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CITIES READY FOR ENERGY CRISES – BUILDING URBAN ENERGY RESILIENCE

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Summary

Various sources indicate that threats to modern cities lie in the availability of essential streams, among which energy. Most cities are strongly reliant on fossil fuels; not one case of a fully self-sufficient city is known. Engineering resilience is the rate at which a system returns to a single steady or cyclic state following a perturbation. Certain resilience, for the duration of a crisis, would improve the urban capability to survive such a period without drastic measures.

The capability of cities to prepare for and respond to energy crises in the near future is supported by greater or temporary self-sufficiency. The objective of the underlying research is a model for a city – including its surrounding rural area – that can sustain energy crises. Therefore, accurate monitoring of the current urban metabolism is needed for the use of energy. This can be used to pinpoint problem areas. Furthermore, a sustainable energy system is needed, in which the cycle is better closed. This will require a three-stepped approach of energy savings, energy exchange and sustainable energy generation. Essential is the capacity to store energy surpluses for periods of shortage (crises).

The paper discusses the need for resilient cities and the approach to make cities resilient to energy crises.

Keywords: engineering resilience, energy crisis, urban energy system, self-sufficiency, urban metabolism

1. Introduction

1.1 Energy and cities

In 2003, David Godschalk identified the threats to which modern cities are confronted, both from natural hazards and terrorism, recommending a resilient cities initiative [Godschalk 2003]. However, a seemingly much more friendly threat to cities is posed by hampering supplies of food, water, products, and – not least – energy. Depending on the source used, buildings use approximately 30-40% of all energy in our society. In a city, with heavy industries lacking, this contribution can be even estimated at 50-60%. In Western Europe, the urban heat demand is still predominant: approximately 80% of all energy use in buildings [SenterNovem, 2008].

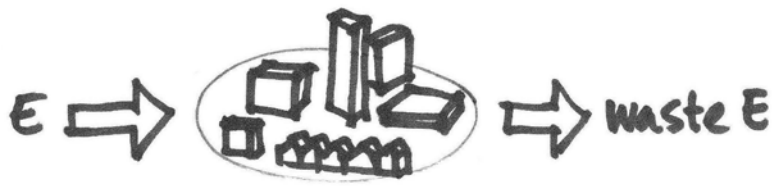

Figure 1: Principle of the current situation of a city using energy generated outside its boundaries and again dumping waste energy (mainly heat)

1.2 Electricity dependence

Nevertheless, whether provided by natural gas, mineral oil, wood or industrial waste heat, this heat cannot be delivered to individual buildings without the use of electricity, which is commonly generated outside the city and transported through high-voltage lines. Recent figures of European Wind Energy Association indicate that by 2007 75% of the energy mix in Europe was constituted from fossil energy sources and nuclear power. Between the years 2000 and 2007 there was a considerable growth in the installation of wind turbines but even more in gas-fired power plants [EWEA 2008]. This means that for the coming decades the built environment will still strongly rely on finite resources, of which secure supply may become uncertain in the near future.

1.3 Halted supplies

Moreover and regardless of the cause of these, the past decade has shown several incidents of power plant black-outs (all over the world), airplane or helicopter crashes into high-voltage lines (e.g. Bommelerwaard, Netherlands, 2007), enforced halting of gas supplies (e.g. Ukraine, 2006 and 2011), terrorist attacks (hydro-power plant, Russia, 2010), and even nuclear meltdowns (Fukushima, Japan, 2011), which temporarily disturbed the functioning of urban areas. Some of these were caused by technical deficiencies, some by accidents, some by natural disasters, some by terrorists. In the near future another cause will be probable: the short-coming supply of oil, gas or coal. Therefore, Godschalk's recommendation to work on resilient cities seems a wise one, although he was not referring to the energy supply.

1.4 Not one self-sufficient city

Despite ambitious climate goals of cities like London, Copenhagen, Hamburg and Amsterdam, not a single European city is fully self-sufficient in terms of energy, which increases the probability of serious problems when energy supplies are hampered by any form of crisis. In order to respond to this, a comprehensive approach to the entire energy system of a city and its environs is needed, but this model or approach is not available yet.

1.5 Directions

What modern cities with aspirations for a long sustainable futures, at least according to us, need is resilience, which will be discussed in the following chapter. Resilience to any form of energy crisis demands for understanding of the current urban metabolism for energy and waste energy. In a resilient, sustainable urban system the energy cycle is better closed. This requires a three-stepped approach of savings, exchange & storage, plus sustainable generation. Quintessential is continuous supply and/or capacity to store energy surpluses for periods of shortage (crises). Our hypothesis is that this will be most probably achieved by a comprehensive approach to the interactive system of a city and its surrounding metropolitan region.

Full self-sufficiency is not necessarily the goal; resilience for the duration of a crisis would however improve the urban capability to survive without drastic measures. Moreover, local provision of energy would help the local economy and significantly reduce greenhouse gas emissions.

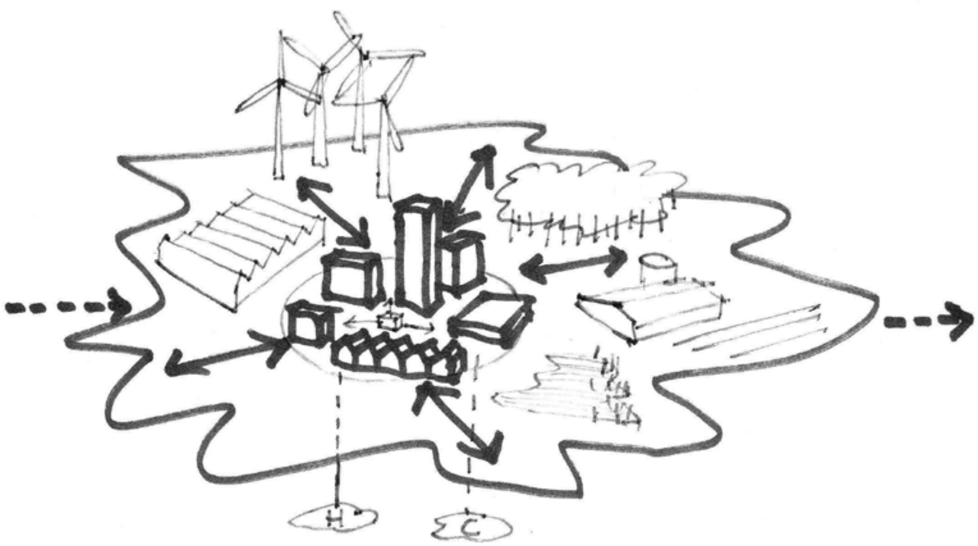

Figure 2: Sketch of a more sustainable, resilient situation of a city more self-reliant and in interaction with its surrounding region, which together predominantly generate, reuse and store energy

The underlying research proposal intends to achieve this goal in an innovative and integrative manner: by creating a comprehensive urban model for an energy system by means of which a city can sustain itself in a time of crisis or disaster for at least one year.

2. Starting-points

2.1 Resilience

Resilience is an ecological term. Resilience Alliance [www.resalliance.org] describe the term as "the ability to absorb disturbances, to be changed and then to re-organize and still have the same identity (retain the same basic structure and ways of functioning). It includes the ability to learn from the disturbance." Authority in the field of ecology C.S. Holling distinguishes ecological resilience and engineering resilience. He defines ecological resilience as "a measure of the amount of change or disruption that is required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures" [Holling 1973], whereas engineering resilience is "the rate at which a system returns to a single steady or cyclic state following a perturbation" [Holling 1996]. Others, such as Pumm [1984], use the term of resilience only in accordance with the meaning of engineering resilience. For the presented research on urban resilience we also use Holling's definition of engineering resilience as the basis, projected at the system of a city or metropolitan region. Usually the term is perceived in relationship with climate change and the adaptation to it, a topic currently addressed in various research projects in Europe. The research project presented however focuses on the urban capability to prepare for, respond to, and recover from hampering energy supplies.

2.2 Charting the energy potentials

The basis of a successful approach to energy-neutral cities probably lies in a meticulous analysis of existing urban areas, as incorporated in Energy Potential Mapping [Dobbelsteen et al. 2011a] and heat mapping [Broersma et al. 2011]. Figure 3 gives examples of these.

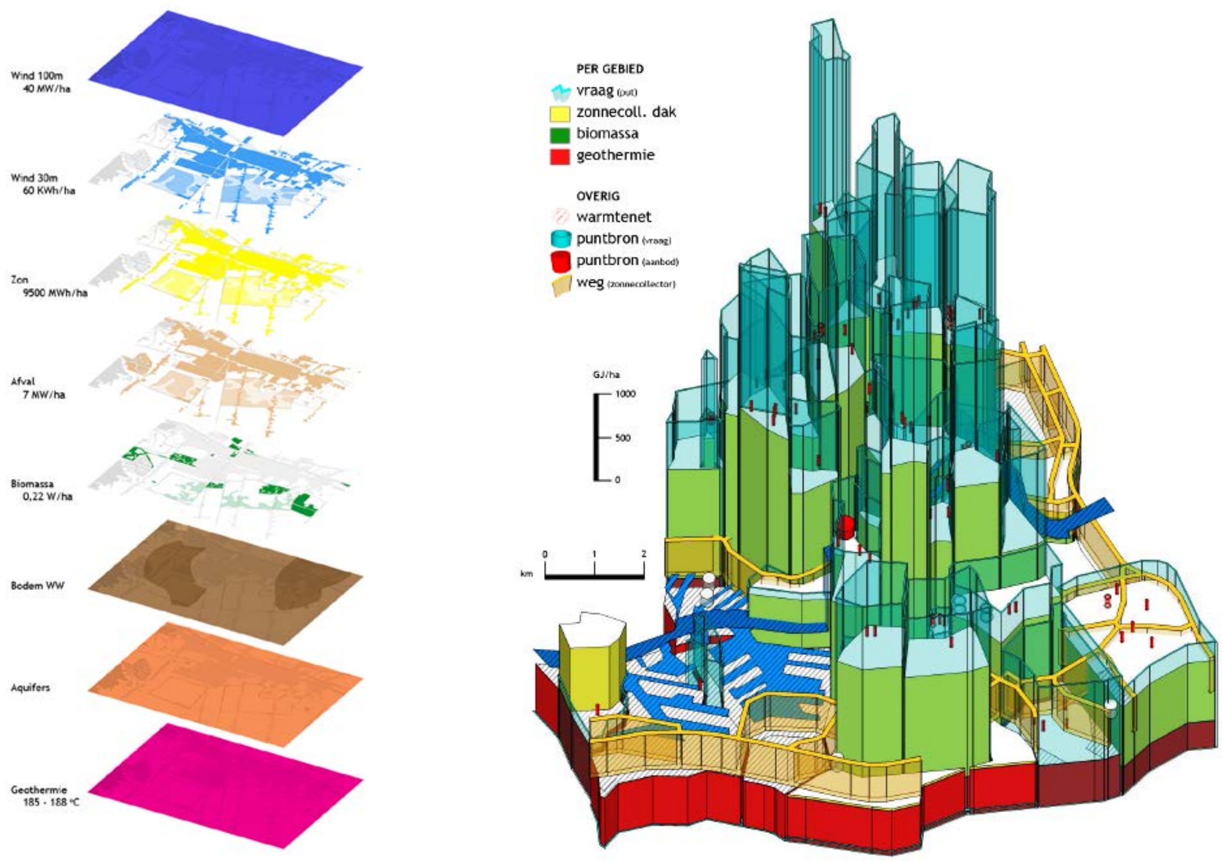

Figure 3: The energy potential stack of the new district of Hoogezand-Sappemeer in the Netherlands, showing all energy potentials, from higher winds down to geothermal potentials [Dobbelsteen et al. 2011a] (left), and heat map of the centre of Rotterdam, depicting demand (hollow cores) and supply potentials (full cores, lines and dots) of heat in the city [Broersma et al. 2010] (right)

In the Netherlands, Energy Potential Mapping has already been used in various studies, at various scale levels. Examples of these are the Province of Groningen, Cities of Amsterdam, Almere and Tilburg, Schiphol Airport and urban extension of Hoogezand-Sappemeer. The method was also used for the

American city of Spokane. Based on the determination of local renewable energy potentials, oftentimes a plan could be proposed that was energy neutral, deviating from a traditional, unsustainable plan.

2.3 Urban energy approaches

Propelled by cities' ambitions to become climate, carbon or energy neutral in due time, research on the energetic consequences of urban planning is becoming an essential expertise for sustainable development. Merging spatial planning with technical knowledge, energy has increasingly become the topic of methods and approaches to what we may call 'energetic urbanism' [Dobbelsteen & Tillie 2011]. Two of the most appealing approaches are the Rotterdam Energy Approach & Planning (REAP) [Tillie et al. 2009] and the Amsterdam Guide to Energetic Urbanism (LES) [Kürschner et al. 2011]. Other important developments relate to the industrial ecology approach to cities, as applied in Hammarby Sjöstad (Stockholm, Sweden) or Kalundborg in Denmark, taking into account all essential streams in a city.

At the basis of these models lies the New Stepped Strategy [Dobbelsteen 2008] (figure 4). This incremental approach was proposed as to improve the older Trias Energetica [Lysen 1996]. Step 1 of the NSS (reduce) is the avoidance or reduction of the demand for energy. Step 2 (reuse) encompasses the reuse, exchange and cascading of waste energy. Step 3 (produce) finally requires that the sustainable supply of the remaining demand is solved by renewable sources and that all waste streams now still coming out of the system does not disturb the environment. This latter advice was inspired by the Cradle to Cradle philosophy [McDonough & Braungart 2002]. In a transition period a fourth step may be necessary: the clean and efficient use of finite energy sources (fossil fuels and uranium).

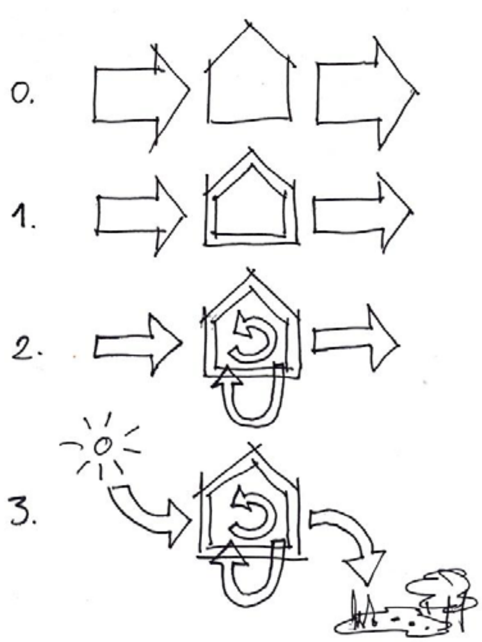

Figure 4: The New Stepped Strategy [Dobbelsteen 2008]

REAP was one of the first worldwide methods to approach energetic urban planning in a structured way. It extended the NSS to different scales of urban planning: buildings, neighbourhoods, districts and cities. Thereby, proceeding from step 1 to step 2 with buildings, the focus could be shifted to a smarter exchange of energy on higher scale levels (the neighbourhood or district level), instead of proceeding immediately to the sustainable generation at the building scale.

Following REAP, Amsterdam worked on guidelines for all parties involved in urban design and planning. For the Amsterdam Guide to Energetic Urbanism (LES in Dutch, coming from Leidraad Energetische Stedenbouw), the New Stepped Strategy also formed the basis. This time it was elaborated to various measures and factsheets for the planner, developer, architect or municipal official.

Meanwhile, in Rotterdam REAP was further enhanced by the REAP2 study [Dobbelsteen et al. 2011b], connecting the approach to technical, spatial, social, legal and institutional aspects. Amongst other ideas REAP2 led to the proposal of new heat exchanging facilities for neighbourhoods, as well as smart grids that could serve different demands from buildings (figure 5).

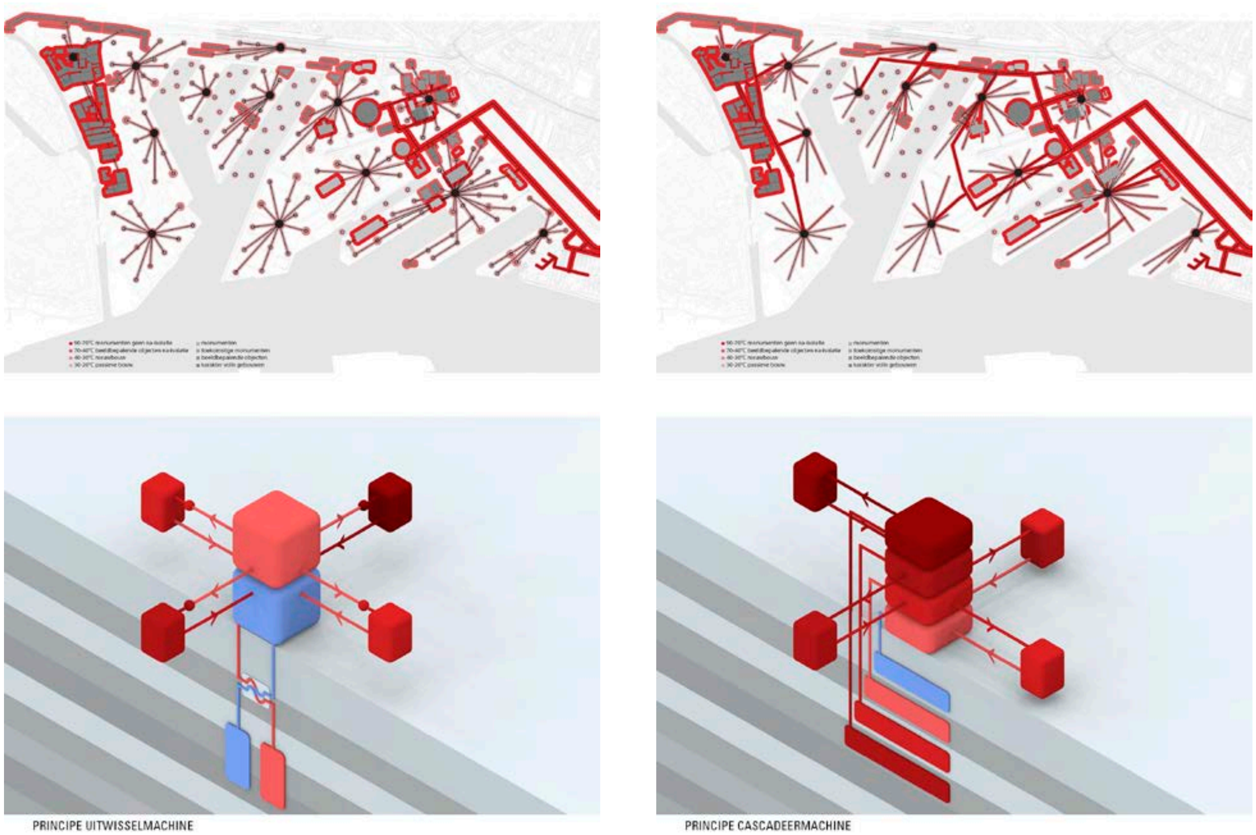

Figure 5: New ideas for heat exchange and storage on the neighbourhood scale in the Merwe-Vierhavens district: inter-exchanging machine (left) and cascading machine (right) [Dobbelsteen et al. 2011b]

2.4 Requirements for a new model

A new model for resilient cities has to comply with certain requirements before it can be effective and realistic. It needs to provide insight in:

- the energy metabolism of the city and its environs
- current energy usage patterns in a city and possibilities to influence them
- solutions for the reduction of the demand for energy in cities
- optimal utilisation of superfluous energy
- possible interaction of cities with their hinterland for the provision of energy
- possible generation of energy in the city and its hinterland.

2.5 Inter-disciplinary, technically

Urban resilience to energy crises cannot be tackled by a focus on just one or two elements of the entire system. We attempt to cover the complete energy system of cities and their hinterland, aiming at a systematic approach for each part of the system, as a first scientific step towards detailed elaboration of these separate parts. Consequently, the urban resilience problem cannot simply be solved by one or two fields of science. The project therefore is inter-disciplinary, involving disciplines that form the building blocks of the theoretic model presented below: urbanism, architecture, technology and engineering, computation and landscape architecture. And this only regards disciplines of technical design and planning (we have to start somewhere…) – not the social, economic, legal and political fields, which are quintessential to the actual realisation of the plans involved. This combination of specialisms is a challenge, but all sustainability assignments are.

3. First model for a resilient city

3.1 Theoretic model

Figure 6 illustrates the theoretic model we propose for a resilient city.

In the current situation of a city with its typical energy patterns, externally generated energy is input to the city (1a) or city region (1b), whilst waste (energy) leaves the city (2a) or city region (2b). In a more resilient situation the demand for energy in the city is reduced (3) and internally reused, exchanged, cascaded or stored (4). When not solvable within the urban boundaries, the city region can help to exchange energy and waste (energy) (5). Finally the city can generate renewable energy within its own boundaries (6) or close a deal with its surrounding region, where more space for energy generation is available, for supply of renewable energy to the city (7).

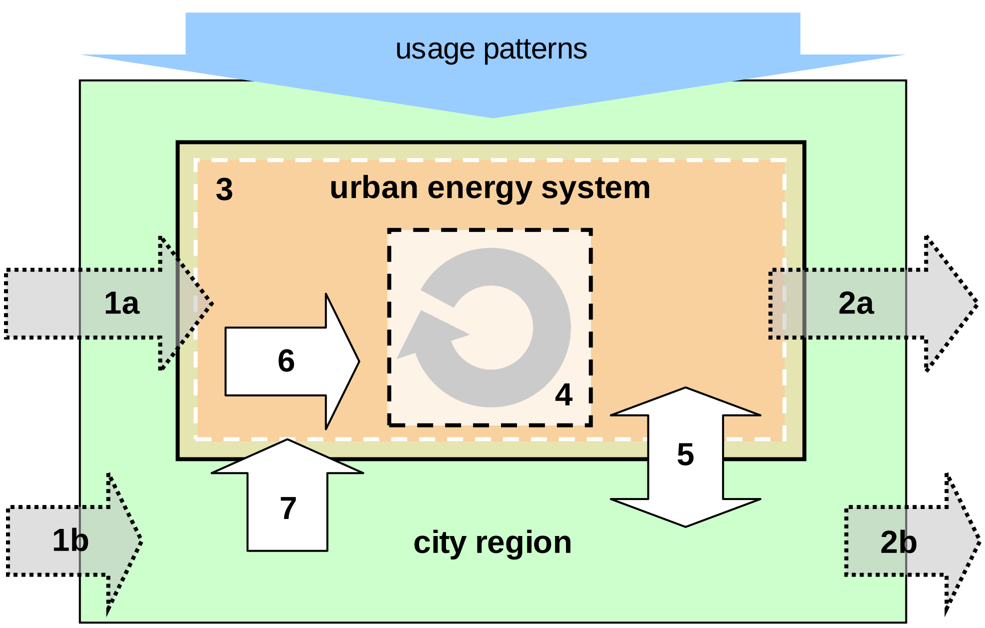

Figure 6: Theoretic model with components of a city as an energy system

3.2 Usage

At the basis of it, knowledge on energy patterns (demands) and potentials (supplies), as well as their particular problem areas are quintessential – and so is the monitoring of these in a new situation. This can only be supported by a comprehensive computer model, tested and validated on case studies before and after the proposed interventions. Furthermore, this model can provide the basis for regular municipal energy accounting, which is needed to show progress or lack of it. Cases as the Danish island of Samsø demonstrated that meticulous accounting of incoming and outgoing streams of energy can help to swiftly indicate successes and weaknesses, supporting effective measures. As may be known, Samsø became energy neutral within ten years after its transition start, thanks to sustainable technology (e.g. wind turbines, a solar plant, straw ovens) invested into by citizens, companies and public institutions.

3.3 Energy conservation

With a common European construction rate of less than 1% per year in regards to the existing real estate stock, less than 10% of new (sustainable, energy-neutral) buildings can be added within ten years. This means that in ten years' time 90% of what you can see today will still be there, including all buildings from energy-inefficient construction eras. Therefore, energy conservation in existing buildings is the most effective solution to reduce the demand for fossil fuels, thereby diminishing the dependence on these. To new buildings, an energy-saving design is often most economical before costly investments in technical solutions.

Based on the inventory of demands, plus an analysis of urban morphology and building typology, energy-saving potentials in urban planning, building design, industrial processes and transport can be calculated, leading to design and planning propositions for the case studies.

3.4 Utilising superfluous energy

As resilience to energy crises will largely be based on availability of energy that once was superfluous, a focus on optimising the use and storage of residual energy is paramount. Hence, the production of waste energy in cities and the potential to seize this superfluous energy for direct or delayed reuse needs to be accurately determined. This type of energy consequently can be utilised for exchange among urban functions, for cascading to functions that require energy of a lesser quality, or for storage enabling use in later periods of possible shortage, such as in cases of crises.

In particular for renewable energy sources inter-seasonal and diurnal storage will become quintessential, since renwable energy does not come as constantly as fossil fuels can be delivered in an undisturbed situation. Therefore, cities will have to prepare, build and maintain these facilities of storage soon.

3.5 Regional exchange

With underground supplies of fossil fuels endangered, the world of tomorrow will have to solve its energy demand at the earth's surface. Hence, energy = space, becoming a competitor to the provision of food, materials, recreation and nature, to mention a few. This implies that from now on we need to carefully reconsider the use of land area as well as built area.

Since dense cities do not have a lot of (horizontal) area per capita, these cannot harness a sustainable energy system on its own: they need the entire metropolitan area and hinterland to get the balance right. Therefore the city-region interaction needs to be mapped and quantified (for instance, exchange of waste with nutrients from the city, for renewable energy and food in return). Furthermore, propositions can be made regarding the design of energy landscapes by means of which the city's energy system can be completed.

3.6 Local generation of energy

Last but not least, the finalisation of a feasible sustainable city resilient to energy crises lies in the generative capacity of the city and its metropolitan region. Cold as many a country may be (for instance the mean temperature in the Netherlands still lies 10^{o}C below comfort level), in most cases heat should not be an unsolvable problem. The sun can provide plenty of (passive and active) heat for hundreds of households; geothermal heat and heat from bio cogeneration can add up to that, and for the remaining part waste heat produced in every part of society can fill the gap. The main issue is intermediate store of heat.

Following the statement of energy equalling space, especially the generation of electricity by renewable energy sources is a challenge that will require a lot of building and land surface. The previously mentioned energy potential maps can chart the site-specific possibilities for the generation of energy. An energy catalogue could contain all technical and spatial possibilities for sustainable production techniques for heat and cold, electricity and fuel. Together these tools constitute the foundations for a proposal for spatial and technical interventions.

4. Conclusions and discussions

4.1 Relevance

The capability of cities to prepare for and respond to energy crises in the near future is supported by greater or temporary self-sufficiency. The model for a city – including its surrounding rural area – that can sustain energy crises is very relevant if we take the future limitations serious. Step one is the accurate monitoring of the current urban metabolism is needed for the use of energy. Measuring raises awareness. As long as cities can make a vow to become carbon, climate or energy neutral without being accounted for the actual figures, there will simply be no incentive or urgency to accelerate the developments. Monitoring will also pinpoint problem areas where measures are most effective.

4.2 Order

The steps from the New Stepped Strategy – reducing, reusing and producing – can support this transition to energy resilience. In the current market the order of the NSS seems to lead to the best results that are feasible. It is however imaginable that if the price of wind turbines and PV panels drops, whereas the construction of infrastructure becomes relatively more expensive, the order might actually change. But in both cases, the capacity to store energy surpluses for periods of shortage (crises) remains essential.

4.3 Impact

The impact of cities attempting to become independent from external provision will be enormous. This applies to all global cities that intend to become energy neutral. A resilient city that relies more on local potentials will demand much less from external sources, having a great impact on the future system of energy supply, which is now supply driven by big energy companies that not necessarily have to strive for a sustainable system as long as economic perspectives for finite resources are still better in the short run. The model and approach resolving from this project can be transferred to other cities, which then could undertake similar endeavours.

4.4 Further research and application

This paper could only discuss the first steps towards the model for cities resilient to energy crises. The work is currently undertaken and will be accelerated within a short timeframe. Then each module can be elaborated and turned into a generic model to be applied anywhere in the world. We notice some reluctance in developed countries to seriously start to work on resilience. Life is probably still too easy. This makes the model ever more important to emerging economies and poor cities of which the reasonably priced supply of energy, water, materials and, not least, food is endangered within the near future. Therefore we embrace any developing country that wants to test and validate the model.

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