a measure that facilitates both heat cascading and the reuse of by-products (Akisawa et al, 1999; Worrell et al, 2009). Connelly and Koshland (2001) synthesized the following five principles to decrease exergy destruction in the industrial sector (table 4-5).

Table 4-5. Principles for decreasing exergy destruction in the industrial sector (based on Connelly and Koshland, 2001)

1	**Consumption**	Reducing exergy destruction by minimizing or avoiding consumption.
2	**Waste cascading**	Using resource outputs from one or more consumptive processes to supply other consumptive processes at equal or lower exergy.
3	**Resource cycling**	The exergy removed from a resource during use is returned to it afterwards.
4	**Exergy efficiency**	Reducing exergy loss during processing, waste cascading, and resource cycling.
5	**Renewable energy**	All energy must originate from renewable sources.

13 The term 'Industrial Ecology' was first mentioned by Cloud in 1977.

The above principles correspond with many of the strategies discussed earlier in this paper. In section 4.5, we provide an initial list of exergy-conscious principles relevant for sustainable spatial planning and landscape design.

Example of an eco-industrial park

Kalundborg is perhaps the best known eco-industrial park (figure 4-6). This symbiotic network developed over a period of more than 20 years. A refinery, a power station and various manufacturing industries are among the symbiotic partners. The exchange of residual energy, water and industrial by-products between the symbiotic partners is facilitated through extensive networks.

Figure 4-6. Photograph eco-industrial park Kalundborg-Asnæsværket, Denmark (S. Stremke).

Ehrenfeld and Gertler argued that the “evolutionary pattern followed at Kalundborg may not be easily transferable to Greenfield developments” (1997, p.67). In other words, this symbiotic network evolved over time rather than being planned. Jørgensen (2006), among others, argued that symbiotic relationships can be planned and that the transformation can be guided through explicit principles and guidelines.

Discussion on Industrial Ecology

The lack of clear definitions and rigorous physical interpretation of resource consumption, and ambiguity about the roles and limitations of resource conservation strategies have prevented integration of IE strategies across the industrial sector (Connelly and Koshland, 1997). Despite the apparent reluctance of the industrial sector to embrace IE strategies, it has become clear that both spatial proximity and connections between different industries are prerequisites for symbiotic relationships. Both conditions can be facilitated through exergy-conscious spatial planning. Mapping of exergy sources and sinks with the help of GIS can be an important initial step towards symbiotic relationships (Stremke and Koh, 2010). Also important from a spatial perspective is that transport and conversion losses limit the spatial extent of symbiotic networks. These constraints must be accounted for in exergy-conscious planning and design.

4.3.3 Low-Exergy architecture and planning

"The biggest causes of irreversibility [in energy conversion processes] are the use of high-quality fuel for the production of middle-quality heat and the dissipation of low-quality energy in the environment" (Cornelissen, 1997, p.33).

Introduction to the Low-Ex approach

In recent decades, the concept of exergy has been 'rediscovered' in architecture and applied at both the building scale and the community scale (Torio et al, 2009). Low-Ex aims to reduce exergy destruction in the built environment by "facilitating and accelerating the use of low-valued and environmentally sustainable energy sources for the heating and cooling of buildings" (LowEx, 2009).

Energy efficiencies of many building service processes are very high: in some cases, such as condensing boilers, up to 95%. However, exergy analysis of the same process revealed that the efficiency of using a 1,500°C gas flame to heat a house to a temperature of 20°C is no more than 15%. If the same heat is utilized in heavy industry, exergy efficiency is close to 100% (Dobbelsteen et al, 2007b).

Heat recovery systems and insulated building envelopes are among the possible low-ex interventions at the building scale (see e.g. Kato, 1998; Schmidt, 2004). Exergy efficiency has also been introduced as indicator for energy performance of buildings, for example in the Swiss canton of Geneva (Favrat et al, 2008).

To minimize exergy destruction, urban planners recently began considering building orientation and configuration (e.g. Balocco and Grazzini, 2000), but the focus has been limited to primary energy savings. Generally speaking, second-law thinking is not yet embraced in urban planning and design. The same is true for planning and design beyond the urban scale. Energy systems are receiving more attention in spatial planning, but second-law thinking has not yet penetrated the environmental design disciplines. We have observed the need to conduct further research on the Low-Ex approach, especially at the regional scale.

The interdependency between spatial organization of functions and exergy has great potential for making improvements through exergy-conscious regional planning and landscape design.

Possible solutions from Low-Ex

The low-ex approach "entails matching the quality levels of exergy supply and demand in order to streamline the utilization of high-value energy resources and minimise the irreversible dissipation of low-value energy into the environment" (Schmidt, 2009, p.332).

In Kerkrade West (the Netherlands) it was proposed to cascade residual heat from high-grade industrial processes (using locally produced biogas) through a series of lower-grade functions. Using residual heat in different industrial processes first, and then for the heating of dwellings, is one example of how to match quality levels between exergy supply and demand. In this way, overall exergy destruction is significantly minimized. It has been estimated that the electricity required to power the pumps is about 3kWh for each GJ of heat transported. Even if the electricity is generated from a fossil fuel power plant with an energy efficiency of 39%, the primary energy investments are very small. In other words, only 27.7 MJ of primary energy are required to make use of residual heat of 1000 MJ. Based on the experiences from several Low-Ex plans, the following three Low-Ex principles were proposed (table 4-6).

Table 4-6. Low-Ex principles for the built environment

	Low-Ex principle	Possible application
1	Use high-exergy sources only for high-grade processes	Natural gas for metal smelting
2	Reduce exergy destruction through efficient technologies	Heat recovery systems
3	Find low-grade functions for waste flows from high-grade processes	Room conditioning

Many of the above Low-Ex principles for the built environment coincide with those of Industrial Ecology. Yet, IE differs from Low-Ex because the latter focuses on the integration of second-law thinking beyond the scale of industrial parks. Low-Ex planning may entail spatial reorganization of land uses according to their exergy economy.

Example for Low-Ex planning

We have applied the Low-Ex approach in a number of planning assignments at the urban and regional scale.[14] In the province of Groningen, for example, we mapped both the heat/cold demand and supply. Figure

14 See e.g. Broersma et al. (2009), Dobbelsteen et al. (2007c), and Tillie et al. (2009).

4-7 shows that the greatest heat and cold surpluses are present in the industrial parks in the North of the province, but the greatest demand for heat and cold is located in the city of Groningen and other cities across the region. Our studies are being used by the spatial planning department of the province to start matching energy demand and supply (e.g. by locating new housing developments near existing heat sources).

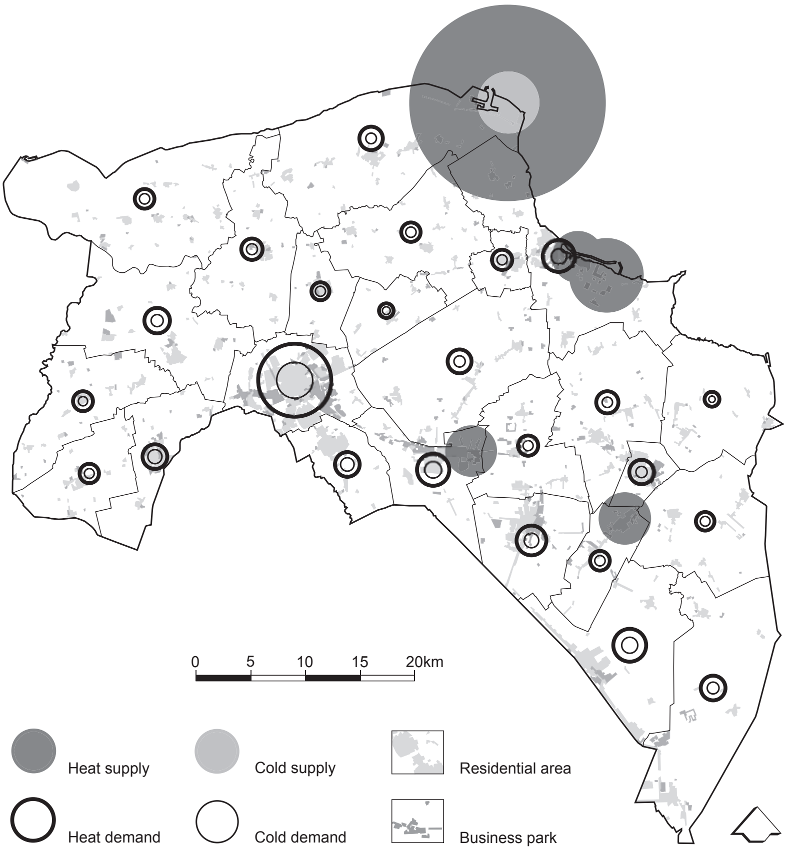

Figure 4-7. Demand and supply of cold and heat in the province of Groningen (based on Dobbelsteen et al, 2007c).

Discussion on Low-Ex

Building design, components, insulation, orientation, configuration and the spatial organization of land uses all play an important role in minimizing exergy destruction in the built environment. At the building scale, there are a number of prerequisites for thermodynamic optimization. Interaction between architectural design, construction of the building envelope and building service equipment appear to be essential (Schmidt, 2009). The presence of low-grade energy sources, for example geothermal and residual heat, is another prerequisite for thermodynamic optimization of the built environment (Hepbasli, 2008). Heat cascades, one possible exergy-conscious intervention, present indeed a challenge to design (De Jong, 2004). Since energy supply and demand differ from one location to another, and fluctuate in time, thermodynamic optimization has to be pursued across spatio-temporal scales.

4.3.4 Summary 'application of second-law thinking'

In section 4.3, we reviewed the application of second-law thinking in three arenas of innovation: engineering thermodynamics, industrial ecology and the planning/design of the built environment.

The literature on engineering thermodynamics (ET) shows that location, energy quality and time are structuring principles of energy systems; they all contribute to the increasing complexity of exergy-efficient energy systems. Spatial organization of exergy sources (e.g. geothermal heat) and exergy sinks (e.g. settlements) influence the efficiency of energy systems. Local exergy potentials should be utilized as much as possible in order to minimize exergy losses in transportation, conversion and storage.

Industrial ecologists (IE) investigate how to close material cycles and limit energy sources to renewables. A number of exergy-conscious principles have been put into practice in eco-industrial parks across the world (e.g. Kalundborg). Industrial ecologists have argued that spatial organization (i.e. co-siting of industries) can reduce exergy consumption.

Proponents of the Low-Ex approach to the planning/design of the built environment state that the location of both residual/renewable energy sources and sinks should be considered in spatial planning. Spatial proximity of and connectivity between sources and sinks are two key strategies in Low-Ex planning. Environmental designers expect that exergetic optimization will increase the complexity of the human built environment, a trend that has also been observed in other disciplines.

Based on ET, IE and Low-Ex, we have derived a set of five exergy-conscious strategies for planning and design of the built environment: (1) increase exergy efficiency, (2) decrease exergy demand, (3) increase use of residual exergy, (4) match quality levels of supply and demand, and (5) increase assimilation of renewable exergy. We believe that all five strategies should be pursued across the various planning and design scales; emphasis should be placed as indicated in table 4-7.

Table 4-7. Exergy-conscious strategies for planning and design of the physical environment

	Exergy-conscious strategy	Building component	Building	Neighbour-hood	City	Region
1	Increase exergy efficiency (e.g. heat recovery systems)	***	**	*	*	*
2	Decrease exergy demand (e.g. building orientation & passive house)	*	***	***	*	*
3	Increase use of residual exergy (e.g. residual heat for room heating)	*	**	***	***	**
4	Match quality levels of exergy supply and demand (e.g. cascade)	*	**	***	***	**
5	Increase assimilation of renewable exergy (e.g. geothermal)	**	**	***	***	***

Key: *** = focal scale, ** = relevant, * less relevant

In this section, we discussed a number of exergy-conscious principles; many of which have been put into practice. Despite the application of second-law thinking in many disciplines, only few of those principles are being considered in current spatial planning and landscape design practice. We will now discuss whether second-law thinking should be embraced by spatial planners, landscape architects and designers.

4.4 Discussion

A Scopus query for ‘thermodynamics’ and ‘sustainable development’ lists more than two-hundred scientific papers, a number that indicates how closely related those two realms are. The key question of this our paper is whether second-law thinking can advance the planning and design of a sustainable physical environment? From the literature research, it became clear that second-law thinking not only offers explicit principles for the exergy-conscious organization of the human environment, but also helps to unravel the complex socio-ecological systems that spatial planners, landscape architects and designers are concerned with. In the following, we juxtapose a number of commonly used arguments to exclude second-law thinking with arguments that support the integration of second-law thinking in spatial planning and landscape design.

The FLT states that energy is always conserved; why “bother” with the SLT and the concept of exergy? Energy is indeed conserved, but it is also converted from high-grade to low-grade energy and ultimately into entropy, without any work capacity. As long as the sun provides solar radiation, energy will be available on Earth. The quality of solar energy, however, may not be sufficient to sustain high-grade functions (e.g. heavy industry). Moreover, entropy released from the combustion of fossil fuels contributes significantly to environmental pollution and climate change.

Optimizing exergy efficiency of thermodynamic processes does not exclude the use of non-renewable energy sources; a thermodynamically optimized power plant may still run on fossil fuel. However, the combustion of fossil fuels will always increase irreversibility. To reduce entropy production, exergy-conscious planning and design must facilitate the use of solar and geothermal exergy. Simply replacing fossil fuels with renewables may however contribute to the further loss of biodiversity (which has been the case with first-generation biomass production). To contribute to sustainable development, exergy-conscious planning and design need to go beyond thermodynamic performance; environmental designers must also consider social and economic factors. Moreover, exergy-conscious interventions should never adversely affect biodiversity.

Despite the benefits of renewable energy sources, technical devices such as wind turbines appropriate both exergy and space during construction, operation and after decommissioning. That is why the efficiency of energy flows from renewable sources must be increased, similar to energy flows originating from non-renewables sources.

Indeed, exergy cannot be the only measure of sustainability. When addressing irreversibility due to energy consumption, however, one cannot ignore the SLT. Engineers, architects and urban planners have shown that second-law thinking can contribute to the transition to sustainable energy systems. At the regional scale, nevertheless, large potentials remain to further reduce energy consumption through exergy-conscious design.

The SLT is indeed more complex than the FLT. The Second Law interconnects energy, matter, information, space and time. In the past, environmental designers have shown that other complex challenges, such as the development of large-scale ecological networks, can be addressed in a multidisciplinary manner. A system approach to design may also facilitate the integration of ecological concepts such as ‘biorhythm’ and ‘niche’ into the planning and design of a sustainable human environment (see Stremke and Koh, 2010).

There is no doubt that the transition to an exergy-conscious physical environment will require large investments, for example for the construction of district heating networks. From the study of ecosystem succession and of human history, we know that such improvements always require subsidies – at least temporarily. These ‘investments’ will however pay off through increased resilience and reduced entropy production.

A final argument for the integration of second-law thinking in spatial planning and landscape design is that, despite all efforts, we are far from reaching GHG emission targets. Energy consumption and emissions have continued to increase at the global scale. Apparently, closed system (or first-law) thinking has no more solutions to offer. Second-law thinking, as discussed in this paper, provides new insights, concepts and principles that can help to reduce exergy destruction and increase the assimilation of renewable energy sources. That is why we believe that second-law thinking should be embraced by environmental designers who are concerned with the development of a sustainable physical environment.

4.5 Conclusion

Second-law thinking is useful for reducing exergy destruction during energy conversion, material processing and in the built environment. The Second Law of Thermodynamics and the concept of exergy are well recognized in engineering thermodynamics, industrial ecology and are partly recognized in architecture and planning. Having studied the possible benefits and limitations of thermodynamic concepts, we believe that second-law thinking should also be embraced by environmental designers. The integration of second-law thinking in regional planning and design could contribute to the emergence of exergy-conscious landscapes. Such 'exergy landscapes', from our point of view, present another important building block in the transition to a sustainable physical environment. They can be conceptualized as the 'successors' to exergy-conscious power systems, industrial parks, buildings and neighbourhoods.

Designing and facilitating the development of exergy landscapes can help to mitigate fossil depletion and climate change; design becomes a problem-solving activity. What we still lack, however, are generally applicable principles (i.e. substantive knowledge). Such principles can be generated through synthesis and translation of knowledge from other disciplines, for instance from engineering thermodynamics. At the risk of being simplistic we would now like to highlight a number of exergy-conscious principles that have been studied through research-by-design. They are derived from both literature and case-study research, and reflect our experiences while designing several regional energy landscapes in the Netherlands.

Composition of system components (structural order)

- Support development of highly diversified and interconnected energy systems.
- Identify and facilitate the use of local exergy sources (e.g. geothermal energy).
- Identify and, if necessary, allocate exergy sinks (e.g. greenhouses).
- Connect exergy sources with sinks (e.g. through district heat network).
- Avoid unnecessary dispersion of functions in space (e.g. urban sprawl).
- Establish mixed land-use that facilitates exchange of low-exergy sources.
- Orient buildings to make optimal use of exergy influx (e.g. 'hot' and cool exergy).

Flow of energy and materials (functional order)

- Minimize or avoid exergy consumption (e.g. through revelatory design).
- Replace exergy-intensive processes with natural processes (e.g. replace artificial lighting with natural lighting; replace active air conditioning with passive cold air channels and vegetation).
- Match energy quality of sources and sinks (e.g. geothermal exergy for heating).
- Facilitate use of exergy-efficient technologies (e.g. cogeneration plant).
- Cascade residual heat from high-grade functions (e.g. heavy industry) through a series of lower-grade functions (e.g. heating of greenhouses and dwellings).
- Increase exergy storage through resource accumulation (e.g. biomass).

Conditions in the system environment (locational patterns)

- Map exergy sources and sinks (e.g. power plants, and greenhouses).
- Identify potential symbiotic partners (e.g. cattle farmer, and energy utility).
- Facilitate communication and collaboration between potential partners.
- Create infrastructure when high potentials for renewable exergy exist (e.g. district heating in area with geothermal energy and high housing density).
- Employ 'stand-alone' devices in areas with low housing density.
- Store hot and cool exergy (e.g. seasonal heat-cold storage in aquifers).

One may argue that many of the above exergy-conscious principles are beyond the scope of conventional spatial planning and landscape design. The question is then: who should address second-law thinking beyond the urban scale? Note that the scale of many exergy-conscious interventions relates to, if not coincides with, that of spatial planning and landscape design practice. This brings us to the final question addressed in this paper: How can we define 'exergy landscape'? We certainly don't want to conceptualize exergy landscape as 'work potential landscape', which could be implied by a strict thermodynamic interpretation of the exergy concept. Instead, we emphasize that landscapes will once again become life support systems. The assimilation of renewable energies will claim parts of the landscape, while the spatial organization of the physical environment will influence how much energy at which quality is required to sustain humanity. That is why we believe that landscapes should develop into highly structured and symbiotic life-support systems that maximize exergy dissipation and minimize entropy production.

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Combined Heat Power plant in Utrecht, The Netherlands, Architect L v/d Pol (Flickr, D. Johnston)

Renewable energy landscape in Güssing, Austria (courtesy A. Boekel & K. Neven)

Energy-conscious Environmental Design

Energy landscapes: Integration of ecological concepts and thermodynamic laws in environmental design[1]

5

Abstract. Resource depletion and climate change motivate a transition to sustainable energy systems that are highly efficient and rely on renewable energy sources. Whereas nature presents strategies on how to sustain humanity on the basis of renewable energy sources, the Laws of Thermodynamics help to increase efficiencies. In previous papers we have identified a number of ecological and thermodynamic concepts which are of special relevance to the planning and design of sustainable energy landscapes. In spite of the apparent benefits of renewable energy sources, the transition is constrained by several issues such as (a) periodic fluctuations in energy supply, (b) relatively low energy density of renewables, and (c) limited capacity to utilize available energy. The central research question of this paper is how ecological and thermodynamic concepts can help environmental designers to overcome those constraints and develop sustainable energy landscapes. Energy requirements of such landscapes, by definition, may not exceed locally available renewable energy sources. A regional case-study in South Limburg (the Netherlands) illustrates how descriptive scientific concepts inform the design of sustainable energy landscapes, and help to define generally applicable descriptive design principles.

Keywords. Sustainable energy landscape; energy-conscious planning, landscape design; energy transition

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5.1 Introduction

The discovery of fossil fuels not only stimulated economic growth but also resulted in spatial patterns which require vast amounts of energy for transportation and conversion (Steiner, 2002). More than half of the human energy consumption is affected by the spatial organization of the built environment (Owens, 1990). The depletion of fossil fuels in combination with climate change necessitates a gradual transformation of today's fossil energy landscapes into sustainable energy landscapes. Environmental designers[2] can not limit the discussion solely to the location of wind turbines or the design of energy-efficient buildings. Rather, one must consider energy-conscious (re)organization of the built environment (Strong, 1992). 'Energy-conscious planning and design' refers to the integration of energetics into spatial planning and landscape design. Energy-conscious design implies (a) increasing the assimilation of renewables, and (b) reducing energy consumption in the built environment – two key objectives of sustainable energy transition (KNAW, 2007).

Energy is indispensable for life, both in the human and the natural world. The lack of energy and/or the inability to utilize available energy flows increases stress and may result in fierce competition. The flow of energy is governed by the Laws of Thermodynamics. In thermodynamics, engineers study how to reduce irreversibility[3] in energy assimilation, conversion, transport and storage (Dincer, 2000). The so-called 'second-law thinking' and concepts such as exergy[4] provide valuable insights for the design of sustainable energy landscapes (Stremke et al, 2010). In ecology, resource scarcity is simply understood as disturbance to which ecosystems adapt (Odum, 1993). Several ecological concepts illustrate how natural ecosystems overcome resource scarcity (Stremke and Koh, 2010). Concepts both from ecology and thermodynamics are relevant to the planning and design of sustainable energy landscapes - a physical environment that can be sustained on the basis of locally available renewable energies.

Despite the benefits of renewables, is the transition to sustainable energy systems constrained by several issues. They include (a) periodic fluctuations in energy supply, (b) relatively low energy density of renewables, and (c) limited capacity to utilize available energy (see e.g.

2 'Environmental designer' refers to the disciplines concerned with the design and organization of the built environment; for instance, architecture, urban and spatial planning, and landscape architecture.
3 Irreversibility refers to the degradation of energy and the emission of greenhouse gases.
4 Exergy refers to the maximum amount of work a system can perform when it is brought to the thermodynamic equilibrium with its environment (Ludovisi et al, 2005).

Laughton, 2009; Smil 2003 and 2008). There persists a general knowledge gap on how to deal with the constraints of renewable energy sources.

The central research question of this paper is whether ecological and thermodynamic concepts can help environmental designers to deal with the constraints of renewable energy sources, and to facilitate the design of sustainable energy landscapes. In this paper, we use the region of South Limburg (the Netherlands) to illustrate how descriptive concepts can inform the design of sustainable energy landscapes, and help to define generally applicable prescriptive design principles.[5]

5.2 Method

There is increasing awareness that resource depletion and climate change cannot be solved by conventional spatial planning and design practice. Not only the time horizon and spatial complexity of sustainable energy transition differ, but we also lack substantive knowledge – energy-conscious design principles. The integration of knowledge from various scientific domains towards energy-conscious design principles can be facilitated through so-called 'translational research'. By translational research we mean the "collaborative learning process between scientists, designers, planners, and engineers who seek to solve complex environmental problems by connecting scientific theory, concepts and principles to the design and planning of the built environment" (Musacchio, 2008, p.3). Whereas translational research may be an 'umbrella concept' for the research presented in this paper, increasing numbers of environmental designers today distinguish between 'research for design' (i.e. search for solutions outside the immediate problem space), and 'research-driven design' (i.e. application of research findings in design). Our literature review and the study of precedent cases represents 'research for design'. The regional case-studies are an example of 'research-driven design'. Both approaches are discussed below.

5.2.1 Research for design

"The Laws of Thermodynamics and the integrated energy-material flows observed in natural ecosystems teach us to reduce resource degradation" (Connelly and Koshland, 1997, p.209). Over the past years, we have examined a large body of literature on system science and identified a number of ecological concepts and ecosystem strategies that

5 Design principles are also referred to as 'spatial organization principles' (Klaasen, 2004)

can inform the design of sustainable energy landscapes (Stremke and Koh, 2010). Ecological concepts describe key properties of the natural world; ecosystem strategies reveal how natural ecosystems improve energy efficiency and sustain on the basis of renewable energy sources (Odum, 1983). Recent publications from the fields of thermodynamic engineering, industrial ecology and architecture presented another source of insights (Stremke et al, 2010).

5.2.2 Research-driven design

In order to define generally applicable principles for the design of sustainable energy landscapes, we have conducted several case-studies in the Netherlands. The region of South Limburg serves to illustrate energy-conscious design principles and interventions in this paper. Located in the South of the Netherlands (see figure 5-1), South Limburg has an area of 660 km^2 with a population of approximately 616000 inhabitants (CBS, 2008). Over a period of two years, we collaborated both with experts in the field of energy transition and a group of stakeholders (including e.g. farmers, representatives from utilities and policy makers). This transdisciplinary part of the study

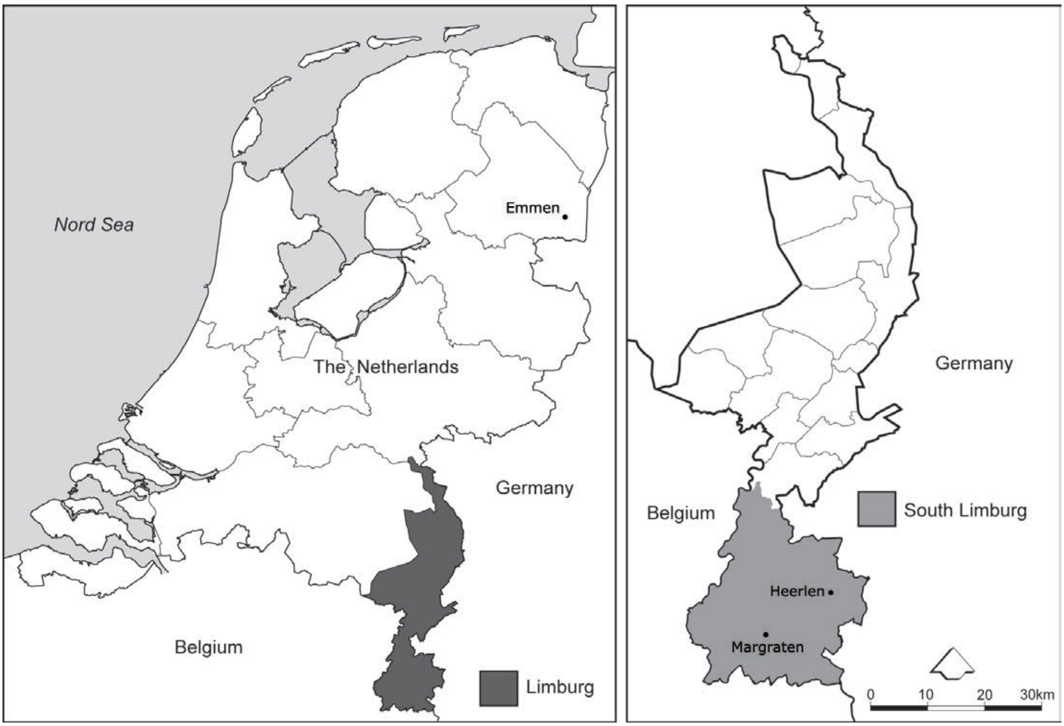
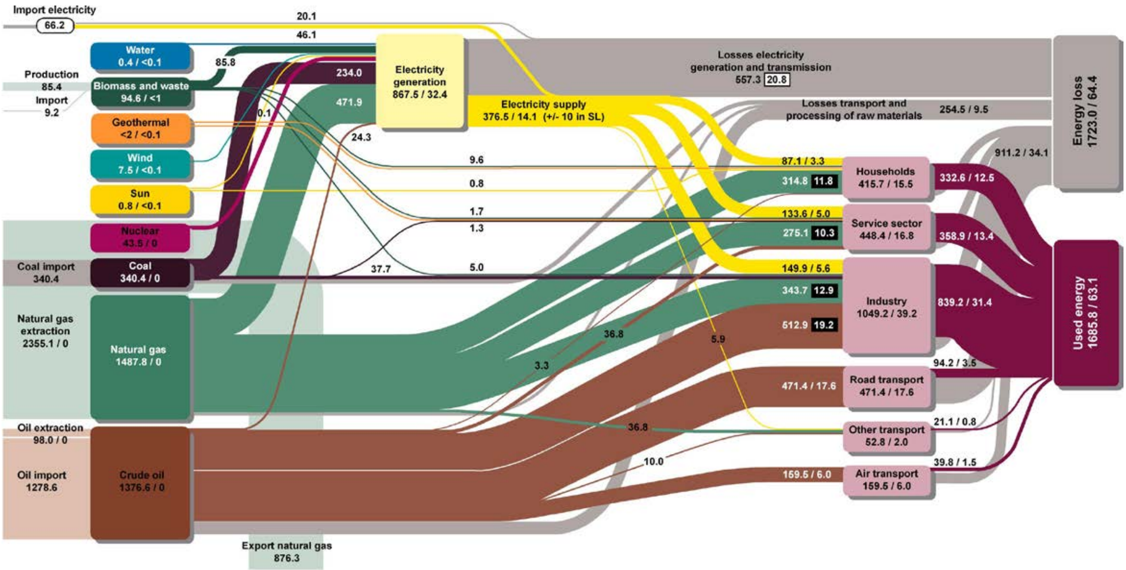


Figure 5-1. Location province of Limburg in the Netherlands (left), and the region of South Limburg (right).

included a series of excursions, workshops and presentations in South Limburg. Literature research and case-studies have been conducted simultaneously: theories informed practice and experiences from the case-studies influenced the literature research. We now briefly introduce the present-day energy system in South Limburg.

5.2.3 Energy system South Limburg

As of 2007, the total energy consumption in the Netherlands amounted to 3.400 PJ (all numbers CBS, 2009). The main energy sources were crude oil (40%), natural gas (44%), and coal (10%). The significant share of fossil-fuels in the Netherlands (more than 90%) provides a high potential to reduce greenhouse gas (GHG) emissions. The energy-flow diagram below (figure 5-2) is based on the Dutch per capita energy consumption of 207 GJ. Inhabitants of South Limburg amount to 3.7% of the Dutch population; energy consumption in the region is assumed to have the same share of the Dutch energy consumption (3.7% of 3.400 PJ is 127 PJ).



Notes: All numbers in Peta Joule (PJ). First numbers account for the entire Netherlands (e.g. Sun 0.8/<0.1), second number for the region of South Limburg.

20.8 Energy loss due to electricity production and transmission for South Limburg amounts to 20.8 PJ. Residual heat of power plants remains to be utilized.

54.2 South Limburg's share of natural gas and crude oil consumption, primarely for heat production, amounts to 54.2 PJ or approximately 50% of total energy consumption.

Figure 5-2. Energy flow diagram for the Netherlands and South Limburg depicting large share of primary energy for room and process heat. Numbers for South Limburg indicated in black boxes. Diagram adapted from Sijmons et al. (2008) and CBS (2009).

Above calculation may neglect regional differences in energy economies but presents a simple way to estimate the current regional energy consumption.[6] In South Limburg, two Combined Heat Power plants (CHP) generate electricity (+/- 10PJ); a small fraction of their residual heat is used for material processing and district heating. Large amounts of primary energy resources are used for room heating in private households (11.8 PJ) and the service sector (10.3 PJ). Industry appropriates excessive amounts of natural gas (12.9 PJ) and crude oil (19.2), primarily for process heat. The large share of primary energy for heat provision presents great potentials for reducing GHG emission through energy-conscious spatial planning and design.

5.3 Constraints of renewable energy sources

The shift from fossil fuels to sustainable energy systems is discussed under the notion of 'sustainable energy transition'. This discussion, however, is not a new one. In the aftermath of the first oil crisis, scholars argued for a 'steady-state economy' where inflows of energy balance the outflows (Odum and Odum, 1976). Nevertheless, sustainable energy transition remains a rather fuzzy notion to some, if not most, environmental designers. This is problematic because energy and the built environment influence each other reciprocally. On one hand, local energy resources and technologies shape landscapes (e.g. Ruhr region in Germany). On the other hand, landscapes can also affect energy assimilation (e.g. Hoover Dam in the United States). However, the majority of today's built environment in the more economically developed countries depends on fossil fuels. This fossil fuel energy landscape with its vast infrastructural networks presents an obstacle in the transition to sustainable energy systems. Several characteristics of renewable energy sources, however, present additional obstacles and deserve special attention (Stremke and Koh, 2009). Three constraints that can be mitigated through energy-conscious spatial planning and landscape design are addressed in this paper.

First, renewable energy supply is characterized by *periodic fluctuations*. This is primarily due to the fact that the planet rotates around the sun and itself, a process which creates day/night differences and divides the Earth into climate zones with more or less distinct seasons. Second,

6 To the best knowledge of the authors there are no numbers on regional energy consumption in the Netherlands.

renewable energy carriers have a relatively *low energy density*, compared with fossil-fuels. Energy density refers to the amount of energy stored in a given unit of mass; low energy density of renewable energy carriers constrains transportation. A third constraint is the limited capacity of many consumers to *utilize available renewable energy*. Energy utilization refers to the assimilation, the conversion, the storage, and use of energy.

Those three constraints (amongst others) complicate the transition from fossil fuels to renewables. Yet, they have triggered many ingenious solutions, both in the biosphere and the technosphere; many of which are explored in the subsequent sections.

5.4 Adapting the built environment to renewable energy

This section discusses concepts and strategies which can help adapting the built environment to renewable energy. The section is subdivided according to the three main constraints of renewable energy introduced earlier. Examples from our case-studies in South Limburg, and elsewhere, illustrate possible energy-conscious design principles. This paper constitutes an attempt to describe and disseminate promising design principles. The list of principles is by no means complete and comprises, at least partially, region-specific solutions which cannot be applied to all situations. Nevertheless, we hope that the principles discussed here contribute to the discussion on energy-conscious environmental design.

5.4.1 Mitigating periodic fluctuations

Periodic fluctuations in the environment constrain the assimilation of renewable energy. Wind, water and solar energy are indeed available indefinitely.[7] However, the supply of these energy sources is not constant (see e.g. Laughton, 2009) and fluctuates between day and night, summer and winter, rainy and dry season (see figure 5-3). Energy demand fluctuates as well, but consumption patterns are easier to predict. How does nature adapt to such fluctuations in energy demand and supply? *Storage*, *biorhythm* and *diversity* are three concepts discussed below.

7 As long as the sun exists.

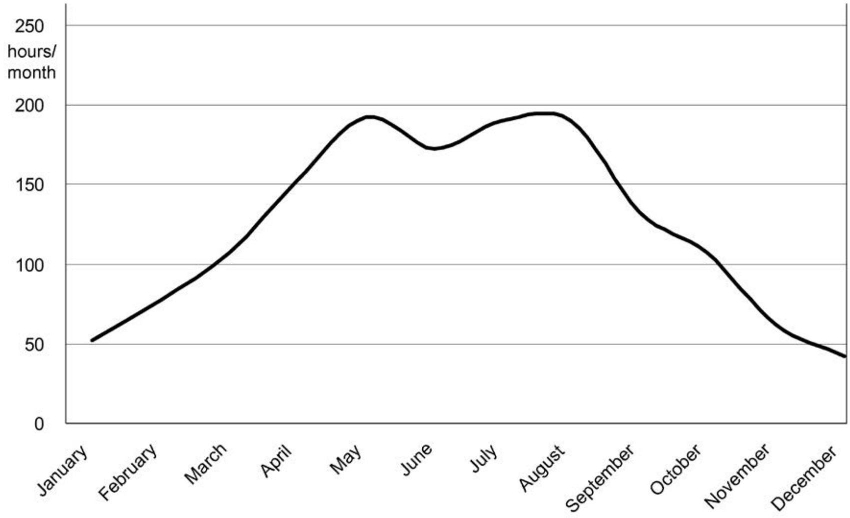


Figure 5-3. Periodic fluctuations of solar irradiation in South Limburg (hours of sunshine per month). Based on data from KNMI (2007).

Storage

Organisms that are exposed to periodic fluctuations in energy supply tend to store energy. Plants, for example, assimilate solar energy during the day. At nighttime, they use the organic energy stored in their biomass. At ecosystem level, surface water bodies store heat/cold and release it over long periods of time to the environment. Heat and biomass derive from solar radiation – they are energy carriers rather than sources. The characteristics of each of these energy carriers may promote or inhibit energy storage in time (i.e. how long can energy be stored) and space (i.e. how far can energy be transported). Based upon distinct properties of the different renewable energy carriers, several strategies can be identified.

Natural aquifers and abandoned mines, for instance, can be turned into seasonal heat/cold storage. This way surplus heat/cold can be stored in the underground and used in times of need. Heat/cold storage is an effective strategy to mitigate periodic fluctuations in energy supply and demand. Residual heat from industry, for example, is of little use for heating houses during the summer. That same heat, however, has significantly higher exergetic quality (work capacity) during the winter (Stremke et al, 2010). Densely built urban areas are favorable locations where heat grids can distribute heat/cold effectively. Nevertheless, it is difficult to define generally applicable principles for heat/cold storage as this intervention depends on energy quality and housing density, among other factors. Regardless, heat/cold storage is a good example of an energy-conscious intervention that necessitates environmental designers to collaborate with geologists, hydrologists, thermodynamic engineers, and other professionals.

In the Parkstad region, South Limburg, flooded coal-mines are used to store and extract heat/cold for 200 apartments, shops and a supermarket, reducing building related CO_2 emissions by 55 percent. The 'Minewater' project receives strong public support because it builds upon the region's history as mining area. Sustainable energy landscapes are thus not limited to the visible surface of the Earth but extend underground. Perhaps even more important than reducing GHG emissions in South Limburg, the Minewater project reinforces the identity of the Parkstad.[8] Similar energy landscapes can be envisioned in many of the derelict mining regions across the world.

Biorhythm

Organisms adapt to periodic changes in their physical environment through physiological and behavioral responses, also referred to as 'biorhythm'. Biorhythm enables organisms to survive through less favorable periods; it balances resource consumption with supply and allows ecosystems to recuperate (Molles, 2005). Plants growing season, animal's hibernation and migration are among the many strategies in the biosphere. Architects and building engineers use the term 'adaptive behavior' when they discuss the relations between energy savings and human comfort in the technosphere. If inhabitants would adapt to periodic changes in buildings, for instance 24 degree Celsius during summer and 20 degrees Celsius during winter, vast amounts of energy could be saved (Santamouris, 2006). Can the concept of biorhythm also inform the design of sustainable energy landscapes and mitigate increasing land-use pressure due to the assimilation of renewable energies?

One possibility is that non-conflicting functions share land surface. In South Limburg, for example, the flooding period of the river Meuse is known. Energy crops can be cultivated and harvested before flooding occurs in December/January (e.g. *Panicum vrigatum* or Switchgrass). In winter, soils receive minerals and nutrients from upstream and can recuperate. Paying attention to periodic changes in the physical environment can help to mitigate increasing land-use pressure due to renewable energy assimilation (see figure 5-4).[9]

8 For more information on the project please see http://www.heerlen.nl/

9 For generally applicable design guidelines for SRC in floodplains refer to Etteger and Stremke (2007).

Figure 5-4. Energy assimilation through energy crops in the floodplains of the river Meuse, South Limburg. Impression of autumn day when energy crops are harvested (courtesy of C. Oude-Aarninkhof).

Diversity

As a region advances in the transition from fossil fuels to local renewables, it gradually becomes independent from energy imports. In order to create a resilient system, the internal energy system must be secured through diversification of sources and technologies. A highly diversified energy system enables regions to cope with possible periodic shortfall of a source (Smil, 2008). It may also, in a market economy, help to balance fluctuating energy prices.[10]

In Margraten, South Limburg, we mapped the potentials for solar, wind, water, biomass, and geothermal energy (see figure 5-5). Revealing both the potentials and constraints of the different energy sources has helped to facilitate the discussion on sustainable energy landscapes in South Limburg. Rather than limiting studies to (often politically) predetermined energy sources and carriers, environmental designers should opt for a highly diversified energy landscape. Nevertheless, while designing sustainable energy landscapes one should not only consider different sources and technologies, but also aim for a spatially diversified system. Dispersion of clusters of wind turbines across a region, just to name one example, can help balance local fluctuations in wind speed and safeguard continuous electricity generation (Laughton, 2009).[11]

5.4.2 Adapting to low energy densities

Renewable energy carriers have a lower energy density compared to fossil-fuels, unless they are upgraded with high energy input. Density varies considerably between renewable energy carriers. Bio-based gasoline, for example, has an energy density of 47 MJ/kg. Bulky biomass, in contrast, might have a density of 10 MJ/kg.

10 For more information on the diversification of energy systems also see Connelly and Koshland (2001); Jelinski et al. (1992).
11 Design principles for the allocation of individual wind turbines and parks can be found, for example, in Franssen et al. (2007).

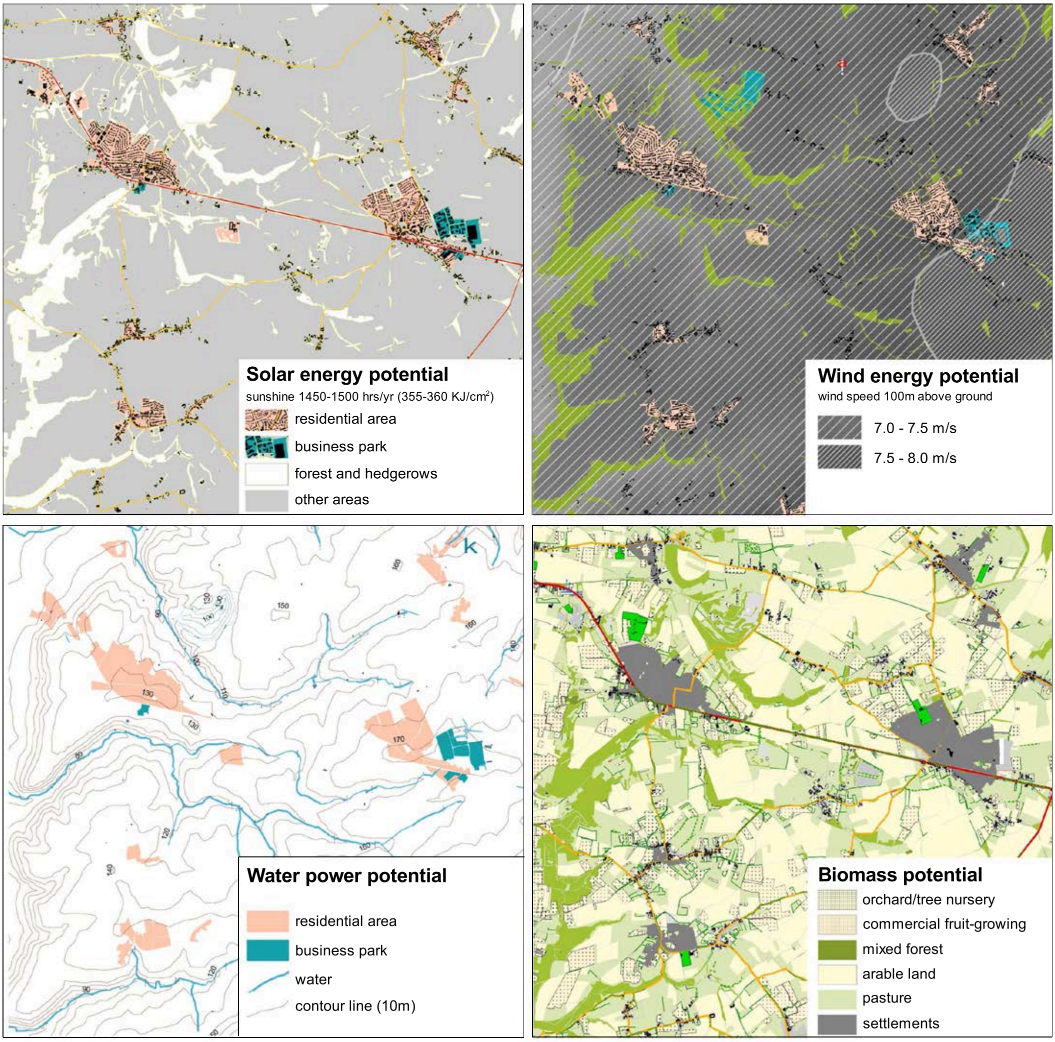


Figure 5-5. Mapping of the diverse renewable energy potentials can facilitate the discussion on sustainable energy landscapes. Example from the Heuvelland area near Margraten in South Limburg (scale approximately 1:100 000).

Many energy crops have such a small energy density that they should only be transported over short distances. The energy density of heat and biomass clearly constrains their distribution in space; a relationship that has direct implications for the design of sustainable energy landscapes. The concepts of *source-sink relationship* and *system size* illustrate how nature adapts to the relatively low energy density of renewables.

Source-sink relationship

The source-sink concept originated as demographic model describing the flow of organisms between different habitats (Pulliam, 1988). The concept is also used in the study of energetics in ecology. In this paper, we suggest understanding source-sink relationship as an inclusive concept considering all kinds of flows, including that of energy (see figure 5-6). From an energetic perspective, 'source area' then refers to that part of a landscape which assimilates more energy than is consumed (see also Odum, 1997). A 'source-sink relationship' is established if one area exports surplus energy to another area with energy deficiency.

Throughout evolution, natural ecosystems increase their energy economy. One strategy is to facilitate relationships between already existing sources and sinks. Often, sources and sinks lie close to each other and can simply be connected through networks. Another strategy is to create new energy sinks (e.g. algae plant requiring heat) in the proximity of energy sources (e.g. industry with residual heat) or vice versa. Ehrenfeld and Gertler highlight that spatial proximity and high connectivity between sources and sinks can reduce costs and, more importantly, energy degradation during transport (Ehrenfeld and Gertler, 1997).[12]

System size

Another concept of relevance to energy-conscious planning and design is system size. Once the size of a system goes beyond its energetic optimum (in either direction), it generates greater energy costs to maintain that system (Odum and Odum, 1976). Optimum system size depends not only on the amount of accessible energy but also on the quality of that energy - that is exergy (Stremke et al, 2010).

Depending on the characteristics of the different renewable energy carriers, energy systems can be divided into a number of 'subsystems'. Heat distribution systems, to name one example, typically serve a neighborhood or a town. The spatial extent of subsystems is limited by the Laws of Physics - in this case heat loss to the environment. Electricity grids, however, can transmit energy over long distances with smaller losses. In other words, each energy carrier has a different optimum system size which should be considered in the planning and design of sustainable energy landscapes.

The maximum size of subsystems is influenced by energy losses; the smallest size is influenced by the minimum capacity of certain energy technologies (e.g. fermentation plant). Paying attention to the density of renewable energy carriers and their respective system size may lead to more decentralized energy systems (KNAW, 2007).

12 For organization principles between energy sources & sinks see Stremke and Koh (2008).

5

Figure 5-6. Spatial distribution of energy sinks: Industrial areas and of private households in South Limburg (the darker the area, the more energy is consumed per square kilometer).

For the municipality of Margraten in South Limburg, we proposed a number of energy systems, each one with a different system size (see figure 5-7). A CHP with a yearly capacity of 10.900 tons of woody biomass can be constructed near the village of Margraten. Since this plant processes biomass from the entire municipality, its systems size is the municipality. Another proposal is to construct decentralized biogas fermentation plants; they process local manure and organic household waste. The size of these systems is limited to a village and immediate surroundings.

Figure 5-7. Proposal for differentiated energy subsystems in the municipality of Margraten (spatial extent indicated with dashed lines). A single CHP near the village of Margraten processes woody biomass from the entire municipality. Decentralized biogas fermentation plants in the different villages process local manure and organic household waste.

5.4.3 Optimizing energy utilization

A final constraint to energy transition, discussed in this paper, is the limited capacity of many consumers both in the biosphere and technosphere to utilize available energy.[13] Autotrophic plants, for instance, only utilize between one and two percent of the available solar radiation. Nutrients, minerals and water are the limiting factors during photosynthesis (Golley, 1996). In the technosphere, the limiting factors are raw materials (to construct assimilation devices) and space (to assimilate renewables). The total energy consumption of humanity amounts to less than 0.5 percent

13 Utilization refers to the assimilation, conversion, storage, transport and use of energy.

(1.4 x 10^{13} Watt) of the incoming solar radiation (435 x 10^{13} Watt). The relative inefficiency in energy conversion, however, results in large areas claimed for energy assimilation (see figure 5-8). Transmission and storage losses further reduce the amount of useful energy.

Optimizing energy utilization is essential in order to mitigate increasing land-use pressure. So far technological innovation has received most attention. Nevertheless, we argue that inquiry cannot be limited to energy technologies alone. This is because global energy consumption is still increasing; efficiency improvements cannot offset growing energy demand (IEA, 2008). In the following, we discuss how natural ecosystems optimize energy utilization through *food chains*, *symbiosis*, and *differentiation of niches*.

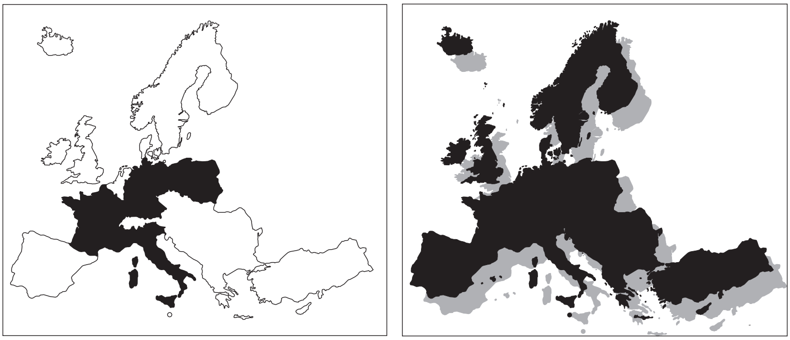


Figure 5-8. Area required to substitute one years natural gas consumption in Europe by biogas produced from rapeseed (left) and from extensive nature maintenance (right).

Food chain

The concept of food chain describes the relations between primary producers and consumers on the different trophic levels. In spite of the relative inefficiency of energy conversion between the different trophic levels, energy is re-used (or cascaded) effectively. Ecosystems with complex food chains not only utilize energy effectively; they are also capable of sustaining a high biodiversity (MacArthur, 1958).

In human systems, energy is (sometimes) cascaded as well. Energy cascading means “the use of residual energy in liquids or steam emanating from one process to provide heating, cooling or pressure for another” (Ehrenfeld and Gertler, 1997, p.68). In Kalundborg (Denmark), about 80% of the residual heat of the local power plant is re-used to heat 3.500 households (ibid.). Given the large primary energy savings of such cascades, they deserve special attention in the planning and design of the built environment (Dobbelsteen et al, 2007a). Energy-conscious planning and design can establish the spatial conditions for energy cascades as illustrated below.

In the city of Emmen,[14] residual heat sources and potential heat sinks have been identified and mapped (figure 5-9). We proposed to cascade residual heat from heavy industry and gas processing installations to older neighborhood first and then further through newer neighborhoods with lower heat requirements. Thanks to the high insulation and heat-recovery standards in the Netherlands, the newest dwellings in Emmen can be heated with low temperature water at the end of this energy cascade (approximately 25° Celsius).

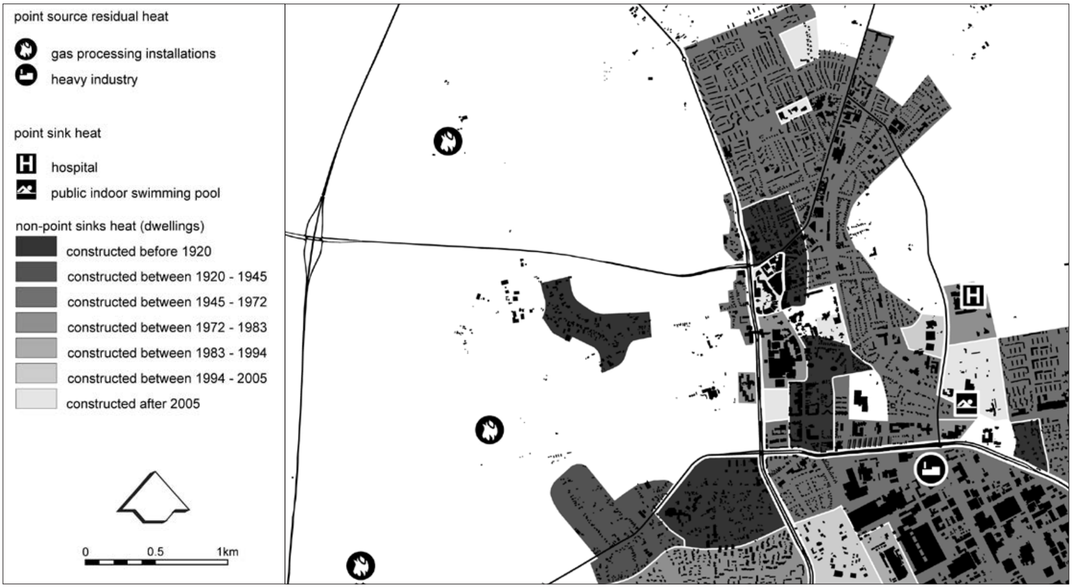


Figure 5-9. Residual heat sources and potential heat sinks in Emmen, The Netherlands.

Symbiosis

In nature, mutual relationships emerge when available resources can no longer be utilized by a single species. The chance for mutual relationships increases significantly when organisms experience resource scarcity (Odum, 1992). If two species sustain a close relationship over long periods of time, the relationship is considered symbiotic. Unsurprisingly, one can find symbiotic relationships in the human world too.[15] If resources are scarce (or expensive), chances emerge that energy will be cascaded and materials re-cycled. In the absence of 'tangible' resource depletion, one can also raise taxes for GHG and heat emissions in order to stimulate symbiotic relationships. Experiences from emissions trading, for instance in Germany, show that such taxation can trigger symbiotic relationships. What are the implications of the concept symbiosis to the design of sustainable energy landscapes?

14 Location of the city of Emmen is illustrated in figure 5-1.
15 Several environmental designers stress the need for symbiotic relationships (see e.g. Dittrich and Schöbel, 2010; Wood, 2007).

Existing roads, railroads, waterways, and pipelines can become important elements for robust symbiotic networks between sources and sinks; they should be mapped and considered in the design. For the Parkstad in South Limburg, we proposed two 'energy rings' connecting heat sources and sinks with each other (figure 5-10). Whereas a direct connection between sources and sinks may be more energy efficient, a ring structure is more robust in case one or more participant(s) withdraw from the symbiotic network.

Figure 5-10. Conceptual sketch of the proposed energy rings in the Parkstad, The Netherlands. Large parts of the outer ring follow the new ring road. Scale approximately 1:200 000 (Etteger and Stremke, 2007).

Differentiation of niches

Resource scarcity can also lead to the differentiation of niches - the last concept discussed in this paper. 'Niche' describes an organism's place in the community, its relations to food and enemies (Elton, 2001). Highly differentiated ecosystems are able to sustain a higher population density and species diversity compared with less differentiated systems (Pulliam and Johnson, 2002). Ecosystems can differentiate by means of vertical stratification, horizontal and temporal zonation. Differentiation of niches can help to optimize energy utilization and to reduce competition for resources; it represents another relevant ecosystem strategy.

In South Limburg, we have mapped vacant areas with potential for renewable energy assimilation. Differentiation of spatial niches, for instance flat roofs of businesses parks and retail centers, can help mitigating increasing land-use pressure. Another spatial niche is the underground, as discussed previously. The temporary use of the floodplains of the river Meuse for energy crop production presents an example for temporal niches (see section 5.4.1).

5.4.4 Discussion case-study South Limburg

Although the search for explicit design principles continues, we have applied above strategies and principles in a series of regional energy studies. The possible effects of energy-conscious interventions on the regional energy system in South Limburg can be described as follows.

In the year 2007, the energy consumption in South Limburg was approximately 127 PJ; more than 98 percent of energy was supplied from outside the region (see section 5.2.3). Our estimation of the regional energy demand in about 30 years[16] is based on two assumptions. Firstly, population numbers continue to decrease by 0.5 percent per year. Secondly, government targets for a reduction of energy consumption between one and two percent per year are met.[17] The energy demand of South Limburg in 2037, is approximately 70 PJ. This estimate allowed us to evaluate proposals quantitatively.

Our regional energy study for South Limburg concludes that by 2037 about half of the regional energy demand can be fulfilled by local renewables (for detailed report see Etteger and Stremke, 2007). Rural areas such as the Heuvelland can become entirely self-sufficient. Urbanized areas such as the Parkstad, on the contrary, will continue to rely on energy imports. Manufacturing and transportation remain the greatest challenges; together they appropriate more than 50% of the total energy. It is important to note that this estimation is based upon existing technologies; major technological innovations are not included.

One may wonder why South Limburg cannot be fully self-sufficient in terms of energy. Part of the answer is the high population density of about 935 inhabitants per square kilometer in South Limburg.[18] Another reason is that two thirds of South Limburg is designated ‘National Landscape’ - a cultural landscape with many restrictions for renewable energy. The final, perhaps most important reason for not reaching self-sufficiency, is that we designed *sustainable* energy landscapes as opposed to *renewable* energy landscapes. Our study for South Limburg

16 We estimate that it may take about 30 years to implement proposed interventions.
17 This reduction of energy consumption is partly realized through energy-conscious (re) organization of the physical environment, as discussed earlier in this paper.
18 The average population density in the Netherlands is 400, in the United Kingdom 255, and in Germany 229 inhabitants per square kilometer.

reveals how to design energy landscapes without compromising food production, biodiversity and scenic landscape quality (see figure 5-11). Throughout the design process, we aimed to identify energy-conscious interventions that have added value,[19] that support the regional economy, and strengthen South Limburg's unique identity.

In South Limburg, our studies have triggered a number of developments, ranging from policy changes by the regional government to investments into biogas fermentation plants by the local farmers. The transition to sustainable energy landscapes has begun.

Figure 5-11. Impression of a sustainable energy landscape in the Heuvelland: Hedgerows are used as extensive energy crop. Profits from energy harvest can pay for the maintenance of these typical landscape elements. Single, medium size wind turbines generate electricity and sign-post the location of the historical farms in this region.

5.5 Conclusion

Transition from fossil fuels to sustainable energy requires changes which go beyond the instalation of wind turbines and PV cells. A full transition to sustainable energy requires energy-conscious (re) organization of landscapes and regions. This is because spatial organization of the physical environment not only determines *where* renewable energy is assimilated and consumed, but also influences *how much* energy is assimilated *at which quality* and at *what time*.

Despite the many benefits of renewable energy sources, is the development of sustainable energy landscapes constrained by periodic fluctuations in supply, low energy density of renewables, and the limited capacity to utilize available energies. The central research question of this paper is whether the employment of ecological and thermodynamic concepts can help to overcome these constraints and facilitate the development of sustainable energy landscapes.

19 For instance by combining energy assimilation with adaptation to climate change in the floodplains.

Both, ecology and thermodynamics provide insights that can inform energy-conscious design. Energy storage, biorhythm, and diversified systems are among the strategies that can help to mitigate *periodic fluctuations* in energy supply and demand. Localized energy systems can help to minimize losses during the transport, storage and conversion of renewable energy. Source-sink relationships and optimum system size can help to adapt the physical environment to the *low energy density* of renewables. Symbiotic networks, energy cascades, and niches can aid the optimization of *energy utilization*.

Certainly, there exist more concepts relevant to the design of sustainable energy landscapes. This paper has rendered a first selection of principles that can inform energy-conscious environmental design. In doing so, the paper adds to the growing body of knowledge on the design of sustainable landscapes. The paper also draws attention to the constraints of renewables energy. Too often, we believe, are those constraints neglected in the design of sustainable energy landscapes.

Last but not least, we like to emphasize that merely substituting fossil fuels by renewable energy is likely to compromise food production, biodiversity and scenic landscape quality. That is why environmental designers should help to develop sustainable energy landscapes, a physical environment that can be sustained on the basis of renewable energy sources exclusively. In order for a landscape to be considered sustainable, energy provision must not harm other landscape services, biodiversity or landscape quality.

Building with district heating plant and solar boilers, Urbersdorf, Austria (S. Stremke)

Prominent element of energy landscapes: High-voltage power line (Flickr, P. Musterd)

Energy and the Regional Scale

Exploring the region as scale for energy-conscious spatial planning and design[1]

6

Abstract: Sustainable energy transition becomes a key issue in the public debate and policy making. Spatial planners and landscape architects are challenged to envision sustainable energy landscapes. Such landscapes are characterized by energy-conscious organization of land-uses, effective energy networks and renewable energy sources. In this paper, it is argued that the regional scale is appropriate to design sustainable energy landscapes and identify energy-conscious interventions. Electricity, heat and biomass all play an important, yet different role in sustainable energy systems. The central question of this paper is how to conceptualize the region in the context of highly complex, layered and symbiotic energy systems? The meaning of the regional scale is explored through system theory and a case-study in the region of Southeast Drenthe, the Netherlands.

Keywords. Regional scale; system theory; sustainable energy landscape; energy conscious design

1 This chapter is based on a manuscript under review as: Kann F van, Stremke S, Koh J "Exploring the region as scale for energy-conscious spatial planning and design" *Regional Studies*

6.1 Introduction

Up until the discovery of fossil fuels, spatial organization of the physical environment and locally available energy sources were directly related. Renewable energies and landscapes were inseparable (Sieferle, 2001; Smil, 2003; Stremke and Koh, 2009). The ongoing reintroduction of renewable energy has various implications to the spatial organization of the physical environment, both in terms of energy assimilation and consumption. Within the planning and design communities, however, the discussion on energy and spatial organization is a relatively new one. So far, most research was somehow limited to energy use for commuting and its implications to city planning (e.g. Owens, 1984). This paper concerns the planning and design of sustainable energy landscapes – a physical environment that can be sustained on the basis of locally available renewable energies.

A first objective to the planner/designer of sustainable energy landscapes is the energy-conscious organization of land uses (Van Dam and Noorman, 2005; Van Hoorn et al, 2010). This is because both energy supply and demand are influenced by the spatial organization of the physical environment. A second objective is to design networks that can transport/transmit energy of different qualities (Stremke and Koh, 2009). District heating networks, for example, allow using residual heat from power plants and refineries (Cornelissen, 1997; Matsuhashi et al, 2000). A third objective is to support the assimilation of renewable energies. Both the spatial claims and the appearance of renewable energy assimilation should be taken into account. Due to lower energy densities of renewables, they are more location bound than fossil fuels (see e.g. Blatter, 2006; Ramachandra and Shruthi, 2007).

A full transition to renewable energy is expected to require several decennia and necessitates energy-conscious interventions from building scale all the way to the regional scale. Spatial planners and landscape designers are challenged both by the long-term character of such transition and the spatial complexity of sustainable energy landscapes. In the field of urban design, however, renewable energies are more and more considered (e.g. Balocco and Grazzini, 1999; Droege, 2006; Herzog et al, 1996). Over the years, energy-conscious urban design principles have been formulated in pursuit of sustainable urban development (Boelen et al, 1995; Elkin et al, 1991; Frey 1999). In the field of landscape planning and design, energy is also addressed. Historically, the focus was limited to energy conservation through vegetation and site planning (e.g. Brown and Gillespie, 1995; Robinette and McClenon, 1983; Thompson and Sorvig, 2000). Recently, the planning/design of renewable energy assimilation has become a scope to landscape architects (Motloch, 2001;

Reinke, 2008). The need to rethink spatial organization of the physical environment and to adapt to renewable energy sources has been emphasized by many (e.g. Thayer, 2008; Van Hoorn et al, 2010).

The central knowledge gap addressed in this paper relates to the regional scale. There are many calls to pursue sustainable energy transition at the regional scale (e.g. Benner et al, 2009; Dobbelsteen et al, 2008; Koh, 2005a; MO-RO-MLV, 2008). Despite the potential benefits of regional energy landscapes,[2] there are only few publications about the possible implications of the regional scale to energy-conscious planning and design. The research question of this paper is how to conceptualize the region in the context of energy-conscious planning and design. The first part of this paper discusses the regional scale by employing three concepts from system theory: open systems, optimum system size and hierarchy. The second part illustrates how these concepts have been employed to envision sustainable energy landscapes in Southeast Drenthe, a region in the North of the Netherlands (figure 6-1).

Figure 6-1. Peat landscape in the Eastern part of Drenthe, the Netherlands (S. Stremke).

6.2 Conceptualizing 'region'

How to define 'region' is a crucial question to the planner/designer of sustainable energy landscapes. Geographers, economists, and politicians all have their own understandings of what a region might be. Regions can be as large as a continent, or as small as a city and its surroundings. The scale of regional planning is considered "highly elastic" (Glasson and Marshall, 2007, p.6). In this paper, 'region' is understood as a territorial system that is part of a country and may comprise several municipalities.

6.2.1 Open system approach to regional energy planning

Cities are thermodynamically open systems, far from equilibrium state. Their future depends on the activities within city limits and the external

2 At the regional scale potentials exists to increase energy assimilation and optimize energy flows.

life-support systems providing, for example, food, water, and energy (Odum, 1992). Regions too are ‘open systems’ because they “receive causes from or generate effects to other systems” (Patten, 1978, p.206).

The energy system of any particular territory can be divided into a number of subsystems[3] with regard to energy sources, carriers and networks. Heat grids, for example, typically serve a neighbourhood or a town. Their spatial extent is limited by heat losses. Electricity grids, on the contrary, are capable of transmitting energy over longer distances without significant energy loss (see e.g. Boels et al, 1994). Nevertheless, spatial proximity of sources and sinks can reduce transportation costs and, more importantly, energy degradation (Stremke and Koh, 2008; Van Kann and Leduc, 2008).

Determining the boundaries of energy subsystems is a rather difficult task. On the one hand, geographic indicators can help defining ‘zonal regions’ (Blatter, 2006). Solar-, wind- or hydro-regions can be determined based on the hours of sunshine, wind speed and topography. On the other hand, there also exist ‘functional regions’, especially as one considers energy networks. The ‘service area’ of a power plant that is connected with consumers via the electricity grid presents a functional region. Nevertheless, many functional regions are somewhat flexible, both in size and structure depending on the kind of energy network (Boels et al, 1994). While designing sustainable energy landscapes, one has to deal with relatively open zonal and functional regions.

Another distinction has to be made based on the spatial structure of an energy system. Let us imagine an island with two possibilities to fulfill electricity demand. One option is a large biomass fired power plant which generates all the electricity needed. The electricity is distributed from one single ‘source’ to the users. Another option is a set of Combined Heat and Power plants (CHP) that run on local biomass. Both the electricity and the heat are distributed via energy networks to the users. The latter energy system is considered multinodal, the former as unimodal. From this discussion, it appears that it is useful to use energetic, geographical, functional and spatial indicators to define ‘energy regions’.

6.2.2 Optimum size of energy systems

The optimum size of energy systems has great relevance to energy-conscious spatial planning and design. This is because once the size of a system is beyond its energetic optimum (in either direction) it requires additional energy to maintain that system (Odum and Odum, 1976).

3 In Patten’s (1978) system approach theory, he conceptualized a ‘system’ as part of larger ‘supersystems’, while at the same time consisting of various ‘subsystems’. This model is referred to as ‘triadic structure’.

In this paper, optimum system size is understood as the spatial extent of a system at which energy supply and demand can be matched most effectively in space and time. Whereas a certain minimum system size is necessary to match supply and demand, unnecessary enlargement should be avoided.

The optimum size of renewable energy systems is generally smaller than fossil fuel systems. Transport distance of woody biomass, for example, is limited by the fuel needed to power trucks. The amount of energy spent for transporting an energy carrier to a centralized plant should not exceed the efficiency wins of converting energy at that plant. Biomass, in general, should be used locally due to its low-energy density (Breuer and Holm-Müller, 2006). Losses during transportation of heat and cold are particularly high (Çomakli et al, 2004). Ten's of kilometres are far more realistic compared to hundreds, or even thousands of kilometres that apply for electricity.

Considering the various energy carriers and the different modes of transportation/transmission, a picture of overlapping energy systems emerges (figure 6-2). The largest system is defined by the global distribution of coal, oil and LNG, followed by the 'service areas' of gas networks, electricity grids, biomass systems, and heat/cold grids.

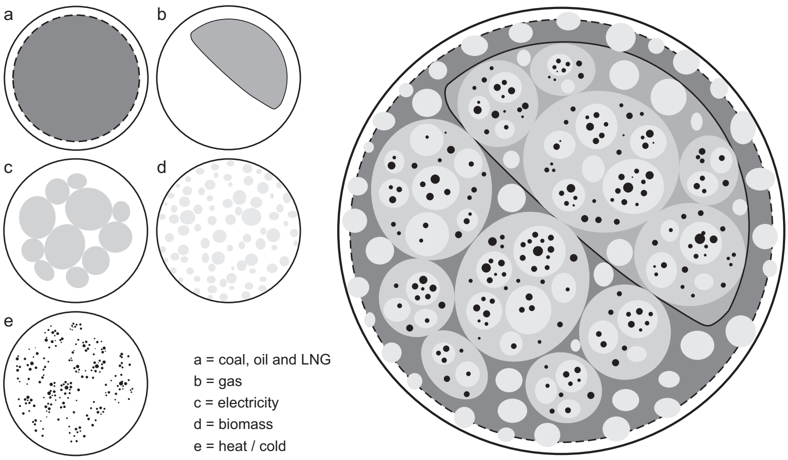


Figure 6-2. Different energy systems with relative system size. Coal, oil and LNG are distributed across the entire planet. Gas networks, on the contrary, extend only over certain parts of the planet. Electricity networks are again smaller but interconnect with each other. Second generation biomass is usually utilized within a region. Yet, heat/cold networks are smaller and extend over a neighbourhood or parts of a town.

6.2.3 Hierarchy between energy system levels

Hierarchy is the third concept of special importance to the discussion on energy-conscious planning and design. Scientists conceptualize systems as consisting of levels defined by physical or spatial structure. Each of these levels is part of a hierarchy (see e.g. Allen and Starr, 1982). The concept of hierarchy is especially useful to the understanding of regional energy systems which are part of a larger super-system and consist of various sub-systems.

Interdependencies between the various system levels can be illustrated, for example, through a CHP plant (see figure 6-3). Access to the electricity grid is a first prerequisite both for the plant and the consumers. Local conditions such as the presence of a heat network determine whether it is possible to make use of the residual heat. Without fuels it is however not possible to run the CHP. Several options exist: The plant can be powered, for instance, by biomass from landscape maintenance, households or algae production. Biogas from anaerobic digestion might be another energy input. Input/output relations of such a CHP have direct feedback in both directions, especially if the plant is powered by local renewables.

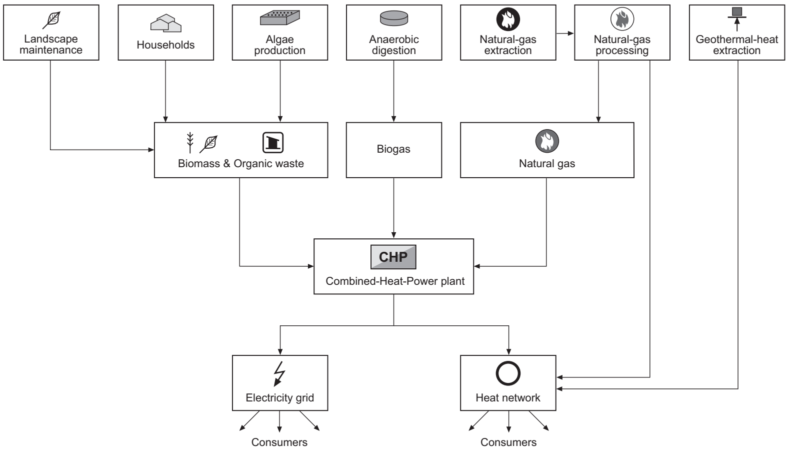


Figure 6-3. Interdependencies between the different energy system levels: energy carriers, conversion technologies, networks and consumers. Energy study for Southeast Drenthe.

Most conventional, fossil fuel energy systems have control hierarchies. There exists only limited control from the users to the utility. In some countries, however, users not only can choose between different energy utilities but can also ‘upload' energy into the networks. Hierarchy is thus also relevant to the discussion on feed-in tariffs and open-access to energy networks. Sustainable energy systems thus not only depend on the physical networks; providers of renewable electricity, bio-gas, and heat also must have the right to feed energies into grids and networks. Only if energy can travel both directions, systems can be optimized.

The following case study illustrates how the concepts of open systems, optimum system size and hierarchy have been employed in the design of sustainable energy landscapes for Southeast Drenthe, the Netherlands.

6.3 Energy region Southeast Drenthe

In the Netherlands, forty COROP-areas[4] are defined based on a nodal classification principle linked to land-use patterns (CBS, 2008). Each of those regions contains a centre (i.e. a city or a group of cities) that provides services to the entire region. Southeast Drenthe is one of the COROP-regions in the North of the Netherlands and contains three municipalities (see figure 6-4). The region also represents a provincial pilot area both for energy and climate policy. The municipalities of Coevorden and Emmen were object to a case study conducted by a group of researchers from the project 'Synergies between Regional Planning and EXergy' (SREX). Coevorden and Emmen present the focus of this part of the paper.

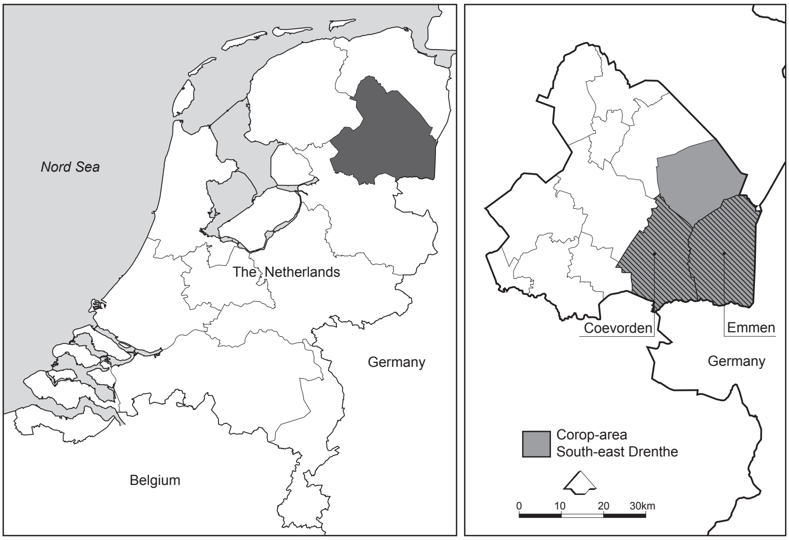


Figure 6-4. Location of the province of Drenthe in the Netherlands (left), the COROP region of Southeast Drenthe and the municipalities of Coevorden and Emmen (right).

Significant energy related features of Southeast Drenthe have been studied and mapped on a 'present energy system map' (figure 6-5). First, energy sources and sinks were localized (e.g. natural gas extraction and heavy industry). Then, energy infrastructure such as power lines, gas grids and main roads were indicated in the map. The reason for mapping the present energy system was to 'visualize' the components of this highly complex system. Although many of those energy features are not yet considered in land-use planning, they are important for the development of a sustainable energy landscape. Although the future energy system may look totally different, the planning and design process commenced with the inventory of the present energy systems as illustrated below.

4 COROP stands for *COördinatie commissie Regionaal Onderzoeks Programma*.

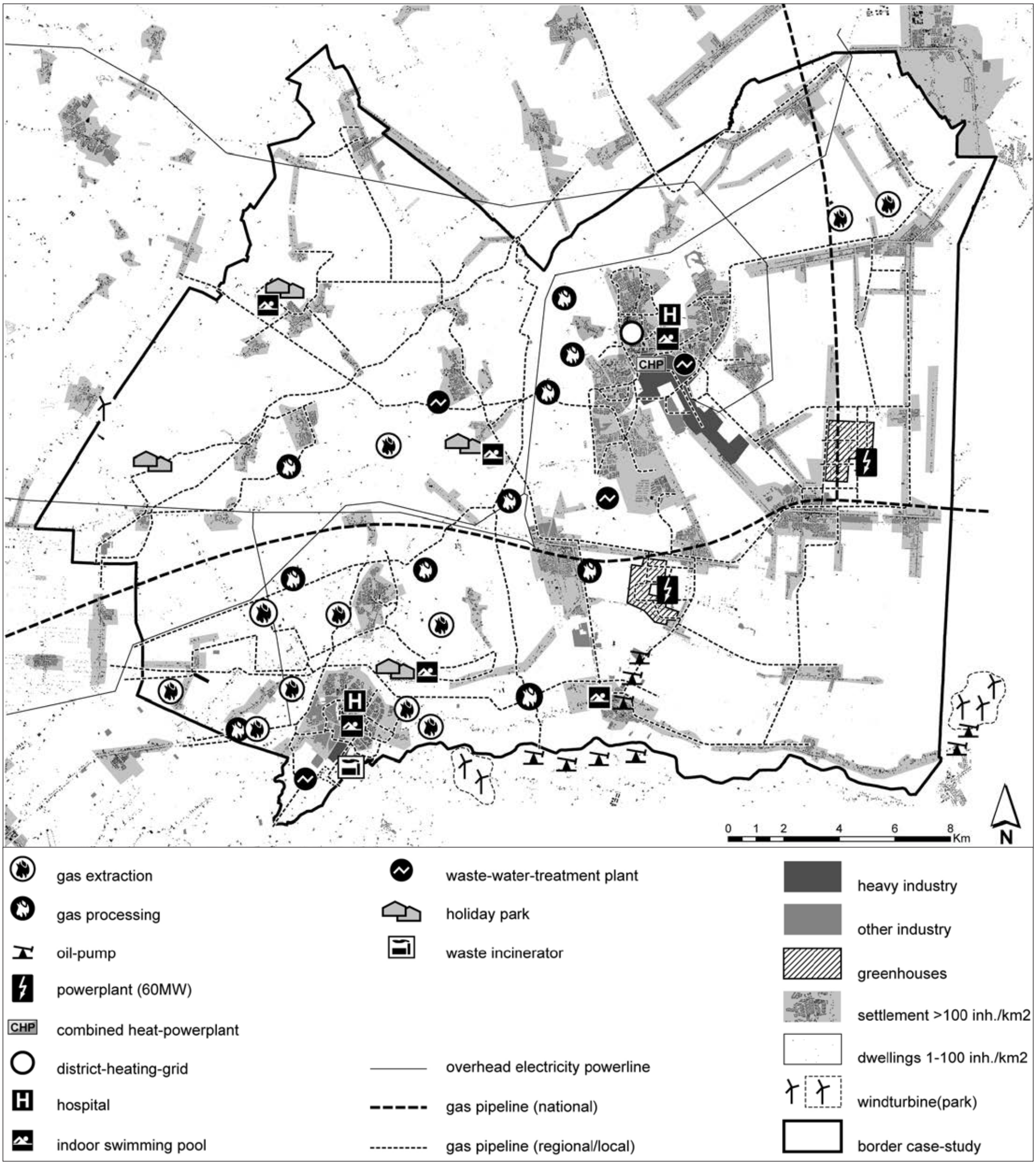


Figure 6-5. Present energy system in Southeast Drenthe.

6.3.1 Boundaries of open regional energy system in Southeast Drenthe

The region of Southeast Drenthe is open and relatively fuzzy in terms of boundaries; flows of people, information, goods, and energy both enter and leave the region. A highway and a railroad connect the region with other parts of the Netherlands and Germany. A high-voltage power line transects the region. It transmits electricity from the Eemshaven to the densely populated areas in the South of the Netherlands.

It is important to recognize that external factors influence the flows that cross the region. In Eemshaven, for example, new power plants are under construction. Electricity generated in Eemshaven will not be used locally but transmitted to other regions in the country and possibly abroad. Electricity from Eemshaven will however claim capacity of the high-voltage power line in the case study region and compete with renewable electricity from Southeast Drenthe.

Also in terms of oil and natural gas, the energy region Southeast Drenthe is open. The extraction of oil is still taking place in this region; the oil is transported through a pipeline to a refinery in Germany. Although the distance is only 35 kilometers, oil crosses the national border. Refined products such as petroleum enter the region via pipelines and trucks. A similar situation applies for natural gas. The gas that is extracted in Southeast Drenthe is transported via the gas grid of the Dutch Gasunie (Gas-Union). This nationwide grid uses high pressure to bridge long distances. Although there are regional and local gas grids with lower pressure, natural gas is injected into the national grid first and then distributed across the country.

Southeast Drenthe is physically connected with other regions in the Netherlands and across the border in Germany. The present energy system of Southeast Drenthe is an open system without strict boundaries.

6.3.2 Identifying system sizes and hierarchies in Southeast Drenthe

For energy-conscious planning and design, it is necessary to determine the spatial extent of the various energy subsystems. One could conceptualize the electricity system - that is electricity generation and transmission - as top ‘layer’ within Southeast Drenthe (see figure 6-6). The present electricity system is top-down, centralized, footloose, and stretches across the entire Netherlands. The nearest large coal and gas fired power plants are located in Eemshaven, about 80 kilometers to the North of Emmen.

When it comes to the gas networks, two perspectives have to be considered. The natural gas system extends far beyond the region of Southeast Drenthe. Gas is extracted across the Northern parts of the Netherlands and transported via an extensive network of gas pipelines throughout the country. There are however more and more initiatives to produce biogas. Because of two reasons, it is disadvantageous to transport biogas via the national gas network: (1) the biogas needs to be ‘cleaned’ before it can be injected into natural gas network, and (2) much energy is needed to pressurize biogas. The construction of new regional biogas grids, as we proposed for Southeast Drenthe, can be an alternative. This presents another argument to study energy systems at the regional scale.

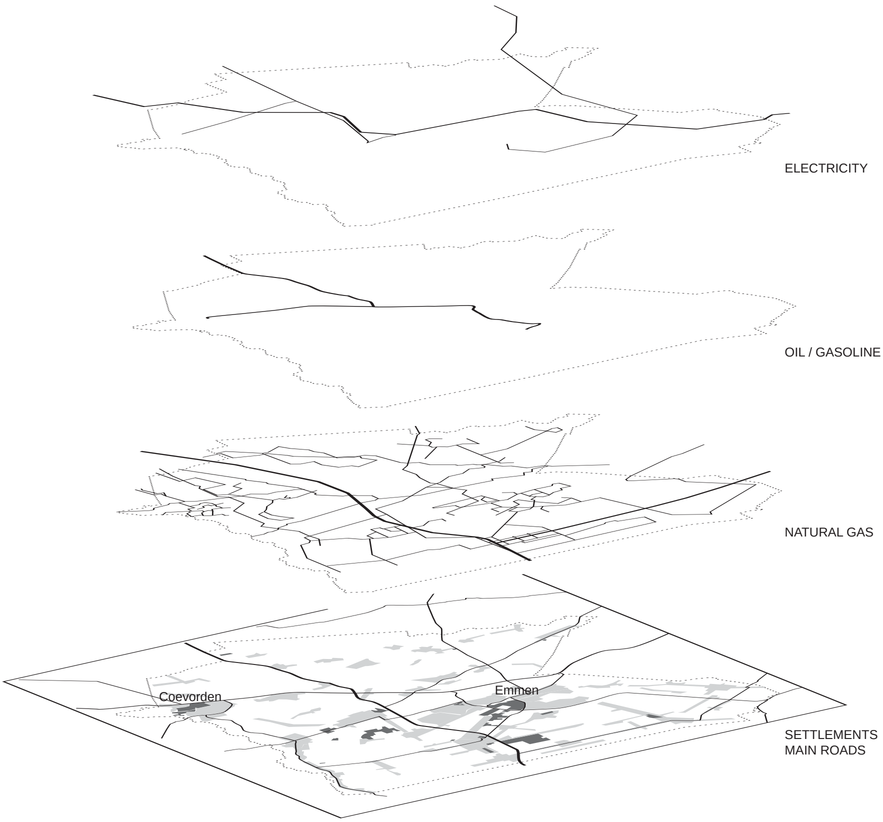


Figure 6-6. Different energy subsystems in the region of Southeast Drenthe.

Heat and cold networks represent a third type of energy networks. In a number of countries, for example Denmark, the combination of heat network and CHP is very common. Combined Heat Power means that both electricity and heat of the plant are used. CHP present an energy-efficient alternative to conventional power plants where residual heat is simply emitted into nearby water bodies or into the atmosphere. In most cases, heat grids extend over a district (district heating) or a city (urban heat network). However, heat networks exist in villages too (e.g. Urbersdorf in Austria, Jühnde in Germany). If a heat grid transports heat of different caloric values between various kinds of users, it is also referred to as 'heat cascade'. Such a heat cascade has been proposed for the city of Emmen (see figure 3-3 and chapter 3 for more information).

Finally, a certain hierarchy exists between the various, interrelated energy systems in Southeast Drenthe. On the one hand, the region contains several smaller energy systems (e.g. existing heat grid in Emmen). Some energy systems, on the other hand, operate beyond the region of Southeast Drenthe (e.g. electricity grid). The proposed low pressure biogas network and the heat cascade are far more localized. There is no single energy system; several systems coexist at different spatial scales. However, multiple interdependencies exist between those systems. The existing heat grid in Emmen, for example, is powered by natural gas that is transported to Emmen via the national and regional gas network.

6.3.3 Towards energy-conscious regional planning and design

A first important step for envisioning alternative regional energy landscapes is to map the present energy system. A second step is to map renewable and residual energy potentials. Although the case study discussed in this paper focused on the municipalities of Coevorden and Emmen, it was useful to include networks that transect the region. Such energy networks could influence, for example, the positioning of wind turbines within the region. That is because not only sufficient wind speeds are needed, but also access to high-voltage power lines.

A regional approach to the design of sustainable energy landscapes also implies looking for synergies between the different urban and rural land-uses. Both the financial and the energetic costs of energy distribution depend on the physical characteristics of a region: they may support or constrain the development of energy networks. Relevant indicators for the feasibility of energy networks include building density, age of buildings, presence of energy utilities and other energy intense functions such as greenhouses and hospitals (Boels et al, 1994). In Southeast Drenthe, one could for instance use organic waste from landscape maintenance and households to power several bio-energy villages. Excess biogas could be transported via a regional gas grid from those villages to the cities.

A regional approach to the design of sustainable energy landscapes would also imply to consider possible future developments. Both regional developments (e.g. increasing amount of greenhouses) as well as developments outside the region (e.g. new coal fired power plants in Eemshaven) affect the regional energy landscape.[5]

6.4 Conclusion

Large potentials exist to develop sustainable energy systems beyond the urban scale. In the Netherlands, more and more communities and provinces are willing to envision how sustainable energy regions could look like. The key objective of energy-conscious regional planning and

5 How to incorporate possible future developments in the design is discussed in chapter 7.

design, as envisioned in this paper, is to reveal alternative energy systems that can be sustained on the basis of locally available renewable and residual energies.

A regional approach to the design of sustainable energy landscapes can help re-establish symbiotic interrelations between urban and rural areas and consequently reduce GHG emissions. A regional approach can assist in synchronizing energy-conscious interventions that take place on various locations and at different scales. A regional approach to energy transition also has the potential to bridge the gap between (inter)national targets and local initiatives. At the regional scale, long-term strategies and short-term actions can be integrated effectively to transform today's fossil fuel depending physical environment into sustainable energy landscapes.

Energy regions are indeed open systems and each subsystem (e.g. district heat network) has a different optimum system size. The different levels of energy systems (e.g. sources, conversion devices and sinks) are however interrelated and organized hierarchically. Renewable energy potentials in particular are influenced by the physical environment. As a consequence, sustainable energy landscapes are highly localized.

As the case-study of Southeast Drenthe shows, a regional approach to the design of sustainable energy landscapes can reveal concrete energy-conscious interventions, facilitate discussions and raise the attention of key decision makers. Nevertheless, it is clear that the here proposed open multi-layered regional approach has to be further tested and refined.

In order to be effective to the development of sustainable landscapes, a regional approach has to facilitate the energy-conscious organization of land uses, the creation of effective energy networks, and the assimilation of renewable energies.

Impression peat landscape in Southeast Drenthe, The Netherlands (Flickr, G. van der Laan)

Offshore wind turbines South of Samsø, Denmark (S. Stremke)

Energy Visions at the Regional Scale

Integrated visions (I): Methodological framework[1]

7

Abstract. The growing complexity of regional planning and increasing concerns about climate change and resource depletion, have revived the discussion on strategic thinking. Spatial planning and landscape architecture compose long-term visions to facilitate the gradual transformation of the physical environment. Despite accomplishments in both disciplines, the two domains have yet to exploit the full potential of a joint approach to strategic regional planning. The objective of the multidisciplinary study reported in this paper, was to explore alternative means of composing imaginative, yet robust, long-term visions. The study is based on planning and design literature, and reflects upon the experiences we made while composing several long-term visions. This paper argues that the following three modes of change should be integrated in the design process: (a) change due to current, projected trends, (b) change due to critical uncertainties, and (c) intended change. A five-step approach to the composition of long-term visions is derived on the basis of existing approaches and illustrated in this paper. The second paper of this series centers on the application and the discussion of the five-step approach for integrated visions.
Keywords. Strategic, regional design, energy conscious, critical uncertainties, five step approach

1 Chapter based on paper: Stremke S, Kann F van, Koh J (2012) "Integrated Visions (part I): Methodological Framework" *European Planning Studies*, in press

7.1 Introduction

Climate change and resource depletion necessitate a transition towards a more sustainable built environment (IPCC, 2007; KNAW, 2007; Strong, 1992) and present new challenges to the disciplines of spatial planning and landscape architecture. Adaptation of the physical environment to a changing climate and renewable energy sources will require decennia (Smil, 2003 and 2008). Hence, it is important to consider external trends and forces (Albrechts, 2004; Börjeson et al, 2006) through the construction of long-term visions (Kunzmann, 2000; Mintzberg, 1994).

Over the past years, spatial planners have composed many visions at the regional scale. Some of which, however, tend to be overambitious (Rodriguez and Martinez, 2003) and lack realism (Albrechts, 2006a). Landscape architects too compose long-term visions (e.g. Weller, 2008), employing a design approach to regional planning (e.g. Milburn and Brown, 2003; Steinitz, 2002). Despite achievements both in spatial planning and landscape architecture, the two disciplines have yet to exploit the full potential of a joint approach to strategic regional design.

This paper is motivated by the need to further advance long-term thinking in regional planning and design. The objective is to discuss how to compose imaginative, yet realistic, long-term visions for desirable futures. In order to compose such visions, the following three modes of change should be integrated in the design process: (a) change due to current, projected trends, (b) change due to critical uncertainties, and (c) intended change. We propose a five-step methodological framework for the composition of 'integrated visions'. The framework is constructed on the basis of existing planning and design approaches, and the experiences we had while composing several integrated visions.

7.2 Method

The research reported in this paper started with a review of important planning paradigms such as rational, incremental, mixed-scanning, and strategic planning. We further studied approaches to strategic spatial planning (Albrechts, 2004) and design-oriented planning (Dammers et al, 2005). We then examined a third approach which originated from landscape planning (Steinitz, 1990 and 2002). All three methods provided important buildings blocks for a joint approach towards long-term visions. Over the past four years, we have employed this approach to compose long-term visions for the energy-conscious reorganization of two regions in the Netherlands. Both studies aimed at the development of substantial knowledge (i.e. design principles), and procedural knowledge (i.e. design process). The project team consisted of architects, urban planners, spatial planners, and landscape architects from three Dutch universities who collaborated with practitioners, decision-makers and stakeholders from the two pilot regions. The emerging approach to integrated visions was also applied in several graduate student design studios, and master's theses. Whereas the literature study provided the key building blocks for the proposed methodological framework, case studies and educational activities enabled us to test and refine the framework.

7.3 Buildings blocks from planning and design literature

7.3.1 Scenario studies and transition management

Any proposal for long-term development of a large territorial system faces a great number of uncertainties due to the trends and forces that are beyond the control of planners and designers. Despite the difficulties of planning with such uncertainties, it is important to envision a desirable future (Rosenhead, 2001) and identify actions that can help reaching that future (Albrechts, 2004). Scenario studies are a major foundation of long-term spatial planning (Hidding, 2006). According to Börjeson et al. (2006), three different types of scenarios exist: predictive scenarios (probable futures), explorative scenario (possible futures), and normative scenarios (desired future).

A desired future can be reached via different pathways. Change can be induced by drivers such as the experience of global warming - the issue is being "pushed" on the agenda. Later, incentives are established to sustain the process of change. Economical benefits, for example, are capable of "pulling" systems from present condition towards a desired future (Van den Brugge and Rotmans, 2007). If drivers and incentives prove inadequate to sustain the transition[2], systems may fail to reach a desired future (figure 7-1). What we learn from the literature on scenarios is that the future of a territorial system is not only affected by external trends and driving forces, but is also influenced through internal developments. Transition management is a relatively new discipline that is specialized in developing normative scenarios based on the study of societal changes and the evaluation of current policies.

2 Transitions are understood as transformation processes in which society changes in a fundamental way over a generation or more (Rotmans et al, 2001).

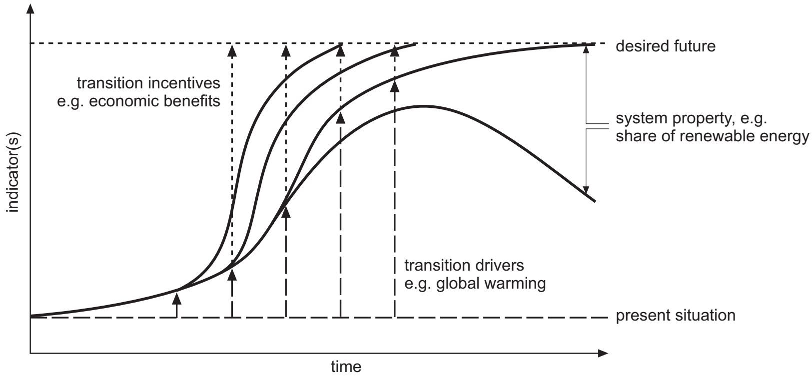


Figure 7-1. Transition scenarios: A desired future can be reached via different pathways. Both transition drivers and incentives are important. Transition may fail and the system returns to it original state (adapted from Van den Brugge and Rotmans, 2007).

7.3.2 Planning paradigms

Supporting policy development is a key objective of spatial planning. Other objectives are to influence the actions of those who shape the physical environment, and to actively involve stakeholders in the planning process (Albrechts, 2004; Healey, 1997). Among the different perspectives on spatial planning that have evolved over the past decades, we now discuss three paradigms that relate to the composition of long-term visions. They are 'rational planning' (e.g. Friedmann, 1973), 'incremental planning' (e.g. Lindblom, 1965), and 'mixed scanning' (e.g. Etzioni, 1967 and 1986).

One advantage of a rational approach to planning is the clarity about how decisions are made. Problems should be identified, goals established and alternatives carefully weighted. Rational thinking in problem analysis and goal definition is also beneficial to long-term planning. Forecasting is one of the techniques for rational decision making (Wachs, 2001). Decision-makers, however, often do not have the resources or the time necessary to collect all information required for rational choice (e.g. Verma, 1996). That is why an advanced approach to long-term visions must be flexible to be adapted to the resources available.

Flexibility is one attribute of the incremental approach to spatial planning. Incrementalists challenge the very idea of THE best solution. A series of analysis and evaluation is considered more appropriate to address problems (Lindblom, 1965). Ends and means are continuously redefined in the incremental process (Jones and Gross, 1996). Incremental approaches, however, do not account for critical uncertainties, such as societal values and technological innovation (Etzioni, 1967). Can mixed-scanning help to address critical uncertainties in long-term planning and design?

Mixed-scanning is an approach that provides explicit procedures for the collection of information and allocation of resources. Mixed-scanning differentiates between incremental and fundamental decisions, and between various levels of scanning (Etzioni, 1967 and 1986). Mixed-scanning, however, offers no explicit answer on how to address critical uncertainties in the construction of long-term visions. What is needed is an approach that can somehow join positive attributes of rational planning, incremental planning, and mixed-scanning.

7.3.3 Design-oriented planning

The objective of design-oriented planning is the spatial organization of landscapes. Design-oriented planners aim to influence the actions of those who shape the physical environment by, for example, discussing probable futures and desired futures. Design-oriented planning is concerned with long-term development at the regional scale (Carsjens, 2009).

Dammers et al. describe a 'cyclic scenario approach' to design-oriented planning (2003 and 2005). Their methodological framework consists of four steps. The planning process develops from concrete present to abstract future and back to the present (see figure 7-2). Because the cyclic scenario approach makes explicit reference to both external[3] and normative scenarios, it is described in more detail below.

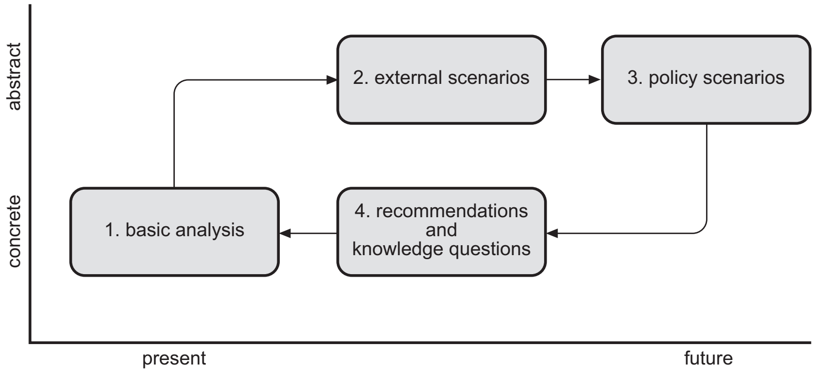


Figure 7-2. Methodological framework of the cyclic scenario approach to design-oriented planning (based on Dammers et al, 2005).

STEP 1: During the first phase of the planning cycle, the conditions in the study area are analysed next to current trends, relevant policies and programs. This can be accomplished, for example, by employing the 'multi-layer approach' (Sijmons, 2002) or the 'network-approach' (Albrechts and Mandelbaum, 2005). In addition, focal issues are identified in close collaboration with decision makers and stakeholders.

3 Often, external scenarios are referred to as 'context scenarios' because the possible future of an area is affected by forces and trends that originate in the larger context (Hanemaaijer et al, 2007).

STEP 2: In the second phase, external scenarios are developed. External scenarios render possible futures for the study region based upon the development of technological, economical, societal and other trends. STEP 3: During phase three, normative policy scenarios are developed. Policy scenarios explore alternative policy strategies and courses of action which, eventually, will result in different futures. STEP 4: During phase four, short-term and long-term actions are identified in order to support policy development. Short-term actions ought to be compatible with all scenarios. Carsjens (2009, p.61) highlights that actions that appear in all scenarios can become part of a 'master plan'. 'Contingency plans', on the contrary, illustrate actions which may only appear in one or two scenarios (also see Maack, 2001).

The cyclic scenario approach is relevant to the discussion on long-term visions for a number of reasons. First, it makes sense to focus on a number of key issues in order to identify strategic interventions (Albrechts, 2004). Second, "external and policy scenarios avoid the problem to specifically predict the future, [an approach] which is appropriate in complex situations with high degree of uncertainty" (Carsjens, 2009, p.52). Essentially, three modes of change are addressed by employing the cyclic scenario approach: (a) current, projected trends, (b) critical uncertainties, and (c) intended change through policies. One drawback of the cyclic scenario approach, from an operational perspective, is that the development of external scenarios requires substantial resources and special expertise. Employing existing context scenarios may present an alternative that we will discuss later in this paper.

7.3.4 Strategic spatial planning

Strategic planning aims to facilitate creative inquiry, and to bridge the gap between scenarios and decision-making (Carsjens, 2009). It is 'strategic' because it is "selective and oriented to issues that really matter" (Albrechts, 2006a, p.1155). The rationale of strategic spatial planning is to "frame the activities of stakeholders to help achieve shared concerns about spatial changes" (Albrechts, 2004, p.749). Sustainable development is one of the shared concerns that require a strategic approach with long-term visions (ibid.). Composing long-term visions is indeed an alternative to conventional planning because it is unlikely that a single (blueprint) plan can address the critical uncertainties and dynamics of large territorial systems.

Spatial planning comprises a set of concepts, procedures, and tools that must be tailored carefully to the situation at hand if any meaningful results are to be generated (Bryson and Roering, 1996). In this context, Healey (2009) highlights that strategic spatial planners should strive to understand the complexities of the study area, be sensitive to the location, embrace synthetic thinking, and be imaginative. Several approaches have been described in order to structure the planning process. We now elaborate on the 'four-track approach' (Albrechts, 2004) as an example from strategic spatial planning (figure 7-3).

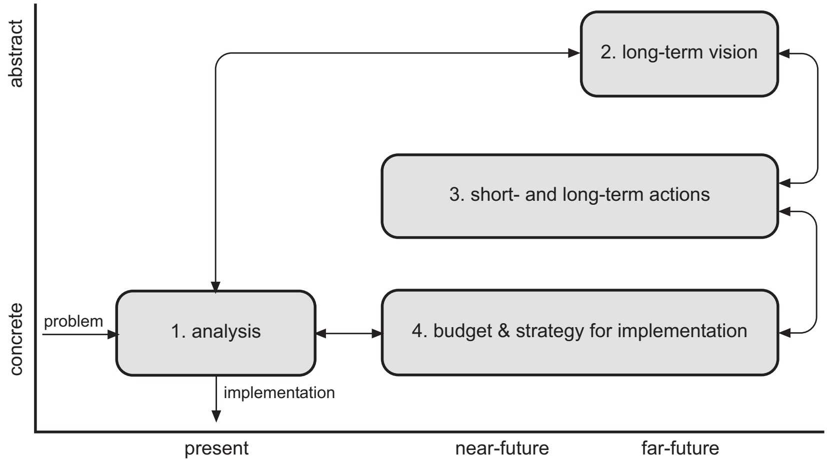


Figure 7-3. Methodological framework of the four-track approach to strategic spatial planning (after Albrechts, 2004).

STEP 1: The planning process commences with an analysis of the main processes that shape the environment. Focal issues are identified in close collaboration with local stakeholders. STEP 2: During the second phase, a dynamic, integrated, and indicative long-term vision is developed. Composing such vision is a conscious and purposive action to represent values and meanings for the future. STEP 3: In phase three, actions are deduced from the vision. The goal is to identify (a) short-term actions that can help solving present problems, and (b) long-term actions that can help reaching a desired future. STEP 4: Implementation of actions is facilitated through the creation of 'commitment packages'. Commitment packages may entail moral, administrative, and financial agreements between planners, citizen, the private sector and different levels of governance.

Generally speaking, much information can be found in the strategic planning literature on who should participate in the envisioning process (e.g. Albrechts, 2004; Healey, 1997). However, only little information exists on how to actually compose the vision. That is, in other words, how to give shape to a desired future. A great value of strategic planning, in comparison with its predecessors, is the emphasis on critical uncertainties and implementable actions as two modes of change. Literature on the four-track approach, however, makes no explicit reference to context scenario studies. Having identified a number of buildings blocks from spatial planning, we now shift the focus to the domain of landscape planning and design.

7.3.5 Landscape planning and design

Landscape architecture is a discipline concerned with the conscious shaping of the human environment. It involves planning, design and management of the landscape to create, maintain, protect and enhance places so as to be functional, beautiful and sustainable, and appropriate to diverse human and ecological needs (ECLAS, 2009). Landscape architect's scale of activities range from site design to regional planning; the time-scale from medium-term to long-term.

Among the different approaches to landscape design, we have chosen Steinitz's 'design framework' (1990 and 2002) which has been applied successfully in many regional projects.[4] The framework is organized around six questions, and should be passed through three times in any project.[5] We now discuss the six phases in sequential order (figure 7-4).

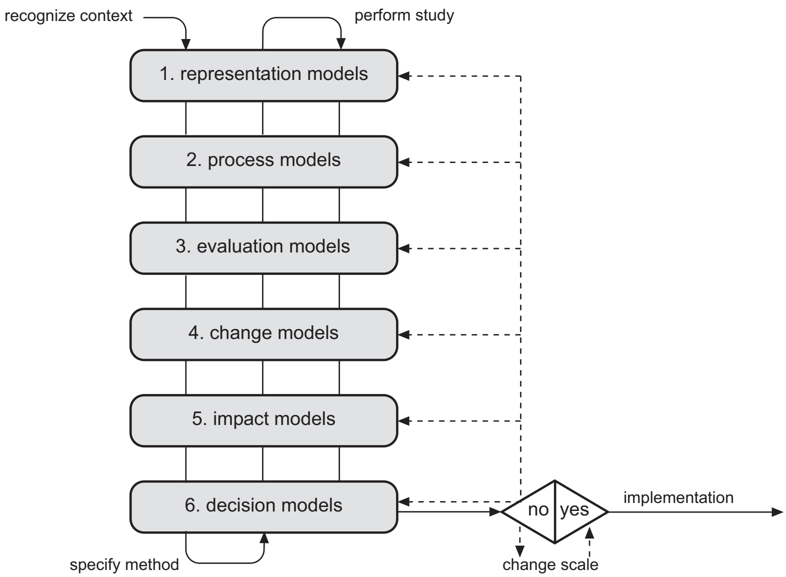


Figure 7-4. Methodological framework for landscape planning and design (after Steinitz 1990 and 2002).

4 For example, Harvard University projects "Alternative futures for the region of La Paz, Baja California Sur, Mexico" (Steinitz et al, 2006) and "Alternative futures for changing landscapes: The Upper San Pedro River Basin in Arizona and Sonora" (Steinitz, 2003).

5 During the first cycle (phase 1-6) the context and scope of the project are defined. The second cycle (phase 6-1) helps to specify the project's methods. The third cycle (phase 1-6) helps to find answers to the six stated questions (Steinitz, 2002).

STEP 1 Representation: How should the state of the landscape be described? The analysis of present conditions includes the characteristics of the study area, its boundaries, and development over time. STEP 2 Process: How does the landscape operate? Functional and structural relationships between the landscape elements are studied. STEP 3 Evaluation: Is the current landscape functioning well? The state of the landscape is evaluated and eventual dysfunctions should be identified. STEP 4 Change: How might the landscape be altered; by what actions, where and when? At least two types of change should be considered in the design process. They are (a) change by current, projected trends, and (b) change by implementable design. STEP 5 Impact: What predictable differences might the changes cause? Estimate the impact of interventions, and compare them with one another. This phase is based on predictive theory, similar to the study of probable futures. STEP 6 Decision: Should the landscape be changed? This phase focuses on how a comparative evaluation of the impacts of alternative changes ought to be made.

7.3.6 Building blocks towards alternative approach

All three frameworks discussed heretofore provide building blocks for an alternative approach to long-term visions. We now compare the cyclic scenario approach, the four-track approach, and the design framework (also see table 7-1).

All three approaches, to begin with the similarities, aim to support decision-making. The first three steps of the design framework correspond to a great extent with the ‘analysis phase’ of the two planning frameworks. The identification of dysfunctions (third step design framework) may be comparable with the selection of focal issues (first step planning frameworks). The estimation of the impact of alternative interventions, suggested by Steinitz, is similar to the evaluation of policy strategies suggested by the planners.

One substantial difference between the three frameworks is that Steinitz (2002) and Albrechts (2004) make no explicit reference to the use of external scenarios. Dammers et al. (2005), on the contrary, suggest the development of context scenarios as part of the planning process. Strategic spatial planners, generally speaking, recognize the significance of external trends and forces that influence the future of a study area (e.g. Friedmann, 2004). In this context, Rosenhead states “strategic planning cannot be firmly based on an attempt to predict what will happen […] identifying a range of versions what might happen, would be a modest and supportable basis for planning analysis” (2001, p.185).

We adopt a similar approach to long-term regional design; critical uncertainties should be integrated in the design process. One critical uncertainty, to name one example, is whether globalization will continue in the future, influence land-use patterns in the study region and consequently affect the development of sustainable energy landscapes. The three 'modes of change' that need to be addressed in the design process are thus (a) change due to current, projected trends, (b) change due to critical uncertainties, and (c) intended change.

Table 7-1. Comparison between the cyclic scenario approach, the four track approach, and the design framework

	Cyclic scenario approach (Dammers et al, 2005)	**Four-track approach** (Albrechts, 2004)	**Design framework** (Steinitz, 2002)
Initial steps	**Basic analysis** - analyse present situation, trends, and policies - identify focal issues	**Analysis** - analyse main processes that shape environment - agenda setting	**Representation** - analyse conditions **Process** - study relationships **Evaluation** - identify dysfunctions
First mode of change: change due to current, projected trends	*Analysis of current trends is part of analysis*	*No explicit reference to current, projected trends*	**Change caused by current trends** - identify trends
Second mode of change: change due to critical uncertainties	**External scenarios** - compose scenarios to identify possible futures	*No explicit reference to external scenarios*	*No explicit reference to external scenarios*
Third mode of change: intended change	**Policy scenarios** - explore alternative policy strategies	**Long-term vision** - represent values and meanings for the future	**Change caused by implementable design** - describe interventions
Final step	**Recommendations and knowledge questions** - support development of policy strategies - masterplan with short-term actions - contingency plan with long-term actions	**Short-term and long-term actions** - short-term actions to solve present problems - long-term actions to achieve desired future **Budget and strategy for implementation** - facilitate creation of commitment package	**Impact** - estimate impact of alternative interventions **Decision** - support decisionmaking process

7.3.7 Prerequisites for an alternative framework

Complex and highly dynamic issues such as climate change and resource depletion challenge the way we plan and design the physical environment. Spatial planners, on the one hand, embrace scenario thinking but little information can be found on how to give shape to a desired future. Landscape architects, on the other hand, may possess the skills to design a desirable physical environment but fail to incorporate critical uncertainties in the design process. For an alternative approach to the composition of long-term visions, we believe, a number of prerequisites must be met. The framework should:

- Be *flexible* to be adjusted to the locality and resources (Jones and Gross, 1996).
- Facilitate development of *context- and area specific solutions* (Healey, 2009).
- Enable *active participation* of stakeholder in envisioning process (Healey, 1997).
- Be *transparent and explicit* about rational/normative steps (Albrechts, 2004).
- Integrate change due to *current, projected trends* (Steinitz 1990).
- Integrate change due to *critical uncertainties* (Dammers et al, 2003).
- Help composing *alternative proposals* rather than a single masterplan.
- Allow making use of *existing scenario studies* (see e.g. Jäger et al, 2007).
- Help to identify *innovative & robust* interventions (see e.g. Albrechts, 2006a).
- Enable *evaluation of robustness* of interventions (see e.g. Rosenhead, 2001).
- Avoid closing off *future options* (Hyslop in Friedmann, 2004).

Composing integrated visions, as Friedmann noted, is "probing the future in order to make more intelligent and informed decisions in the present" (2004, p.56). We now turn to the question of how to organize the different buildings blocks towards a coherent approach for the composition of integrated visions.

7.4 Methodological framework for integrated visions

Albrechts pointed out that in order "to construct visions for the future we need both the solidity of the analysis that seeks to discover a place that might exist and the creativity of the design of a place that would not otherwise be" (2006a, p. 1160). The framework proposed here aims to facilitate the composition of imaginative, yet realistic, long-term visions at the regional scale. We suggest integrating (a) near-future developments, (b) possible far-futures, and (c) change by implementable design in the envisioning process. Those three 'activities' are complemented by an analysis of the study region and an evaluation of possible interventions (figure 7-5).

The methodological framework is organized around a set of five questions, each one subject to one step of the envisioning process. The sequence of five steps should be passed through twice. During the first cycle, the context and scope of the study are defined. Also, maps and data are gathered, stakeholders and decision-makers invited to participate in the study. During the second cycle, the actual visions are composed. Although, the framework consists of five consecutive steps, the envisioning process is iterative. It may be necessary to return to an earlier step in order to fully answer all questions. If necessary, certain steps can be more elaborated than others - the framework thus can be adapted to the time and resources available. Table 7-2 presents an overview of the five steps and the respective means of representation. We now describe the five steps in detail.

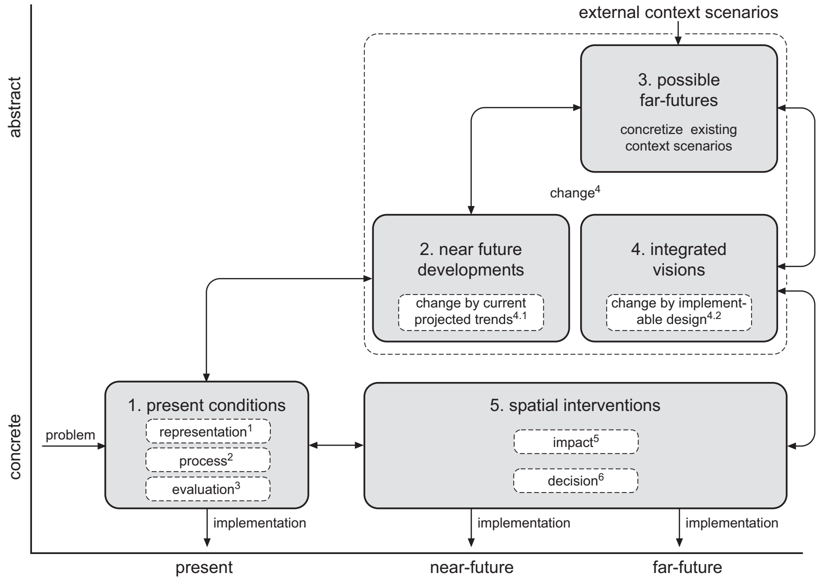


Figure 7-5. Methodological framework of the five-step approach for integrated visions. White boxes and superscript numbers refer to the design steps as described by Steinitz (2002) and illustrated in figure 7.4.

7.4.1 Analysing present conditions

The first step centers on the question "how does the present region function and how can it be evaluated in comparison with other regions?" In order to compose integrated visions for sustainable energy landscapes, it is necessary to analyse both the landscape and the present energy system. In addition, renewable energy potentials should be identified and illustrated (see e.g. Dobbelsteen et al, 2007; Nielsen et al, 2002; RPLS, 2007). The analysis of present conditions can best be conducted by a multidisciplinary team consisting of planners, designers, experts on the focal issue of the study, and experts from the study region.

7.4.2 Mapping near-future developments

The guiding question of the second step is "how will the region change in the near-future?" In order to answer that question, one needs to analyse current, projected trends and policies, and consult key decision-makers in the study region. This way, one can reveal, for example, where land is being set aside to expand ecological corridors. Near-future developments are depicted in the so-called 'near-future base-map'.[6] Many of the developments illustrated in this map may have not yet left any marks in the environment but will influence long-term development of the region.

6 Examples of the different maps are presented in the second paper of this two-part series (chapter 8).

7.4.3 Illustrating possible far-futures

The guiding question of step three is “what kind of possible long-term developments (at which location) are expected in the study region?” A range of possible far-futures can be illustrated with help of existing national and regional scenario studies (in the Netherlands e.g. Hanemaaijer et al, 2007; Engelen et al, 2006). The more explicit a scenario study is, the easier it is to concretize and map possible developments. Each scenario storyline (e.g. Global Market scenario) is illustrated with help of a ‘scenario base-map’. Rational analysis of existing context scenarios and illustration of possible far-future changes can be conducted by experts and verified by the stakeholders.

7.4.4 Composing integrated visions

The objective of step four is to compose a set of integrated visions. Each of those visions is supposed to reveal “how to turn a possible future into a desired future?” That question, of course, can be further specified to meet the focal issue of the study. Integrated visions do not aim to render THE ideal future; rather they reveal different pathways of reaching a desired future. Each vision thus identifies possible interventions under the conditions established by the respective scenario. In order to identify a wide range of possible interventions and maintain a sense of realism, we suggest conducting this normative step in a transdisciplinary manner. Workshops and design charettes can facilitate the collaboration between experts, decision-makers and stakeholders.

7.4.5 Identifying spatial interventions

The final question of the five-step approach is “which possible intervention should be implemented?” Possible spatial interventions need to be identified and listed in a comprehensive manner. Tables and reference images are also helpful in the discussion with decision-makers. Another task is to assess the robustness of possible interventions, for instance through comparative analysis of the different visions. The robustness of an intervention is considered high when it appears in multiple visions. Robust interventions can be implemented in the short-term because they are less depending on critical uncertainties (also see Carsjens, 2009). Often, however, less robust interventions are necessary to perform a full transition to a desired future (e.g. 100 percent renewable energy). Both robust and less robust interventions need to be considered in decision-making. If resources allow, interventions can be further examined employing methods such as ‘strategic choice approach’ (Friend, 2001) and ‘robustness analysis’ (Rosenhead, 2001).

Table 7-2. Five-step approach: Overview of activities and respective means of presentation. Example from study on integrated energy visions for Margraten, presented in chapter 8

Step	Activity		Representation
1	Analysing present conditions	Landscape characteristics	Topographic map Land-use map Infrastructure map
		Present energy system	Energy provision map Transport, conversion & storage Energy consumption map
		Renewable energy potentials	Solar energy map Wind power map Hydro power map Biomass map Heat-cold storage map Geothermal energy map
2	Mapping near-future developments		Near-future base-map
3	Illustrating possible far-futures	Four scenario base-maps	Global Market base-map Secure Region base-map Global Solidarity base-map Caring Region base-map
4	Composing integrated visions	Four energy visions	Global Market energy vision Secure Region energy vision Global Solidarity energy vision Caring Region energy vision
5	Identifying spatial interventions	Energy-conscious interventions	Table, text and reference images for possible interventions

7.5 Conclusion and outlook

Climate change and resource depletion challenge the way we plan and design the physical environment. Adaptation to climate change and renewable energy sources requires long-term thinking and strategic decision-making. The far-future of large territorial systems, however, depends on critical uncertainties and is considered rather unpredictable. Yet, a range of possible futures can be explored through scenario studies.

In this paper we presented an approach that allows integrating context scenarios in the design process. In fact, three modes of change are considered in order to compose imaginative and yet realistic visions. They are (a) change due to current, projected trends, (b) change due to critical uncertainties, and (c) intended change. The proposed approach consists of building blocks from both strategic planning and landscape design theory. The design process commences with the analysis of present conditions in the study region. Today's physical reality is however not the only 'starting point'; current, projected trends and critical uncertainties too are integrated. Consequently, a set of visions is composed, each one based on one context scenario. Each of the visions depicts one desired future and identifies interventions that can help realizing that future.

The objectives of the five-step approach are to identify possible interventions, to facilitate commitment packages, and to support the development of strategic policies. Employing the five-step approach does not necessarily lead to a spatial plan in the conventional sense. Rather, it results in a set of integrated visions, and a list of possible spatial interventions. These interventions can be illustrated with the help of reference photographs and photomontages. Empirical data such as the relative assimilation of renewable energy of each possible intervention can further facilitate decision-making.

In the second paper of this two-part series, we illustrate the application of the five-step approach for the envisioning of sustainable energy landscapes. There we also discuss the five-step approach with respect to the prerequisites listed earlier in this paper (section 7.3.7). Both papers, we hope, contribute to the discussion on strategic regional planning in general and sustainable energy landscapes in particular.

Impression rural landscape in Southeast Drenthe, The Netherlands (Flickr, G. van der Laan)

Heuvelland with historical wind mill, South Limburg, The Netherlands (S. Stremke)

Energy Visions for Margraten

Integrated visions (II): Envisioning sustainable energy landscapes[1]

8

Abstract. Climate change and resource depletion motivate the transition to renewable energy sources. The assimilation of solar energy, hydro- and wind power results in new space claims. Both the supply and the demand of energy is influenced by the physical environment and therefore concerns spatial planning and landscape design. To envision and facilitate the development of sustainable energy landscapes presents a new challenge to spatial planners and landscape designer. The first paper of this two-part series discussed several existing approaches to long-term regional planning and landscape design, and presented an alternative approach for the composition of integrated visions. This paper, firstly, illustrates how a set of integrated visions has been created for a large municipality in the South of the Netherlands. Secondly, it examines the proposed five-step approach with respect to a set of criteria discussed in the planning and design literature.
Keywords. Strategic, regional design, case-study, energy conscious, critical uncertainties, five-step approach

1 Chapter based on paper: Stremke S, Koh J, Neven K, Boekel A, Koh J (2012) "Integrated visions (part II): Envisioning sustainable energy landscapes" *European Planning Studies*, in press

8.1 Introduction

Climate change and resource depletion motivate a transition from fossil-fuels towards sustainable energy systems which are “cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks” (Hepbasli, 2008, p.598). More than half of the energy demand in the developed world is affected by the spatial organization and distribution of land uses (Owens, 1990). The assimilation of renewable energy claims space and contributes to increasing land-use pressure (Boyle, 2004). Both the demand and the supply of energy influence the physical environment and thus concern spatial planning and landscape design.

Design-oriented planning, strategic spatial planning, and landscape design offer different approaches to long-term transformation of large territorial systems. Many design-oriented planners employ scenario thinking. They integrate both current, projected trends and critical uncertainties in the planning process (see e.g. Dammers et al, 2005). Proponents of strategic spatial planning emphasize the importance of long-term visions (Albrechts, 2004 and 2006a). Landscape architects too compose visions for long-term transformation of regions (see e.g. Weller, 2008). Commonly, they integrate current, projected trends and implementable change in the design process (see e.g. Steinitz, 2002). To the best knowledge of the authors, however, no comprehensive framework is available that embraces all three modes of change: (a) change due to current, projected trends, (b) change due to critical uncertainties, and (c) implementable change.

In the first paper of this two part series, we argued that integrating those three modes of change in one approach can facilitate the composition of imaginative, yet robust, long-term visions. We also discussed several existing approaches to long-term planning and design and proposed a ‘five-step approach’ for the composition of integrated visions. The paper at hand illustrates how this approach has been employed to envision sustainable energy landscapes for the municipality of Margraten, the Netherlands (see figure 8-1). The method of the study is described in section 8.2; findings are summarized in section 8.3. In section 8.4, we examine the proposed approach with respect to a set of criteria discussed in the planning and design literature. The paper is concluded in section 8.5.

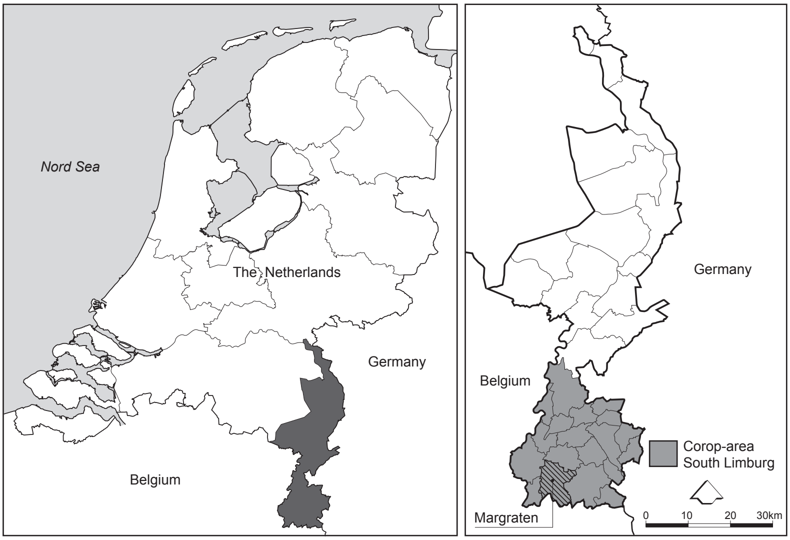


Figure 8-1. Location of the province of Limburg in the South of the Netherlands (left map). Municipality of Margraten located in the South of Limburg (right map).

8

8.2 Method

The study presented here employed an approach that is organized around five steps: (1) analysing present conditions, (2) mapping near-future developments, (3) illustrating possible far-futures, (4) composing integrated visions, and (5) identifying spatial interventions (see figure 8-2). The process was iterative, the framework passed through twice. During the first cycle, the context and scope of the study were defined, maps and data were gathered. In addition, stakeholders and decision-makers were invited to participate in the study. During the second cycle, sustainable energy landscapes were envisioned and energy-conscious interventions identified.

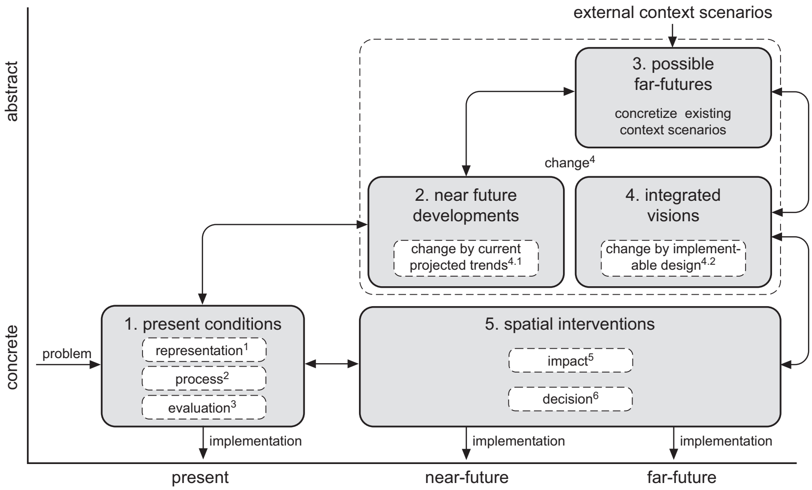


Figure 8-2. Methodological framework of the five-step approach to integrated visions.

Figure 8-3. Design charette during the first workshop in Limburg, October, 2007 (A. Boekel).

Stakeholders, decision-makers, energy experts, architects, urban planners, spatial planners and landscape architects participated in the larger study for the entire region of South Limburg (see figure 8-1). Cooperation was facilitated through excursions, interviews and design charettes (figure 8-3). This paper, however, focuses on a study for the municipality of Margraten, which is part of the province of Limburg. In that study, the authors collaborated with representatives from the municipal council, various NGOs, and local farmers. We now briefly summarize the activities of each of the five steps towards the integrated visions.

STEP 1: Analysing present conditions

During the initial phase, we studied "how does the present region function, and how can it be evaluated in comparison with other regions?" Since this study dealt with the development of sustainable energy landscapes, both the present energy system and the landscape were analysed. In addition, we mapped renewable energy potentials.[2] The present conditions in Margraten were analysed by a team of landscape architects and local experts. Please note that table 8-1 presents an overview of the five steps of the approach and respective means of representation.

STEP 2: Mapping near-future developments

The second guiding question was "how will the region change in the near-future?" In order to answer that question, we analysed current, projected trends and policies. Near-future developments such as the expansion of the ecological network in Margraten were mapped on the

2 Since there is no heavy industry/power plant in Margraten, residual heat potentials can be neglected.

basis of the 'new map of the Netherlands' (RPB, 2008), the 'provincial environmental plan' (Province of Limburg, 2001), the 'landscape vision South Limburg' (Kerkstra et al, 2007), and the 'land-use plan for Margraten' (Margraten, 2008).

STEP 3: Illustrating possible far-futures

The third guiding question was "what kind of possible long-term developments (at which location) are expected in the study region?" Possible far-futures were illustrated on the basis of a national scenario study (Hanemaaijer et al, 2007) and a provincial scenario study (Engelen et al, 2006). The four studied scenarios were the Global Market, Secure Region, Global Solidarity, and Caring Region scenario (figure 8-4). We then concretized and illustrated the four scenario plots by means of reference images, storylines and a set of 'scenario base-maps'. In the process, we had to decide which parts of the scenario studies are relevant for Margraten. This is because not all the possible far-future developments rendered in the context scenarios have consequences for this part of South Limburg.[3]

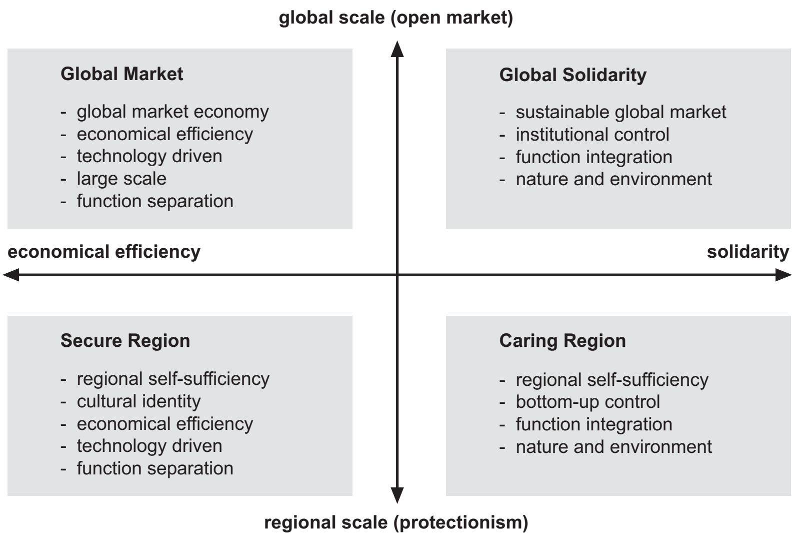


Figure 8-4. Scenario matrix for the Netherlands and the Province of Limburg (based on Engelen et al, 2006; Hanemaaijer et al, 2007).

STEP 4: Composing integrated visions

The objective of phase four was to compose a set of integrated visions. Each of the four visions aimed to reveal "how to turn a possible future (i.e. context scenario) into a desired future?" For the Margraten study, we

3 The provincial scenario study, for example, describes the possible development of large-scale pig farms of Limburg. Due to the absence of highways, railroads and waterways in Margraten, it is unlikely that such 'mega-farms' will be constructed in the municipality.

composed visions at the scale 1:10.000. Each vision illustrates a sustainable energy landscape that can be developed under the conditions established by the respective context scenario. Relative shares of renewable energy provision were computed for each possible intervention. Close collaboration between stakeholders and specialists helped to maintain a sense of realism while envisioning sustainable energy landscapes. At the same time, insights from local experts helped to reveal a wide range of possible interventions.

STEP 5: Identifying spatial interventions

During the final phase of the study, we investigated "which possible intervention should be implemented?" Possible energy-conscious interventions were listed, and their robustness evaluated. If an intervention appeared in multiple visions, it is considered relatively robust in comparison with interventions that only appeared once. The robustness of energy-conscious interventions was assessed in close collaboration with stakeholders. At times, the stakeholders indicated area-specific constraints that could complicate realization of certain interventions. However, they also brought forward innovative solutions that can help realizing other interventions. Finally, the results of the study were presented and discussed with stakeholders and decision-makers in Margraten.

Table 8-1. Overview of activities and respective means of presentation for the study

Step	Activity		Representation
1	Analysing present conditions	Landscape characteristics	Topographic map Land-use map Infrastructure map
		Present energy system	Energy provision map Transport, conversion & storage Energy consumption map
		Renewable energy potentials	Solar energy map Wind power map Hydro power map Biomass map Heat-cold storage map Geothermal energy map
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4	Composing integrated visions	Four energy visions	Global Market energy vision Secure Region energy vision Global Solidarity energy vision Caring Region energy vision
5	Identifying spatial interventions	Energy-conscious interventions	Table, text and reference images for possible interventions

8.3 Envisioning sustainable energy landscapes for Margraten

We now present the results of the Margraten study in sequence with the five steps. In order to illustrate the findings of all five phases (within the constraints of this paper) we focus on interventions that relate to wind power. Section 8.3.5 holds a summary of all interventions.

8.3.1 Present conditions

Landscape characteristics: In the Netherlands, a number of unique cultural landscapes are protected by law. The municipality of Margraten lies within the 'Heuvelland National Landscape'. The four core qualities of the Heuvelland are: (a) the contrast between enclosed and open landscapes, (b) a green character, (c) a unique topography, and (d) a rich cultural history (Kerkstra et al, 2007). Large parts of the municipality lie on a plateau though the height difference between plateau and valleys is less than 100m (figure 8-5). The municipality extends over an area of 58km^2; major land uses are arable land, pasture, forest, and settlements (figure 8-6 and table 8-2).

Figure 8-5. Typical valley of the 'Heuvelland National Landscape' in Limburg (S. Stremke).

Present energy system: About 98% of the energy in Limburg is imported; only five percent of all energy is derived from renewable sources (CBS, 2008). Energy consumption of the 13.500 inhabitants in Margraten amounts to approximately 110 TJ of natural gas equivalents and 14 GWh of electricity per year.[4] Natural gas is distributed via regional and local gas grids. High-voltage power-lines and petrol stations are present just outside the municipal border. Margraten is highly depending on the import of energy from other parts of the Netherlands and abroad. About 95% of the energy is currently supplied from non-renewable sources. The energy system is unsustainable, both in terms of self-sufficiency and energy sources.

4 Calculation of energy consumption in Margraten is based on average per capita energy consumption in the Netherlands (CBS, 2008).

Renewable energy potentials: South Limburg has relatively high potentials for wind energy, especially on the plateaus of the Heuvelland. The average wind speed 100m above the plateaus is between 7 and 8 meter per second. In spite of these potentials, only a single historical wind mill can be found in the municipality. The absence of wind turbines is partly due to legal restrictions; current legislation constrains the construction of large-scale wind turbines. Across the border with Germany, however, wind parks are omnipresent. Also in neighboring Belgium, similar landscape characteristics and wind turbines coincide.

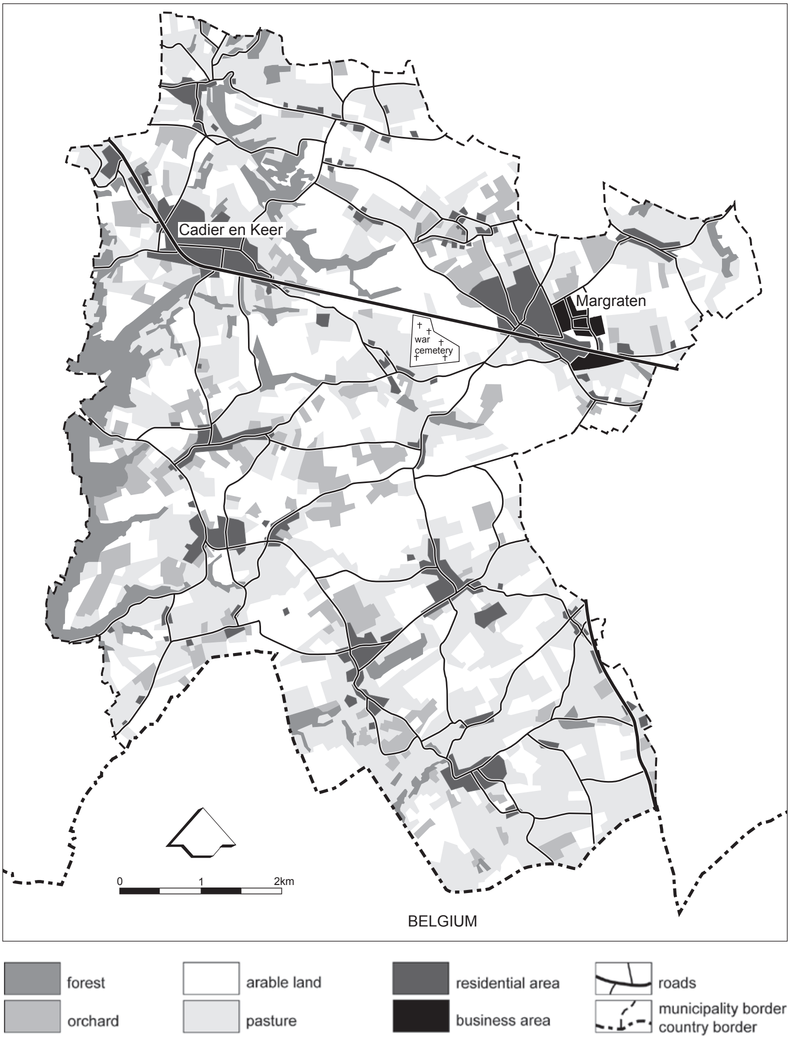

Figure 8-6. Map of major land uses in the municipality of Margraten.

8.3.2 Near-future developments

Plans exist to expand the forest area in the municipality of Margraten by 26%. Residential areas and natural grasslands are expected to expand at the expense of pasture and arable land (RPB, 2008; Margraten, 2008; Kerkstra et al, 2007). Planned land use changes were mapped and quantified (see table 8-2). Based on the available planning documents, we concluded that near-future developments will have a marginal effect on the exploitation of wind energy. The construction of wind turbines could be constrained by new forests because sufficient distances must be maintained between turbines and forests (see e.g. Pasqualetti et al, 2002).

Table 8-2. Planned land use changes in Margraten. Numbers based on RPB (2008), Margraten (2008), and Kerkstra et al. (2007)

land-use type	size area now	relative share	planned change	relative change
forest	555 ha	10%	+142 ha	+26%
residential area	241 ha	4%	+16 ha	+7%
pasture	2.106 ha	36%	-214 ha	-10%
arable land	2.433 ha	42%	-214 ha	-9%
other land uses	465 ha	8%	+270 ha	+58%

8.3.3 Possible far-futures

How Margraten may change in the far-future is described in several scenario studies (e.g. Hanemaaijer et al, 2007). A provincial scenario study (Engelen et al, 2006) offered the most explicit storylines which we further concretized as shown below.

Global Market scenario: The first scenario is characterized by continuous globalization and liberalization. Economy is capitalistic and market oriented. Citizens are individualistic and the welfare state is deteriorating. In Margraten, pasture and arable land will remain the largest land uses. The current trend of scale enlargement continues and results in even larger farm plots. Consequently, the number of farms decreases while the remaining farms grow to mega farms (between 200 and 300ha each). The cities of Maastricht (The Netherlands) and Aachen (Germany) strengthen their position as economical centers in the larger region. The regional road N278 between Maastricht and Aachen is turned into a highway. In the Global Market scenario, a bypass will be built around the village of Margraten, increasing traffic flow and creating favorable locations for building developments (see figure 8-7).

Secure Region scenario: In the second scenario, globalization comes to an end and the world divides into protectionist regions. Cultural identities are important and regions strive for self-sufficiency. In the Secure Region scenario, the ratio of land uses in Margraten is not expected to change significantly. The number of farms, however, decreases due to further economic optimization. Many farms within or near the villages lose their agricultural functions. Business areas expand and dwellings are built to fulfill the demand for high-quality housing. Forests are planted near settlements for recreational purposes.

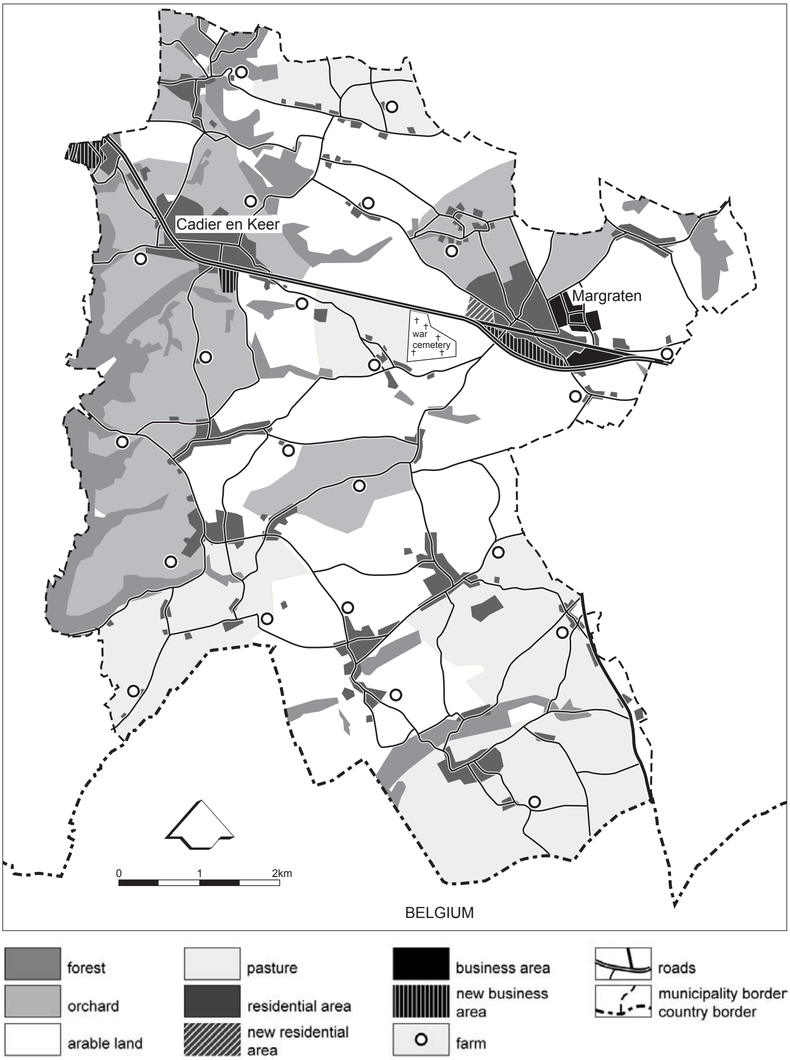

Figure 8-7. Base-map for Global Market scenario illustrating possible far-future developments in the municipality of Margraten (e.g. highway bypass, new residential and business areas).

Global Solidarity scenario: In the third scenario, sustainable development takes place at the global scale. Governments, businesses, and citizens pay special attention to environmental quality and social equity. In Limburg, a strong provincial government enforces the status of the Heuvelland as protected landscape and the area develops into an extensive recreation park. The core qualities of the Heuvelland National Landscape are strengthened. Topography, for instance, is accentuated by forest plantations along the slopes. Existing landscape elements are well preserved and maintained by the local farmers. Landscape maintenance, organic farming, and recreation offer new sources of income. Construction of new dwellings is prohibited in the municipality, except for a sustainable housing development near the village of Margraten.

Caring Region scenario: The fourth scenario is characterized by a significant decrease in international trade of goods, materials and energy; protectionism prevails. Regions strive to improve social equity and environmental quality while increasing self-sufficiency. In Margraten, landscapes do not change much. The typical landscape elements such as hedgerows are maintained by farmers. Some farmers practice organic farming. In this scenario, farms are being turned into centers of rural living. Farmers offer recreational activities and sell local products. New business parks do not develop in Margraten. High energy and material standards apply for new dwellings. Local food production, material provision, and energy assimilation all contribute to an increasing land-use pressure in the Caring Region scenario.

8.3.4 Integrated energy visions

On the basis of the above storylines and scenario base-maps, we then studied how to turn each of the four possible futures into a desired future - a sustainable energy landscape. Each of the following four integrated visions identifies energy-conscious interventions under the conditions established by the respective context scenario.

Energy vision for the Global Market scenario: In the first, economy-driven scenario, landscape quality is of little importance. Since our study, however, concerned the transition to *sustainable* energy systems, we tried to minimize adverse effects of renewable energy assimilation both to the inhabitants and the natural environment. The Global Market energy vision for Margraten proposes the construction of a wind park on the plateau with the highest wind speed (see figure 8-8). Such a wind park can be accepted from a landscape quality point of view because the most attractive parts of the municipality lie in the brook valleys. The wind park, however, sits on the plateau and is not visible from the valleys. Turbines are configured according to state-of-art design guidelines (see e.g. Twidell and Weir, 2006). The park consists of 30 turbines (120m high) that generate about 120 GWh of electricity each year. Electricity provision exceeds the local demand of 14 GWh severalfold. Surplus electricity can be transmitted to the nearby cities of Maastricht and Aachen.

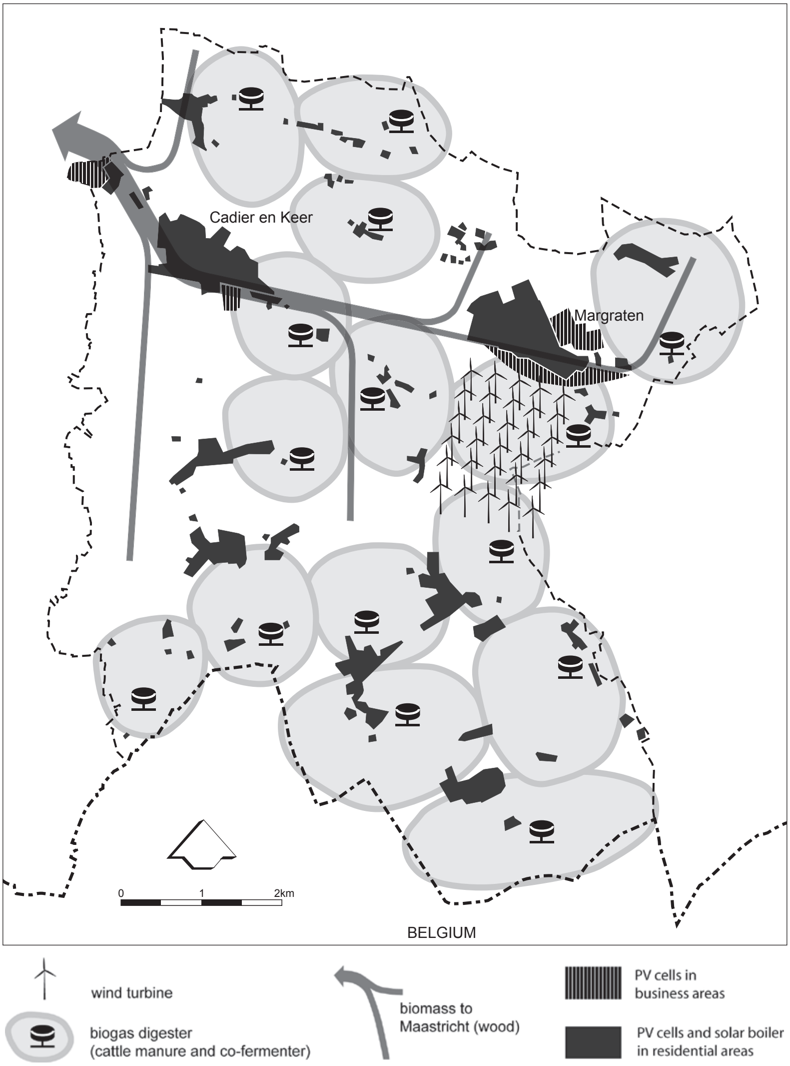

Figure 8-8. Energy vision for the Global Market scenario indicating the location of a wind-park and other energy-conscious interventions in the municipality of Margraten.

Energy vision for the Secure Region scenario: Main objective of this energy vision was to reduce dependency on energy import while preserving the regional landscape qualities. Moreover, the distinct identity of the Heuvelland had to be maintained and if possible strengthened. The Secure Region energy vision suggests 'connecting' the assimilation of wind energy with two business parks and the regional road traversing the municipality. Both, at the Western and Eastern entrance to the municipality, medium sized wind turbines (60m high) are located in proximity to existing business parks. These turbines are 'scale compatible' with the factory and office buildings. Turning turbines into a prominent 'energy landmark' can help enhancing the identity of

Margraten; especially as they are located near the two main entry ways to the municipality. All seven turbines combined generate approximately 10 GWh of electricity per year which equals about 70% of the total demand. The turbines should be supplemented by combined heat power plants (CHP) to meet the electricity demand in the municipality and to buffer fluctuations in wind power[5].

Energy vision for the Global Solidarity scenario: The main challenge for the third energy vision lay in the restrictions for wind turbines. The objective was to search for integral solutions that minimize visual impact. One possibility is to construct a large wind park just outside the Heuvelland, in the West of Margraten. This wind park, however, remains visible from many elevated viewpoints in the Heuvelland. Alternatively, small turbines (4m height) can be integrated into the villages and settlements in Margraten. Assuming that about half the dwellings in the municipality (2.500) install one turbine each, approximately 4.4 GWh of electricity can be generated per year. In this energy vision, wind power can fulfil only 32% of the total electricity demand and must be supplemented by other technologies such as CHPs and PV panels.

Energy vision for the Caring Region scenario: The objective for the fourth energy vision was to identify interventions which facilitate citizen involvement and create long-term benefits for the local community. Consequently, we proposed to construct relatively small wind turbines on farms which are situated outside settlements and far enough from (existing and planned) forests. The turbines are custom-designed; their height (22m) is influenced by the layout of the characteristic farms in the Heuvelland. Metal-frame towers minimize the visibility of these turbines. In addition, turbines are placed on the back of the farm plots in order to reduce nuisance. In Margraten, about 112 farms can install such a turbine and generate approximately 12 GWh of electricity per year (86% of total demand). In this energy vision, electricity generation of wind turbines and PV panels combined exceeds the electricity demand.

8.3.5 Energy-conscious interventions

Heretofore, we focused on wind energy to illustrate the application of the five-step approach. Sustainable energy systems, however, should be diversified in order to balance fluctuations in supply and demand (Laughton, 2009). That is why each energy vision proposes a number of different interventions. The stakeholders in Margraten, however, asked for assistance for choosing among the many possible interventions. They wanted to know which interventions are the most robust in a long-term

5 A summary of energy-conscious interventions is provided in section 8.3.5.

perspective. Comparative analysis of the four energy visions revealed a set of five robust interventions.[6] We now describe how wind power, liquid/dry biomass, and thermal/electrical solar energy can be utilized to establish a sustainable energy system in Margraten.

Wind power: Energy visions indicate that wind power can be utilized under the conditions established by all four context scenarios. Yet, four different means of assimilating wind power were identified (table 8-3). The kind of technology and specific location of turbines depend on the perceived impact of turbines on the landscape quality. The visual impact of the different models and the possible locations were debated by the stakeholders. One question, for example, was "is the impact of 30 large turbines (120 GWh/year) really 12 times the impact of seven medium-size turbines (10 GWh/year)?" To answer this question goes beyond the scope of this paper. What we conclude from the comparative analysis of the four energy visions, however, is that each intervention appears only once. In other words, a large wind park is not necessarily more robust (from a strategic point of view) than two smaller clusters of wind turbines. Wind power as a source of renewable energy, however, appears feasible in all four energy visions. This is especially true if one assumes rising prices for fossil fuels. Moreover, wind turbines score best when it comes to material and financial investments and can, if alternatives emerge, be dismantled easily (see e.g. Pasqualetti et al, 2002). From the comparative analysis of the four energy visions for Margraten, we concluded that wind power can contribute to a sustainable energy system in this municipality. As noted earlier, present legislation constrains the construction of wind turbines. In the light of climate change and resource depletion, however, legislation is currently being re-evaluated both at the provincial and the national level.

Table 8-3. Overview of the different possible interventions to assimilate wind power

energy vision	height of turbines	number of turbines	electricity generation
Global Market	120 m	30	120 GWh/yr
Secure Region	60 m	7	10 GWh/yr
Global Solidarity	4 m	2.500	4.4 GWh/yr
Caring Region	22 m	112	12 GWh/yr

Liquid biomass: All four visions propose the use of animal manure as energy source. System size (or catchment area) and conversion technology, however, vary among the different visions. The Secure Region energy vision suggests constructing one large biogas plant. The three other energy visions, on the contrary, propose to collect manure from local cattle farmers and to process it at one strategically located farm in each village.[7]

6 For more information on how to evaluate the robustness please refer to chapter 7.
7 In the Heuvelland, this system size would correspond with 300 to 500 cows.

Anaerobic digestion of manure can be combined with solid biomass from landscape maintenance; a strategy that offers extra financial incentives for local farmers. The biogas can be used locally or injected in the present gas grid.[8]

Dry biomass: The construction of CHPs represents another energy-conscious intervention. Wood and other second generation biomass is collected, stored and eventually incinerated in cogeneration plants. Electricity can be put on the 220V grid; heat can be used on site or distributed via heat networks. Similar to wind power, possible interventions vary in scale and location. One possibility is to export dry biomass to Maastricht where a new CHP can be connected to an existing district heat grid. Two other energy visions, however, suggest to combust dry biomass in a new CHP in the village of Margraten. Constructing smaller CHPs for each village is a third possibility. This intervention requires more investments but reduces transportation losses to a minimum. The final choice between the different interventions, however, remains with the stakeholders. The outcome is difficult if not impossible to predict; preference for centralized or more decentralized interventions may influence the choice.

Thermal solar energy: Another possible intervention is the installation of solar boilers on the roofs of individual buildings. Solar boilers use sunlight to heat water which can be stored effectively and used whenever needed. Consumers can determine the capacity of their solar boiler according to their needs. For greatest energy harvest, south-facing roofs should be used. Solar boilers are relatively inexpensive and require little maintenance - two more positive attributes of this intervention. The installation of solar boilers appears feasible in all four energy visions and is thus considered a robust intervention. From a spatial perspective, one must however emphasize that solar boilers do not necessitate any planning. That is because solar boilers do not depend on the spatial organization of the physical environment, nor do they depend on major infrastructure.

Electrical solar energy: Photovoltaic (PV) cells can be integrated in solar panels, or into the roof/wall construction of buildings. Three possible interventions have been identified for Margraten: (1) To install PV panels on flat roofs of existing office buildings and warehouses. (2) To install PV panels on south-facing roofs of dwellings and farm buildings. (3) To integrate PV cells in new dwellings and office buildings. All these possible interventions occur, similar to solar boilers, at the building scale. Stakeholders can determine the location and number of panels depending on their own preferences and electricity needs.

8 Before injecting biogas into the natural gas grid, biogas has to be upgraded to natural gas quality.

8.4 Discussion

A large part of our environment is already used intensively. In order to accommodate additional land uses such as energy assimilation, innovative approaches to strategic spatial planning and landscape design are needed. In the first paper of this two-part series, we discussed relevant planning and design theories, and described a five-step approach for the composition of integrated visions. This approach has been applied in several studies (e.g. Southeast Drenthe and South Limburg) and refined continuously. The paper at hand illustrated how the five-step approach was employed to envision sustainable energy landscapes for Margraten, in the South of the Netherlands. We now discuss the five-step approach with respect to a set of criteria for strategic planning and design that was derived from the literature (see section 7.3.7).

One of the key characteristics of strategic planning and design is being *flexible* (e.g. Jones and Gross, 1996). The five-step framework is flexible: the five questions should be adapted and further specified to meet the objective of each study. Activities and outputs also depend on the characteristics of the study area. If a landscape, for example, lacks relief, there is no need to create an energy potential map for hydro power.

A thorough understanding of the characteristics of the study area presents a prerequisite for the identification of *area specific and appropriate interventions*; as demanded by Albrechts (2006a) and Healey (2009). Careful analysis of the physical landscape and the present energy system can help to learn how the study area functions.

The *active participation of stakeholders* is imperative to strategic planning and design (Albrechts 2004; Healey, 1997). We found that it is best to involve citizen from an early stage on. Collaboration should (at least) take place during step 3 (possible far-futures), step 4 (integrated visions), and step 5 (interventions). Working closely with citizens can also facilitate development of *shared interest*, a precondition for many of the energy-conscious interventions discussed in this paper.

Envisioning long-term transformation of large territorial systems involves both *rational and normative thinkin*g. Whereas the analysis of the present energy system has a rational character, composing visions is a rather normative process. In fact, each vision is based upon a set of conditions established by the respective scenario, and the perspectives of the persons composing the vision. Neither the context scenarios nor the visions are value-free. The five-step approach, however, is explicit about rational and normative steps. Discussing our approach with citizens has helped to *increase transparency* of the envisioning process.

While envisioning alternative futures for an area, one should not forget *change due to current, projected trends and policies* (Steinitz, 1990). Though those trends and policies may have not left any marks in the physical environment yet, they influence the future. Case-studies have shown that it is important to pay special attention to near-future developments because they can affect proposed interventions.[9]

Since strategic planning and design cannot be based on current projected trends only (Rosenhead, 2001), *critical uncertainties* should be integrated in the envisioning process. This integration may indeed introduce a certain degree of 'vagueness' (Faludi and Valk, 1994). One must also note that most context scenarios render rather extreme possible futures. The most probable future lies somewhere between the different scenarios. Despite the limitations of working with critical uncertainties, we agree with Rosenhead (2001) who argues that integrating a range of possible futures can support strategic inquiry.

Scenario thinking facilitates creative inquiry and imagination (Jäger et al, 2007). Our case-studies also show that composing a set of visions (as opposed to a single plan) leads to a multitude of possible interventions. Developing *alternative proposals* has also proven to attract the attention and facilitate the cooperation of key decision-makers.

Context scenarios are indeed an essential component of strategic planning and design. Generating such context scenarios, as suggested by many planners, is both resource- and time-consuming. For many regions, scenarios studies are already available. We believe that many of these *existing scenario studies* are sufficient enough to be used in the envisioning process. They should, however, be reviewed critically. Also, it might be necessary to further concretize possible spatial developments because (scenario) map resolution is coarse.

Since strategic planning and design aims to identify *innovative and yet realistic interventions* (Albrechts, 2006a; Healey, 2009), we deliberately chose to work with existing technologies rather than counting on exponential efficiency improvements and technological breakthroughs. This decision helps to maintain a sense of realism and to identify the kind of interventions that allow stakeholders to start with the implementation.

Employing the five-step approach, one should be able to identify a multitude of possible interventions. Decision-makers may be overwhelmed by the amount of choices they have. Either way, decision-making can be facilitated by *evaluating the robustness* of each possible intervention. In this paper, we conceptualize robustness as a measure of how independent interventions are from critical

9 In Margraten, the planting of forest may affect construction of wind turbines.

uncertainties.[10] Consequently, we propose to assess robustness of interventions through comparative analysis of the visions. If time and resources allow, other methods such as 'strategic choice approach' (Friend, 2001) and 'robustness analysis' (Rosenhead, 2001) can be employed.

8.5 Conclusion

Our research on the design of sustainable energy landscapes commenced with the hypothesis that three modes of change (current trends, critical uncertainties and intended change) could be integrated in the design process. The approach presented in this paper is one way to incorporate developments that lie beyond the control of the planner/designer in the process of envisioning alternative futures. The five-step approach consists of the following phases: (1) analysing present conditions, (2) mapping near-future developments, (3) illustrating possible far-futures, (4) composing integrated visions, and (5) identifying spatial interventions.

This paper illustrates how the five-step approach has been employed to envision several sustainable energy landscapes for the municipality of Margraten. We show that the approach was useful both for composing integrated visions and identifying energy-conscious interventions. Based upon the application and the discussion of the five-step approach, we conclude that many of the prerequisites for strategic inquiry can be met. The approach presented in this paper is adaptable and can be complemented by other methods.

With regard to the study area, the paper shows that a sustainable and self-sufficient energy landscape could be developed in Margraten, even on the basis of already available technologies. We like to highlight that it is necessary to utilize as many different renewable energy sources as possible. Such mix of sources can help to cope with fluctuations in energy supply and demand. Considering the impact of the different potential interventions on landscape quality, land use competition and biodiversity enables planners and designer to mitigate adverse effects of renewable energy sources.

The gradual transformation of our physical environment from fossil-fuel dependency towards renewable energy sources presents a challenging and rewarding task. As demonstrated by the study presented in this paper, planners and designer can indeed contribute to sustainable development by envisioning alternative futures. One question that deserves further research is if the set of visions should be consolidated in one single vision and (if so) how this can be done.

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10 We refer to the critical uncertainties that are described in the context scenario study.

Plateau near Margraten, Heuvelland, The Netherlands (S. Stremke)

Landscape maintenance, South Limburg, The Netherlands (Flickr, B. Kers)

General discussion

9

This thesis set out to explore and advance the planning and design of sustainable energy landscapes through research and design. For that purpose, the following central research questions were pursued: (1) What can we learn from natural ecosystems in order to develop sustainable energy landscapes? (2) How can the Second-Law of Thermodynamics inform the design of sustainable energy landscapes? (3) How can we conceptualize the region in the context of energy-conscious spatial planning and landscape design? (4) How to incorporate current trends and critical uncertainties in long-term regional planning and landscape design? I now discuss the most significant results of my studies with respect to those four research questions. The thesis is then concluded by discussing the implications of my research and suggesting topics for further research.

9.1 What can we learn from natural ecosystems?

Natural ecosystems tend to increase the assimilation of renewable energy and optimise energy flows as they mature. They can serve as model for sustainable development in general and sustainable energy landscapes in particular.[1] A selection of descriptive ecological concepts and ecosystem strategies were discussed in this thesis. Concepts such as *system size*, *sources/sinks* and *succession* are relevant to energy-conscious landscape design. Strategies such as *energy cascading, differentiation of niches* and *symbiotic relationships* provide additional insights.

The integration of system thinking in the planning and design of buildings, cities, landscapes and regions is already practiced for several decades.[2] On its face this seems logical - after all, what model for sustainable development do we have at our disposal other than the natural world? In spite of the many similarities between natural and human ecosystems, a number of crucial differences exist. In nature, for example, goal-oriented planning does not exist.[3] Humans, on the contrary, have the capacity to plan for the future.

Energy-conscious planning and design, the focus of this thesis, relies on the ability to 'foresee' climate change and resource depletion, and to adapt accordingly. In order to advance the planning and design of a physical environment that can be sustained on the basis of renewable energies, I am applying what Corner (1997) called 'translation' of fundamental ecological knowledge. Design principles that have emerged from the study of natural ecosystems should inform, but not determine, decision making.

9.2 What can we learn from the Second Law of Thermodynamics?

To address the second research question, I studied the Laws of Thermodynamics[4] and the application of *second-law thinking* in engineering, industrial ecology, architecture and planning. The objective of this part of the research was to study the knowledge on energy flows in the technosphere, to define 'exergy-conscious' principles, and to apply these principles in the design of sustainable energy landscapes.

1 See for instance Johnson et al. (2002) and Nielsen (2006).
2 See for instance Newman (1975), Hough (1984), Lyle (1994), Golley (1996), Pulliam and Johnson (2002).
3 The apparent purposefulness of living organisms that derive from their evolutionary history and adaptation is referred to as 'teleonomy' (see Mayr, 1974).
4 While the First Law of Thermodynamics states that energy is always conserved, the Second Law states that during any process, exergy (work capacity) is destroyed and entropy (disorder) is produced.

The literature review showed that thermodynamic engineers have indeed succeeded to reduce primary energy consumption through the application of second-law thinking. Over the past decade, civil engineers, architects and urban planners too have begun embracing the Second Law of Thermodynamics to reduce energy consumption in the built environment.[5]

One key insight of this part of the research is that energy demand must be further decreased. Even though energy may be derived from renewable sources, their provision will contribute to indirect exergy destruction[6] and increase land-use pressure. Exergy-conscious spatial organization of functions can help matching energy demand and supply, and reducing primary energy demand. The location of renewable/residual energy sources and sinks, for example, should be considered in spatial planning and design. The following *exergy-conscious strategies* have been defined: (1) increase exergy efficiency, (2) decrease exergy demand, (3) increase use of residual exergy, (4) match quality of energy supply and demand, (5) increase assimilation of renewable exergy.[7]

Many scholars stress the fact that *exergy* is a key concept for developing sustainable energy systems (e.g. Cornelissen, 1997; Dincer and Rosen, 2007). In order to contribute to the development of a sustainable physical environment, exergy-conscious interventions must however be socially acceptable, economically feasible, and not harmful to biodiversity. By introducing 'exergy' to environmental design, I emphasize the need to consider energy quality, time, and location in the design of sustainable energy landscapes. A self-sustaining environment that effectively matches energy supply and demand in quality, space and time could be called 'exergy landscape'.

9.3 How can we conceptualize the region in energy-conscious design?

Sustainable energy transition must take place at all scales ranging from individual buildings to the region.[8] The question of how to conceptualize the 'region' in the context of energy-conscious planning and design has been pursued through literature research, theoretical discussion, and a regional case-study in Southeast Drenthe.

5 See for instance Schmidt (2006), Tillie et al. (2009) and Torio et al. (2009).
6 Exergy is defined as the maximum amount of work that can be produced by a stream of matter, heat or work as the medium comes into equilibrium with a reference environment (Dincer, 2000). Work capacity depends on the quantity and quality of energy, on the location and the time.
7 These strategies should be pursued across the different planning and design scales. Please see table 4-7 for more details.
8 See for instance Benner et al. (2009), Dobbelsteen et al. (2008), Koh (2005a).

Three concepts are of particular relevance to advance energy-conscious planning and design at the regional scale. They are *open systems*, *optimum system size*, and *hierarchy*. All regions are *open systems*; energy, matter and information can be exchanged with other systems. Typically, regional energy systems consist of several subsystems such as local gas networks or heat grids. Once the size of such a subsystem is beyond its energetic optimum, it requires additional energy to maintain that system. The *optimum size* of energy systems depends on the quality of the energy carrier and energy infrastructure, among other factors. In the context of energy landscapes, we define optimum size of a system as the spatial extent at which energy supply and demand can be matched most effectively in space and time. The concept of *hierarchy*[9] also needs to be considered. Regions do not only consist of several interrelated sub-systems, they are also part of a larger super-system. Only when energy can travel in both directions and across regional borders can systems be optimized energetically.

Energy-conscious planning and design at the regional scale is useful because it can facilitate synergy between different land uses, for instance the use of residual heat and CO_2 from power plants in greenhouses. In addition, case-studies show that regional energy visions can facilitate the interests of policy and decision-makers. A regional approach can also help to bridge the gap between (inter)national targets and local initiatives. At the regional scale, however, the level of complexity rises. Energy-conscious regional planing and design thus needs to be considered a multi-criteria decision making process.

9.4 How to incorporate trends and uncertainties in regional design?

The fourth research question relates to the procedure of regional design: how to envision alternative futures for large territorial systems. In a time of increasingly rapid change and technological innovations, we need to find means to incorporate current trends and critical uncertainties in the regional design process. Methodological frameworks from strategic spatial planning, design-oriented planning and landscape planning[10] provided the key building blocks for a new approach to the composition of integrated visions that was then applied and tested through case-studies and design laboratories.

The so-called *five-step framework* aims at facilitating the composition of long-term visions by integrating current trends (i.e. near-future

9 Each system consists of several levels or subsystems which are parts of a hierarchy.
10 For instance Albrechts (2004), Dammers et al. (2005) and Steinitz (2002).

developments) and critical uncertainties (i.e. possible far-futures) in the design process. The process commences with the analysis of present conditions. Today's physical reality is however not the only 'starting point'. Rather than starting with a single topographic map, visions are composed on the basis of a 'near-future base-map' and a set of 'scenario base-maps'. Each vision illustrates one alternative future and identifies interventions that are necessary to realize that future. The design process is organized around a set of five questions - each one subject to one of the following steps: (1) analysing present conditions, (2) mapping near-future developments, (3) illustrating possible far-futures, (4) composing integrated visions, and (5) identifying spatial interventions.

Employing the five-step framework does not necessarily lead to a regional plan in the conventional sense. Rather, it results in a set of visions and a list of possible interventions. The proposed framework is flexible[11] for several reasons: First, the five questions must be adapted to the focal issue of the study.[12] Second, activities depend on the physical characteristics of the study area. Third, the framework can easily be complemented by other methods such as 'multi-layer analysis' (Sijmons, 2002). One drawback of integrating critical uncertainties in regional design is that they indeed introduce a certain degree of 'vagueness' (Faludi and Valk, 1994). Working with a range of possible futures, however, has proven to facilitate strategic inquiry. Composing a set of visions helps to identify a multiplicity of possible interventions (compared with a single plan). Methods such as 'robustness analysis' (Rosenhead, 2001) can help decision-makers to chose among the potential interventions. This 'way of designing' can facilitate the development of commitment packages and strategic policies, and motivate citizens to participate in the sustainable transformation of their region.

9.5 Discussing design principles

In this thesis, I have formulated principles that can be employed in the design of sustainable energy landscapes.[13] Comparing the principles inspired by the study of the biosphere with those from the technosphere, one can notice a certain similarity. In nature, for example, solar energy is used several times; it is cascaded from autotrophs through highly complex food webs. Energy efficient industrial parks reuse energy as well, for instance through heat cascades. In nature, systems tend to improve

11 As requested by many scholars (e.g. Jones and Gross, 1996; Healey, 2009).
12 For a list of possible questions please see chapters 7 and 8.
13 Please refer to chapters 3, 4 and 5 for a list of principles.

energy utilization as they mature; for instance by symbiosis. Mixed land use and compact building enable the development of similar, symbiotic relationships in the built environment.

Over the past decade we have witnessed a certain trend towards a 'systems view' (Vroom, 1997) or 'systemic approach' (Berger, 2009) to environmental design. No longer, we simply design *with* nature (McHarg, 1969). Instead, we combine scientific knowledge with human creativity and design *like* nature; an approach that has been described as 'eco-mimetic' (Nielsen, 2006). Problems such as resource depletion and climate change, which we have no ready-made design principles for, change the way we design. Principles derived both from the study of the biosphere and the technosphere, in combination with 'architectural imagination' (Koh, 2005b), can facilitate the design of sustainable energy landscapes.

Most of the principles presented in this thesis are of tactical or strategic nature. To some extent, this is due to the sensitivity of energy-conscious design principles to the locality and time: what might be useful at one moment and location may not work at other times and places. The final aim of the SREX project, however, is to define operational principles for energy-conscious planning and design.

9.6 Discussing design procedures

While embarking with the design of sustainable energy landscapes, we realized that many of the existing planning and design approaches are insufficient to structure the design process. This is because the period of time needed to adapt large territorial systems to renewable energy sources is long and involves many uncertainties. The five-step methodological framework described in this thesis is one means to incorporate some of the critical uncertainties in long-term regional design.

While the precise steps and sequence of actions may be interpreted differently, theories of the planning and design process continue to include a phase of (1) observation, (2) analytical and interpretative thinking, (3) creative exploration of possible futures, and (4) of determination of action. So does the five-step approach. Latest research on transition as well as adaptive management, however, challenges some of the 'matters of course' in environmental design.[14] Sustainable energy transition necessitates more than a mere energy-conscious organization of the built environment; it also necessitates a shift in thinking. To facilitate such shifts, one relies, for instance, on transition arenas, knowledge development,

14 See for instance Van den Brugge and Rotmans (2007) and Pahl-Wostl (2009).

and long-term integrated visions (Kemp et al, 2007). One approach to the composition of such integrated visions has been described in this thesis. Environmental designers, however, can deliver more than "just" the visions; we have much experience with moderation of complex, multi-scalar transformation processes that stretch over long periods of time.

Another important point of discussion is in how far energy-conscious transformation of the physical environment can actually be planned. Ehrenfeld and Gertler (1997) argue that the symbiotic networks in Kalundborg (Denmark) have simply evolved over time. In other words, they are not planned *a priori*. Jørgensen (2006), on the contrary, argues that symbiotic relationships can and should be planned. In this context, Van der Brugge and Van Raak (2007) refer to the studies of Prigogine (1987) and others on self-organization and increasing complexity in nature. Whether transitions (in the human world) are self-organized or can be planned, is a question that certainly deserves further attention.[15]

9.7 General conclusion

Having studied both the theories and the existing cases of renewable energy landscapes, I find the gap between theoretical knowledge and practice unsettling. The majority of renewable energy landscapes utilize only few energy sources and technologies. All too often, the discussion is limited to the assimilation of renewable sources rather than addressing the sustainability of the entire system. Sustainability, in this context, means that energy demands can be fulfilled by locally available renewable sources. A second condition for sustainability is that energy provision may not harm other landscape services, biodiversity or landscape quality.

The reduction of energy demand through energy-conscious planning and design deserves more attention both in design research and practice. The concept of exergy is essential to the planning and design of sustainable energy landscapes. The concept calls special attention to the quality of energy, and the organization of sources and sinks in space and time. Over the course of the last years, more and more environmental designers have begun embracing system thinking and contribute to a growing body of knowledge on the design of sustainable energy landscapes.[16]

The research presented in this thesis has several implications to environmental design practice, education and research. Practitioners must

15 We are currently studying several existing renewable energy landscapes in Austria, Germany and Denmark. The guiding question is whether these landscapes were planned or evolved over time?

16 See for instance Dittrich and Schöbel (2010) and Sijmons et al. (2008).

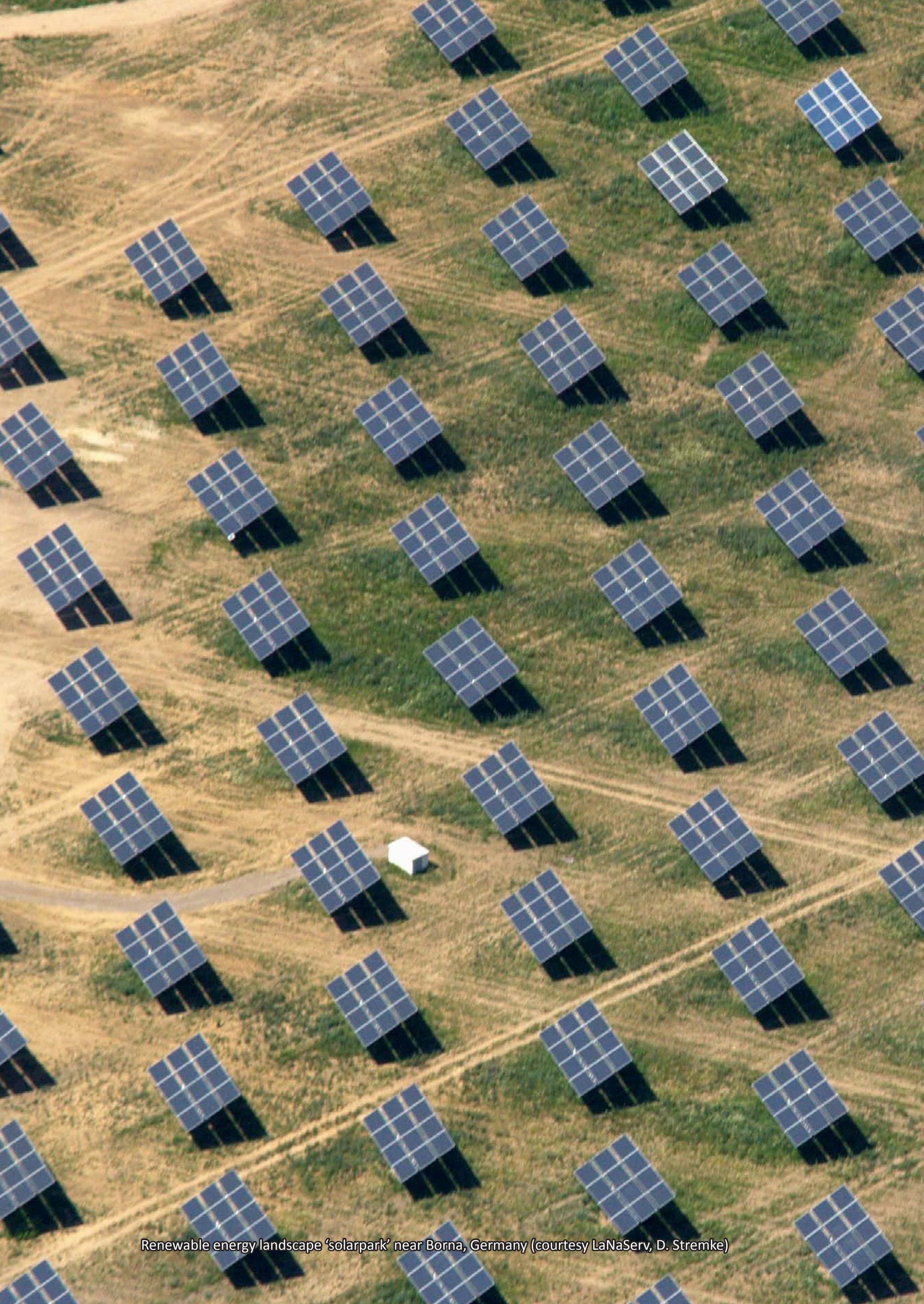
strive to design in an energy-conscious manner; starting with the selection of plant material and reaching all the way to the spatial organization of land uses at the regional scale. With regard to education, I believe that a more systemic approach to landscape architecture requires slight changes in students' curricula. We need to provide students with the tools that can help them to deal with the increasing complexity of today's design issues. In this thesis, I have presented one means to envision alternative futures at the regional scale. This research also revealed, that the transition to sustainable energy offers many possibilities for landscape architects to broaden and deepen the theoretical knowledge base of the discipline.

Further research is required on the perception of sustainable energy landscapes and the consequences for landscape planning and design. Too often, interventions that are needed to develop a sustainable physical environment are dismissed for aesthetic reasons. In spite of the importance of an attractive environment, we must also learn how to sustain on the basis of the very landscape that we live in. Additional research is also necessary on the role of the landscape architect in the creation of sustainable energy landscapes. Another (personal) challenge is to apply and test the five-step approach in the design of climate-proof landscapes.

"Problems cannot be solved at the same level of thinking that created them"

Albert Einstein

Namafjall hot springs energy landscape, Iceland (courtesy of G. Nauman)


Renewable energy landscape 'solarpark' near Borna, Germany (courtesy LaNaServ, D. Stremke)

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Biogasplant, Bio-energy village Barlissen near Jühnde, Germany (S. Stremke)

Pumped storage plant Goldisthal, Germany (courtesy LaNaServ, D. Stremke)

Summary

The depletion of fossil fuels, in combination with climate change, necessitates a transition to sustainable energy systems. This transition implies the reduction of energy demand and the replacement of fossil fuels by renewable energy sources. In his discussion on energy transition, the former Secretary-General of the United Nations Conference on Environment and Development stressed that “the whole concept of human settlements needs to be rethought, including […] the broader issues of land use and urban planning” (Strong, 1992, p.493). The demand for energy is partly determined by the spatial organization of the built environment. The supply of renewable energy requires space and shapes landscapes. The transition to sustainable energy systems thus not only presents a great challenge to sustainable development in general but to environmental designers in particular.

This thesis concerns the fact that, in the near future, large shares of energy will need to be provided by renewable sources. My research is motivated by the need to increase the assimilation of renewables while, at the same time, reducing the demand for energy. In order to develop truly sustainable energy systems, they have to be well integrated in the landscape. I define *sustainable energy landscape* as that part of the physical environment where energy needs can be fulfilled by locally available renewable sources. In order to be sustainable, the provision of energy must not harm the quality of life of the local population, biodiversity or landscape quality.

One question of particular interest to environmental designers is how to transform the present-day, fossil fuel depending environment into a sustainable energy landscape. What are the *principles* by which sustainable energy landscapes can be designed, and how to organize the *design process*? The study of both literature and existing renewable energy landscapes has revealed several knowledge gaps. Generally applicable, energy-conscious design principles are scarce. Two key sources of insights for the formulation of energy-conscious principles - nature and thermodynamics - have been neglected. Moreover, the regional scale

has not yet been fully explored in energy-conscious planning and design. The long-term character of transforming large territorial systems clearly deserves more attention.

The objective of my thesis was to advance the planning and design of sustainable energy landscapes, with special attention to the regional scale. The following four questions guided my research: (1) What can we learn from natural ecosystems? (2) What can we learn from the Second Law of Thermodynamics? (3) How can we conceptualize the region in energy-conscious design? (4) How to incorporate trends and uncertainties in regional design? Whereas the first three research questions relate to design principles, the fourth question concerns the design procedure.

Three different approaches to research and design have been pursued in this thesis. *Research for design*: the 'translation' of knowledge from ecology and thermodynamics to define energy-conscious design principles. *Research of planning and design*: the study of existing planning and design methods to advance regional design procedures. *Research-driven design*: the design of sustainable energy landscapes based in part on research.

First, the field of ecology was studied to reveal how natural ecosystems make optimum use of renewable energy. Natural ecosystems tend to increase assimilation of renewables and optimise energy flows as they mature. Concepts such as *system size*, *sources/sinks* and *succession* are highly relevant to energy-conscious planning and design. Ecosystem strategies such as *energy cascading*, *differentiation of niches* and *symbiosis* provide additional insights on how to design sustainable energy landscapes. It is important to note that the design principles which have emerged from ecosystem studies should inform, and not determine, decision making.

In order to address the second research question, I have studied the *First and Second Law of Thermodynamics* and the application of *second-law thinking* in engineering thermodynamics, industrial ecology and architecture/urban planning. Literature review showed that engineers have succeeded in reducing primary energy consumption through the application of second-law thinking. Over the past decade, architects and urban planners have begun to embrace the Second Law of Thermodynamics for reducing energy consumption in the built environment. *Exergy* is a key concept in second-law thinking. Exergy is defined as the maximum amount of work that can be produced by an energy carrier as the carrier comes into equilibrium with its environment. The work capacity of energy carriers depends on their quality, as well as on their location and time. My second-law perspective on the design of sustainable energy landscapes resulted in the formulation of additional design principles and 'exergy-conscious' interventions.

Sustainable energy transition is constrained by several issues. Among the issues that can potentially be solved through energy-conscious planning and design, I have focused on the following three: (1) periodic fluctuations in energy supply, (2) relatively low energy density of renewables, and (3) limited capacity to utilize available energy. Can ecological and thermodynamic concepts help to overcome those constraints and develop sustainable energy landscapes? Regional case studies in South Limburg and Southeast Drenthe show that descriptive scientific concepts can not only inform the design of sustainable energy landscapes, but also help to mitigate some of the 'problems' of renewable energy sources. The case studies also illustrate that the spatial organization of landscapes not only determines *where* renewable energy is assimilated and used, but also influences *how much* energy is assimilated at *which quality* and at *what time*.

Energy transition receives more and more attention in architecture and urban planning. At the regional scale, however, there remain significant potentials to reduce energy demand and increase the assimilation of renewables. Several concepts from system theory are important to the understanding of 'region' in the context of sustainable energy transition. Every region is an *open system*; energy, matter and information are exchanged with other systems. Once the size of such a system is beyond its energetic optimum, additional energy is required to maintain that system. *Optimum system size* depends on the quality of energy carriers and energy infrastructure, among other factors. The concept of *hierarchy* is especially useful to the understanding of energy regions. Every region consists of several subsystems but is also part of larger super-systems. Regional energy systems can be optimized best when energy can travel in both directions and across regional borders. Apart from advancing the discussion on the design of regional energy landscapes, the Southeast Drenthe case-study shows that a regional approach can help to bridge the gap between (inter) national targets and local interventions. At the regional scale, however, the level of complexity rises.

How to deal with the complexity and uncertainties of the regional scale in planning and design is discussed in a separate chapter. Many scholars stress the need to compose visions, as opposed to spatial plans, when it comes to long-term transformation of large territorial systems. A review of methodological frameworks from strategic spatial planning, design-oriented planning and landscape design provided the key building blocks for an advanced approach to regional design. The *five-step approach* aims to facilitate the composition of long-term visions by integrating current projected trends and critical uncertainties into the design process. As common in spatial planning and landscape design, the study commences with the analysis of present conditions. Today's physical reality is, however, not the only 'starting point'. Rather than starting with a single topographic map, visions are composed on the basis of a 'near-future base-map' and a set of 'scenario base-maps'. Each vision depicts one alternative future and identifies interventions that can help realizing that future. The design procedure is organized in five steps: (1) analysing present conditions, (2) mapping near-future developments, (3) illustrating possible far-futures, (4) composing integrated visions, and (5) identifying spatial interventions. Employing the five-step approach does not necessarily result in a regional plan but in a set of visions and a list of possible interventions. This 'way of designing' presents an alternative means to facilitate the commitment of decision-makers, inform the development of strategic policies, and motivate citizens to participate in the sustainable transformation of their regions.

The five-step approach has been employed to envision several *sustainable energy landscapes for Margraten*, a large municipality in the South of the Netherlands. The case-study shows that the approach was useful both for composing long-term visions and identifying concrete actions in Margraten. Moreover, the case-study illustrates that self-sufficiency can be reached in Margraten, even on the basis of available technologies. In order to cope with the fluctuations in energy supply and demand, it is important to employ a mix of renewable energy sources and technologies. Illustrating the possible impacts of each intervention can help to facilitate decision-making. As hypothesized earlier, environmental designers can indeed contribute to sustainable energy transition by investigating, illustrating and evaluating possible energy-conscious interventions in the physical environment.

This thesis set out to explore and advance the design of sustainable energy landscapes. Embracing systemic thinking, inspired by the study of nature and thermodynamics, contributes to a growing body of knowledge on the design of sustainable energy landscapes. We (speaking broadly and not *ad hominem*) must strive to be energy-conscious at all design scales, beginning with the selection of plant material and reaching all the way to the spatial organization of land uses at the regional scale. Throughout this thesis, I emphasize the need to develop *sustainable* energy landscapes. This is because I am convinced that the transition to renewable energy will occur anyhow, with or without participation of environmental designers. Ensuring that this transition takes place in a sustainable manner should become an objective to spatial planners and landscape architects. The development of sustainable energy landscapes not only deserves special attention, it also offers many possibilities for landscape architects to broaden and deepen the theoretical knowledge base of the discipline. The combination of thorough research and creative design illustrated in this thesis has proven to enrich the knowledge on sustainable energy landscapes.

Samenvatting

Het opraken van fossiele brandstoffen in combinatie met klimaatverandering maakt een transitie naar een duurzaam energiesysteem noodzakelijk. Deze transitie behelst een reducering van de energiebehoefte en het vervangen van fossiele brandstoffen door hernieuwbare energie. In zijn bijdrage over de energietransitie heeft de voormalig Secretaris-Generaal van de VN Conferentie 'Environment and Development' benadrukt, dat "het complete idee over nederzettingen moet overdacht worden, inclusief [...] ruimtelijke thema's in de breedste zin van het woord" (Strong, 1992, p. 493). De vraag naar energie wordt gedeeltelijk bepaald door de ruimtelijke structuur van de gebouwde omgeving. Het voorzien in hernieuwbare energie vereist ruimte en vormt het landschap. De transitie naar alternatieve energiesystemen is daarom niet alleen een grote uitdaging voor duurzame ontwikkeling in zijn algemeenheid, maar ook voor stedenbouwkundigen, ruimtelijke planners en landschapsarchitecten in het bijzonder.

Dit proefschrift heeft betrekking op de constatering dat in de nabije toekomst een groot deel van het energieaanbod uit hernieuwbare energiebronnen zal moeten komen. Het motief voor deze studie is ingegeven door de noodzaak om de vraag naar energie te laten afnemen en tegelijkertijd de winning van energie uit hernieuwbare energiebronnen te laten groeien. Om een echt duurzaam energiesysteem te ontwikkelen moet het systeem op een goede manier in het landschap worden geïntegreerd. Een *duurzaam energielandschap* wordt gedefinieerd als dat deel van de fysieke leefomgeving waar de energiebehoeftes kan worden ingevuld door lokaal beschikbare hernieuwbare bronnen. Om duurzaam te zijn, mag de energievoorziening geen negatieve effecten voor de lokale bevolking, de biodiversiteit en de kwaliteit van het landschap hebben.

Een vraag die bijzonder belanghebbend is voor planners en landschapsarchitecten, is hoe de hedendaagse omgeving, gekenmerkt door een grote afhankelijkheid van fossiele brandstoffen, te transformeren is naar een duurzaam energielandschap. Welke principes zijn er, waarmee een duurzaam energielandschap kan worden ontworpen en hoe moet het ontwerpproces dan worden ingericht. Literatuurstudie en de bestudering van bestaande energielandschappen hebben verschillende hiaten in kennis aan het licht gebracht. Algemeen toepasbare, energiebewuste ontwerpprincipes zijn zeldzaam. Twee belangrijke bronnen om inzicht te verwerven voor het opstellen van energiebewuste ontwerpprincipes zijn genegeerd, te weten de natuur en de thermodynamica. Daar komt bij, dat de regionale schaal tot nog toe te weinig aandacht heeft gekregen met betrekking tot energietransitie. Het langetermijnkarakter om territoriaal omvangrijke gebieden te transformeren verdient duidelijk meer aandacht.

De doelstelling van dit proefschrift is om de planning en het ontwerp van duurzame energielandschappen verder te ontwikkelen met daarbij bijzondere aandacht voor de regionale schaal. De volgende vier onderzoeksvragen stuurden het onderzoek: (1) Wat kunnen we leren van natuurlijke ecosystemen? (2) Wat kunnen we leren van de Tweede Hoofdwet van de Thermodynamica? (3) Op welke manier kunnen we de regio conceptualiseren in relatie tot energietransitie? (4) Op welke manier kunnen we trends en onzekerheden in een regionaal ontwerp incorporeren? Hierbij hebben de eerste drie onderzoeksvragen betrekking op ontwerpprincipes, de vierde onderzoeksvraag gaat over het ontwerpproces.

In dit proefschrift is gebruikgemaakt van drie verschillende aanpakken. *Research for design*: het afleiden van energiebewuste ontwerpprincipes gebaseerd op kennis uit de ecologie en de thermodynamica. *Research of planning and design*: het bestuderen van bestaande planning- en ontwerpmethodes om het regionaal ontwerpproces te verbeteren. *Research-driven design*: ontwerpen van energielandschappen gebaseerd op onderzoek.

Eerst is bestudeerd hoe natuurlijke ecosystemen optimaal gebruik maken van hernieuwbare energie. Natuurlijke ecosystemen neigen naar het laten toenemen van de assimilatie van duurzame energie en het optimaliseren van energiestromen als deze systemen groeien. Concepten als *systeemomvang*, *sources/sinks* en *successie* zijn in hoge mate relevant voor energiebewust plannen en ontwerpen. Ecosysteem strategieën zoals *energiecascadering*, *differentiatie van niches* en *symbiose* bieden extra inzichten in hoe duurzame energielandschappen te ontwerpen. Het is echter belangrijk om op te merken dat ontwerpprincipes die zijn ontleend aan ecosysteemstudies meer informatief dan bepalend zouden moeten werken bij besluitvorming.

In relatie tot de tweede onderzoeksvraag is een studie gemaakt van de *Eerste en Tweede Hoofdwet van de Thermodynamica* en de toepassing hiervan in de technische thermodynamica, industriële ecologie, architectuur en stedenbouwkunde. Een beschouwing van de literatuur toont aan dat ingenieurs met succes het primaire energiegebruik kunnen reduceren door toepassing van de Tweede Hoofdwet. Gedurende het laatste decennium is het energiegebruik in de gebouwde omgeving succesvol gedaald doordat architecten en stedenbouwkundigen in toenemende mate handelen vanuit de Tweede Hoofdwet. *Exergie* is een sleutelbegrip in relatie met het Tweede Hoofdwet. Exergie wordt gedefinieerd als de maximale hoeveelheid arbeid die kan worden geleverd door een energiedrager als deze drager in equilibrium wordt gebracht met de omgeving. Het vermogen van energiedragers om arbeid te leveren hangt af van hun kwaliteit, maar ook van hun locatie en tijd. Het hier gebruikte *second-law thinking* (i.e. het denken vanuit de Tweede Hoofdwet) heeft geresulteerd in extra ontwerpprincipes en 'exergiebewuste' interventies.

Ondanks de duidelijke voordelen van hernieuwbare energiebronnen wordt de transitie naar een duurzaam energiesysteem door een aantal factoren verhinderd. Tussen de factoren die mogelijk kunnen worden opgelost door een energiebewuste planning en ontwerp, ligt de nadruk in dit proefschrift op de volgende drie beperkingen: (1) periodieke fluctuaties in het energieaanbod, (2) relatief lage energiedichtheid van hernieuwbare energiedragers, en (3) beperkte capaciteit om gebruik te maken van beschikbare energie. Kunnen ecologische en thermodynamische concepten helpen om deze beperkingen te overbruggen en duurzame energielandschappen te ontwikkelen? Regionale casusstudies in Zuid-Limburg en Zuidoost-Drenthe tonen aan dat wetenschappelijke concepten niet alleen informatief zijn, maar ook helpen met een aantal van de 'problemen' van hernieuwbare energiebronnen om te gaan. De casusstudies laten ook zien, dat de ruimtelijke organisatie in een landschap niet alleen bepalend is voor *waar* hernieuwbare energie wordt gewonnen en gebruikt, maar ook beïnvloedt *hoeveel* energie wordt gewonnen van *welke kwaliteit* en *wanneer*.

Duurzame energietransitie krijgt steeds meer aandacht in de architectuur en stedenbouwkunde. Echter op de regionale schaal ligt er nog een significant potentieel om de vraag naar energie te reduceren en de assimilatie van duurzame energie te verhogen. Verscheidene concepten uit de systeemtheorie zijn belangrijk om regio's beter te begrijpen in samenhang met energietransitie. Iedere regio is een *open systeem*; energie, materie en informatie kunnen worden uitgewisseld met andere systemen. Als de systeemgrootte voorbij het energetisch optimum ligt, is extra energie nodig om het systeem te onderhouden. De *optimale* *systeemgrootte* is afhankelijk van de kwaliteit van de energiedragers, de infrastructuur en andere factoren. Het concept van *hiërarchie* is daarbij in het bijzonder behulpzaam om energieregio's te begrijpen: iedere regio bestaat uit verscheidene subsystemen, maar is tegelijkertijd ook onderdeel van een groter supersysteem. Regionale energiesystemen kunnen het best geoptimaliseerd worden, als energie twee kanten en ook voorbij regionale grenzen kan stromen. Naast het naar voren brengen van de discussie over het ontwerp van regionale energielandschappen, toont de casusstudie Zuidoost-Drenthe aan dat een regionale aanpak ook kan bijdragen aan het overbruggen van de kloof tussen (inter)nationale doelen en lokale interventies. Niettemin neemt op de regionale schaal het niveau van complexiteit toe.

De vraag hoe om te gaan met de complexiteit en onderzekerheden van de regionale schaal komt aan bod in een afzonderlijk hoofdstuk. Veel wetenschappers benadrukken de noodzaak om visies te ontwikkelen als het gaat om langetermijntransformaties van territoriaal omvangrijke gebieden. Een studie van methodieken uit strategische planning en landschaparchitectuur leverde het materiaal op om een meer geavanceerde methode te ontwikkelen voor regionaal ontwerp. Het *five-step approach* beoogt het opstellen van langetermijnvisies te faciliteren door de op dit moment al geprojecteerde trends en kritieke onzekerheden te integreren in het ontwerpproces. Zoals gebruikelijk in de planologie en het landschapsontwerp begint de studie met een analyse van de huidige situatie. Echter, de realiteit van vandaag is niet het enige vertrekpunt. Veel meer dan te beginnen met een enkele topografische kaart komen visies tot stand op basis van een 'nabije-toekomst basiskaart' en een set van 'scenario basiskaarten'. Iedere visie schildert een andere toekomst en maakt interventies zichtbaar, die kunnen helpen om die specifieke toekomst te realiseren. De ontwerpprocedure is opgebouwd uit vijf stappen: (1) analyse van de huidige condities, (2) in kaart brengen van ontwikkelingen in de nabije toekoms, (3) illustreren van verre mogelijke toekomsten, (4) ontwerpen van geïntegreerde visies en (5) het identificeren van ruimtelijke interventies. Het toepassen van het five-step approach resulteert niet noodzakelijkerwijze in een regionaal plan, maar in een aantal visies en een lijst met mogelijke interventies. Deze 'manier van ontwerpen' biedt een alternatief middel om het engagement van besluitvormers te vergroten en motiveert burgers om te participeren in een duurzame transformatie van hun regio.

Dit proefschrift laat zien hoe de five-step approach is toegepast om verschillende *duurzame energielandschappen in Margraten* te ontwerpen, een grote gemeente in het zuiden van Nederland. Deze casusstudie laat zien dat de benadering bruikbaar is voor zowel het opstellen van langetermijnvisies als ook om concrete interventies te identificeren. Bovendien toont de casusstudie aan dat zelfvoorzienendheid bereikt kan worden in Margraten, zelfs op basis van al beschikbare technologieën. De fluctuaties in energievraag en –aanbod maakt het belangrijk om een mix van hernieuwbare energiebronnen en technieken in te zetten. Zoals eerder als hypothese genoemd, kunnen stedenbouwkundigen, ruimtelijke planners en landschapsarchitecten daadwerkelijk een bijdrage leveren aan een duurzame energietransitie, bijvoorbeeld door het onderzoeken, illustreren en evalueren van mogelijke energiebewuste interventies in de fysieke leefomgeving.

De doelstelling van dit proefschrift was om de planning en het ontwerp van duurzame energielandschappen verder te ontwikkelen met daarbij bijzondere aandacht voor de regionale schaal. Het omarmen van systeemdenken, ingegeven door het bestuderen van de natuur en de thermodynamica, levert een bijdrage aan de groeiende kennis over het ontwerp van duurzame energielandschappen. Wij ontwerpers moeten er naar streven om energiebewust te zijn op alle schaalniveaus. Dat begint bij de selectie van planten en loopt door tot de ruimtelijke organisatie van landgebruik op de regionale schaal. In het hele proefschrift benadruk ik de noodzaak om *duurzame* energielandschappen te ontwikkelen. Reden hiervoor is dat ik er van overtuigd ben dat de transitie naar hernieuwbare energiebronnen sowieso zal plaatsvinden, met of zonder deelname van ontwerpers. Juist ruimtelijke planners en landschapsarchitecten zouden hun engagement moeten tonen en het voortouw moeten nemen in het duurzaam laten plaastvinden van deze transitie. De ontwikkeling van duurzame energielandschappen verdient niet alleen meer aandacht, het biedt ook mogelijkheden voor landschapsarchitecten om de theoretische basis van de discipline te verbreden en te verdiepen. De combinatie van onderzoek en ontwerp, gepresenteerd in dit proefschrift, verrijkt de kennis over duurzame energielandschappen.

Zusammenfassung

Die Verknappung fossiler Brennstoffe und der Klimawandel erfordern einen Übergang zu nachhaltigen Energiesystemen. Das heißt Reduzierung des Energiebedarfs sowie Ersatz fossiler Brennstoffe durch erneuerbare Energien. Der ehemalige Generalsekretär der UN Konferenz für Umwelt und Entwicklung betont in diesem Zusammenhang, dass “das ganze Konzept menschlicher Siedlungen neu überdacht werden muss, einschließlich [...] Landnutzung und Stadtplanung” (Strong, 1992, S.493). Die räumliche Organisation von Städten, Dörfern und Landschaften beeinflusst den menschlichen Energieverbrauch. Die Assimilation erneuerbarer Energien erfordert Raum und formt Landschaften. Die Energiewende stellt somit nicht nur eine Herausforderung für nachhaltige Entwicklung im Allgemeinen dar, sondern für Stadtplaner, Raumplaner und Landschaftsarchitekten im Besonderen.

Diese Arbeit geht davon aus, dass bereits in naher Zukunft große Anteile unseres Energiehaushaltes durch erneuerbare Quellen bereitgestellt werden. Um nachhaltige Energiesysteme zu entwickeln, müssen Energiegewinnung, Transport und Speicherung optimal in die Landschaft integriert werden. Das Ergebnis einer solchen Integration, die sogenannte *nachhaltige Energielandschaft*, kann man definieren als den Teil der physischen Umgebung, in welcher der Energiebedarf durch lokal verfügbare erneuerbare Quellen gedeckt werden kann. Um wirklich nachhaltig zu sein, darf das neue Energiesystem keine negativen Auswirkungen auf die Bevölkerung, Artenvielfalt und Landschaftsqualität haben.

Eine Frage von besonderem Interesse für Raumplaner und Landschaftsarchitekten ist, wie man die heutige, von fossilen Brennstoffen abhängige, Umwelt schrittweise zu nachhaltigen Energielandschaften entwickeln kann. Nach welchen Entwurfsprinzipien kann man nachhaltige Energielandschaften gestalten, und wie kann man den Entwurfsprozess organisieren? Mehrere kritische Wissenslücken wurden mit Hilfe von Literaturstudien sowie der Untersuchung bestehender Energielandschaften aufgedeckt: Der Entwurf von Energielandschaften folgt keiner systematischen Herangehensweise; es existieren nur wenige, allgemeingültige energiebewusste Entwurfsprinzipien. Zwei wichtige Quellen für die Formulierung solcher Prinzipien - natürliche Ökosysteme und Thermodynamik - wurden bisher vernachlässigt. Darüber hinaus bestehen noch besonders große Potenziale für energiebewusste Planung im regionalen Maßstab. Der langfristige Charakter einer Entwicklung von nachhaltigen Energielandschaften im regionalen Maßstab verdient deutlich mehr Aufmerksamkeit.

Das Ziel meiner Forschung ist zur besseren Planung und Gestaltung nachhaltiger Energielandschaften beizutragen. Meine Arbeit orientiert sich an den folgenden vier Fragen: (1) Was können wir von natürlichen Ökosystemen lernen? (2) Was können wir vom Zweiten Hauptsatz der Thermodynamik lernen? (3) Wie kann man im Zusammenhang mit nachhaltiger Energiewende den Begriff Region konzipieren? (4) Wie kann man in der Regionalplanung mit heutigen Trends und langfristigen Unsicherheiten umgehen? Während sich die ersten drei Fragen auf Entwurfsprinzipien konzentrieren, beschäftigt sich die vierte Frage vor allem mit dem Entwurfsprozess.

Drei verschiedene methodische Ansätze wurden in dieser Arbeit verfolgt: *Research for design*: Definition von energiebewussten Entwurfsprinzipien basierend auf Wissen aus der Ökologie und Thermodynamik. *Research of planning and design*: Verbesserung des regionalen Entwurfsprozesses basierend auf dem Studium von bestehenden Planungs- und Entwurfmethoden. *Research-driven design*: Entwurf von nachhaltigen Energielandschaften auf der Basis von Literatur- und Fallstudien.

Zunächst wurde studiert wie natürliche Ökosysteme im Laufe ihrer Entwicklung die Assimilation erneuerbarer Energien steigern und optimieren. Eine Anzahl von Konzepten aus der Ökologie, zum Beispiel *Systemgröße*, *Energiequelle/Senke* und *Sukzession*, sind höchst relevant für energiebewusste Raum- und Landschaftsplanung. Verschiedene Ökosystemstrategien, zum Beispiel *Energiekaskade*, *Differenzierung von Nischen* und *Symbiose*, vermitteln weitere Einsichten für den Entwurf von nachhaltigen Energielandschaften. Es ist wichtig anzumerken, dass die von der Natur inspirierten Entwurfsprinzipien informierend sind, nicht alle können hundertprozentig in der Stadt- und Landschaftsplanung angewandt werden.

Um die zweite Untersuchungsfrage zu beantworten, habe ich den *Ersten und Zweiten Hauptsatz der Thermodynamik* und deren Anwendung in der Technischen Thermodynamik, Industrial Ecology und Architektur/ Städteplanung studiert. Während der Erste Hauptsatz beschreibt, dass

Energie weder produziert noch zerstört werden kann, ergänzt der Zweite Hauptsatz, dass während jeder Energieumwandlung nutzbare Energie in weniger nutzbare Energie umgewandelt wird und somit für die weitere Nutzung verloren geht (zum Beispiel Wärme in Umgebungstemperatur). Mit Hilfe des Zweiten Hauptsatzes ist es Ingenieuren gelungen, den Primärenergieverbrauch von Kraftwerken und in der industriellen Produktion zu verringern. Architekten und Städteplaner haben begonnen, den Energieverbrauch in der bebauten Umgebung zu reduzieren, unter anderen durch die Anwendung des Zweiten Hauptsatzes der Thermodynamik. *Exergy* ist ein Schlüsselbegriff für das so genannte *second-law thinking*. Exergie ist definiert als die maximale Menge an Arbeit, die von einem Energieträger verrichtet werden kann, bis sich der Energieträger im Gleichgewicht mit seiner Umgebung befindet (zum Beispiel gleiche Temperatur). Die Arbeitsfähigkeit von Energieträgern ist somit nicht alleine von ihrer energetischen Eigenschaften, sondern auch von Ort und Zeit abhängig. Das Verständnis des Zweiten Hauptsatzes erlaubte mir zusätzliche (exergie-bewusste) Entwurfsprinzipien für die Entwicklung nachhaltiger Energielandschaften zu beschreiben.

Trotz der vielen offensichtlichen Vorteile von erneuerbaren Energieträgern wird der Übergang zu nachhaltige Energiesystemen durch verschiedene Probleme erschwert. Unter den Aspekten, die möglicherweise durch energiebewusste Raumplanung und Landschaftsarchitektur gelöst werden können, habe ich mich auf die folgenden drei Schwerpunkte konzentriert: (1) periodische Schwankungen in der Energieversorgung, (2) relativ niedrige Energiedichte von erneuerbaren Energieträgern und (3) die begrenzte Kapazität, die zur Verfügung stehenden Energien zu nutzen. Kann das Wissen aus Ökologie und Thermodynamik helfen, diese Probleme zu überwinden und die Entwicklung nachhaltiger Energielandschaften voranzutreiben? Erfahrungen aus den regionale Fallstudien in Süd-Limburg und Südost Drenthe zeigen, dass die theoretischen Konzepte aus Ökologie und Thermodynamik nicht nur den Entwurf von nachhaltigen Energielandschaften erleichtern, sondern auch helfen mit den spezifischen „Nachteilen“ von erneuerbaren Energien umzugehen. Die Fallstudien zeigen auch, dass die räumliche Organisation nicht nur bestimmt *wo* erneuerbare Energien assimiliert und verwendet werden, sondern auch Einfluss darauf hat *wie viel* Energie assimiliert wird, mit *welcher Qualität* und zu *welchem Zeitpunkt*.

In den Bereichen Architektur und Stadtplanung hat die Energiewende in den letzten Jahren mehr und mehr Aufmerksamkeit erfahren. Auf der regionalen Ebene besteht jedoch noch ein erhebliches Potenzial, den Energiebedarf weiter zu verringern und den Anteil erneuerbarer Energien zu erhöhen. Mehrere Konzepte der Systemtheorie können dabei helfen das räumliche Konstrukt “Region” besser zu verstehen. Jede Region ist ein *offenes System*; Energie, Material und Informationen werden mit anderen Systemen ausgetauscht. Sobald die Größe eines solchen Systems vom energetischen Optimum abweicht, wird zusätzliche Energie benötigt, um das System aufrechtzuerhalten. Die *optimale Systemgröße* hängt unter anderen von der Qualität der Energieträger und der Infrastruktur ab. Das *Hierarchie* Konzept besagt, das Regionen nicht nur aus mehreren Subsystemen bestehen, sondern auch Teil eines (oder mehrerer) größeren Supersystems sind. Regionale Energiesysteme lassen sich am besten optimieren, wenn Energie in beide Richtungen fließen und über regionale Grenzen hinaus transportiert werden kann. Die Fallstudien zeigen, dass eine regionale Herangehensweise helfen kann, die Lücke zwischen (inter)nationalen Zielsetzungen und lokalen Initiativen zu schließen. Dennoch, mit dem regionalen Maßstab steigt auch die Komplexität von Städteplanung, Raumplanung und Landschaftsarchitektur.

Wie man mit der Komplexität von Planung und Entwurf im regionalen Maßstab umgehen kann, wird in einem separaten Kapitel diskutiert. Viele Planer und Architekten betonen die Notwendigkeit mit Visionen zu arbeiten, insbesondere wenn es um die langfristige Umgestaltung großer Gebiete geht. Eine Studie verschiedener Methoden in der strategischen Raumplanung und Landschaftsplanung liefert wichtige Bausteine für eine neue Herangehensweise. Dieser so genannte *five-step approach* zielt darauf ab, das Erstellen von langfristigen Visionen zu erleichtern, unter anderen durch die Integration von aktuellen Trends und kritischen Unsicherheiten. Wie allgemein üblich beginnt der Prozess mit der Analyse der gegenwärtigen Bedingungen. Die heutige physische Realität ist jedoch nicht der einzige Ausgangspunkt für den Entwurfsprozess. Anstatt mit topographischen Karten zu beginnen, werden die regionalen Visionen auf der Grundlage einer “Karte für die nahe Zukunft” und eine Reihe von “Szenario Karten“ erstellt. Jede einzelne Vision illustriert eine alternative Zukunft und identifiziert Maßnahmen, die dazu beitragen, dieses Zukunftsbild zu realisieren. Der Entwurfsprozess ist in fünf Schritten organisiert: (1) analysieren von gegenwärtigen Bedingungen, (2) kartieren von möglichen Entwicklungen in der nahen Zukunft, (3) illustrieren von möglichen langfristigen Entwicklungen, (4) erstellen von integrierten Visionen, und (5) identifizieren von strategischen (in diesem Fall energiebewussten) Interventionen in der Region. Dieser Methode führt nicht zu einem Regionalplan im herkömmlichen Sinne, sondern zu einer Anzahl von Zukunftsvisionen sowie einer Liste möglicher räumlicher Eingriffe. Die Fallstudien zeigen, dass diese alternative Herangehensweise das Engagement von Entscheidungsträgern verbessert sowie Bürger motivieren kann, an der nachhaltigen Umwandlung ihrer Region mitzuwirken.

Das letzte Kapitel diskutiert den Einsatz der von mir beschriebenen Methodik für die Erstellung einer Reihe von *regionalen Energievisionen* für eine große Gemeinde im Süden der Niederlande. Die Fallstudie offenbart, dass die Methodik nicht nur für die Erstellung von langfristigen Zukunftsvisionen nützlich ist, sondern auch für die Identifikation konkreter Interventionen. Darüber hinaus zeigt die Fallstudie, dass Energieautarkie in Margraten erreicht werden kann, selbst auf der Grundlage heute verfügbarer Technologien. Um Schwankungen in Energieangebot und Nachfrage zu bewältigen, ist es wichtig einen Mix von verschiedenen Energiequellen und Technologien zu etablieren. Die Veranschaulichung von möglichen Auswirkungen einzelner Eingriffe (z. Bsp. auf das Landschaftsbild) kann die Entscheidungsfindung erleichtern. Ich bin überzeugt, dass Planer, Architekten und Landschaftsarchitekten zur Energiewende beitragen können, zum Beispiel durch die Identifikation, Illustration und Evaluierung energiebewusster Eingriffe.

Das Ziel dieser Forschungsarbeit war es, zur besseren Planung und Gestaltung nachhaltiger Energielandschaften beizutragen. Inspiriert durch das Studium von Ökologie und Thermodynamik, trägt diese Arbeit zu einem wachsenden Fundus an Wissen über nachhaltige Energielandschaften bei. Designer (im Allgemeinen und nicht *ad hominem*) müssen danach streben, energie-bewusster zu werden. Das beginnt mit der Auswahl von Pflanzenmaterial und reicht bis zur räumlichen Organisation von Landnutzung im regionalen Maßstab. An vielen Stellen in dieser Arbeit betone ich die Notwendigkeit *nachhaltige* Energielandschaften zu entwickeln. Ich bin davon überzeugt, dass der Übergang zu erneuerbaren Energien stattfinden wird, mit oder ohne Beteiligung von Raumplanern und Landschaftsarchitekten. Sicherzustellen, dass die Energiewende in einer nachhaltigen Art und Weise stattfindet, sollte unsere Zielsetzung sein. Die Entwicklung von nachhaltigen Energielandschaften verdient nicht nur besondere Aufmerksamkeit, die Energiewende bietet auch viele Möglichkeiten die Wissensbasis der Landschaftsarchitektur zu erweitern und zu vertiefen. Die Kombination von Forschung und Entwurf, präsentiert in dieser Arbeit, hat geholfen energiebewusste Entwurfskriterien zu definieren und eine alternative Herangehensweise für den regionalen Entwurfsprozess zu entwickeln.

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C E R T I F I C A T E

The Netherlands Research School for the
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Sven Stremke

born on 11 July 1976 in Rostock, Germany

has successfully fulfilled all requirements of the
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- Techniques for Writing and Presenting Scientific Papers
- Seminar Landscape Architecture

Oral Presentations

- Ruimteconferentie 2007 (RPB), 30 October 2007, Rotterdam, The Netherlands
- SENSE-EPCEM Symposium 2008, 10 October 2008, Wageningen, The Netherlands
- Passive and Low Energy Architecture PLEA 2008 conference, 24 October 2008, Dublin, Ireland
- Smart And Sustainable Built Environment SASBE 2009 conference, 17 June 2009, Delft, The Netherlands,
- International Conference on Renewable Energy Approaches for the Spatial Environment INCREASE 2009, 16 October 2009, Beijing, China
- International Federation of Landscape Architects IFLA 2009 world congress, 22 October 2009, Rio de Janeiro, Brazil

SENSE Coordinator PhD Education and Research

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Curriculum Vitae

Sven Stremke was born on July 11, 1976 in Rostock, Germany. After graduating from the Albert Schweitzer secondary school in Blankenhain in 1995, he volunteered for one year at the local hospital. Before enrolling in the Landscape Architecture program in Erfurt, he did an one-year preparatory internship with LaNaServ. During his studies, Sven received a scholarship from the Carl Duisberg trust and worked for six months for Madison Cox Design in New York City. In 2001, Sven graduated with honors as Diplom Ingenieur Landscape Architecture. His graduation project, the design of a roof garden in New York City, was supervised by Madison Cox and Prof. Dr. Andreas Naumann.

For the following two years, Sven worked as a freelance landscape architect both in the United States and Germany. In 2003, he enrolled in the English-taught Master of Landscape Architecture program (MLA) at Anhalt University in Germany. In 2004, Sven did an internship with 1:1 Stadslandschappen in Amsterdam. In 2005, he obtained his M.Sc. degree with cum laude; his graduation project on the perception and design of transitional spaces along highways and railroads was awarded the MLA best thesis award.

After graduating from Anhalt University, Sven started working with Soler Morató Architects in Barcelona. Soon after moving to Spain, he was offered a position at the Landscape Architecture chair group at Wageningen University. Having the chance to conduct his doctoral research in the Netherlands, Sven started working for the university and joined the WIMEK research school in the summer of 2006. In his doctoral research, he studied sustainable landscapes with a special focus on the regional scale and energy. Between 2006 and 2010, Sven collaborated with researchers from three Dutch Universities in a project entitled 'Synergies between Regional Planning and Exergy'. Over the past years, Sven has had the opportunity to present and discuss his research at various occasions in the Netherlands, Belgium, Ireland, South Africa, China and Brazil.

Sven combines research with conducting graduate student ateliers and supervising thesis projects. He is also an examiner for the 'Mooi Nederland' innovation program on the identity of energy landscapes, funded by the Dutch ministry of spatial planning. Following his doctoral research, Sven will continue to work with the Landscape Architecture chair group at Wageningen University. His aim is to combine research on the mitigation of and the adaptation to climate change. In addition, Sven will continue teaching and conducting external projects, both within the Netherlands and abroad.

DESIGNING SUSTAINABLE ENERGY LANDSCAPES
CONCEPTS, PRINCIPLES AND PROCEDURES

SVEN STREMKE

Abstract The depletion of fossil fuels, in combination with climate change, necessitates a transition to sustainable energy systems. Such systems are characterized by a decreased energy demand and an increase in the use of renewables. The objective of this dissertation is to advance the planning and design of sustainable landscapes, where energy needs can be fulfilled by locally-available renewable sources. What is important to the designer is to understand the principles by which sustainable energy landscapes can be designed, and how to organize the design process. Three different approaches have been pursued: research for design, research of design, and research-driven design. The study reveals three points of particular importance. First, the concept of exergy is critical; it draws special attention to the quality of energy carriers and the organization of sources and sinks in space and time. Second, the optimum scales of energy systems vary and depend on factors such as the quality of the energy carrier and infrastructure. Third, the long-term nature of creating sustainable landscapes requires us to go beyond conventional planning and design practice. The five-step framework proposed in this dissertation can help to integrate current trends and critical uncertainties into the design process.

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