The Energy Master Plan: Transition to self-sufficient city regions by means of an approach to local energy potentials

Prof. **Andy van den Dobbelsteen**, PhD MSc

Nico Tillie, MSc

Siebe Broersma, MSc

Michiel Fremouw, MSc

Email address of corresponding author: a.a.j.f.vandendobbelsteen@tudelft.nl

ABSTRACT

City regions and metropolitan areas form the scale on which the battle for will be won or lost, and the level at which cities can become resilient and even self-sufficient. A master plan for a sustainable energy system for city regions is not a luxury anymore.

An energy master plan will be based on incremental steps of transition. The approach needs to start with the charting of energy sources, sinks and unused potentials of a studied area. Herein the method of Energy Potential Mapping can play an essential role. The next step deals with the identification of demand reduction possibilities in the existing built environment – new construction can already be zero energy. Differences in simultaneous discrepancies between supply and demand can be bridged by synergetic systems, heat exchange, cascading and intermediate storage of energy. Finally the remaining demand needs to be solved with renewable energy, inside the city as well as in its environs, which become ever more indispensable to the modern metropolis.

In the energy master plan EPM deals with the identification of supply and demand, supports the finding - in place and time - of energy potentials from sun to magma, helps the discovery of simultaneous mismatches, surpluses and shortages, and helps determine the effect on the urban climate. Mapping is done in 3D, soon to be 4D, including the time factor (diurnal differences, seasonal differences, long-term developments).

Since 2005 Energy Potential Mapping has been developed at TU Delft. It has gained international scientific standing. The advanced 3D method has been used for sustainable energy plans and currently forms the basis for making Dutch regions energy-neutral, in cooperation with local stakeholders. The full paper will describe the Energy Master Plan approach and Energy Potential Mapping method, illustrated by cases executed so far.

1. INTRODUCTION

Sustainable development will become a question of climate adaptation and mitigation (IPCC, 2014) on the one hand and the lasting availability of resources on the other (Haas, 2013). Of these resources, after the basic needs for human survival – oxygen, drinking water and food – energy is the most quintessential element for human society. Without energy no element of civilization can be continued: buildings cannot be operated anymore, drinking water cannot be pumped around or poured into bottles, food cannot be transported from farms to cities and people will be limited again by travel distances they can cover by foot, bike or horse. Energy is the fuel of modern society – the end of energy will be the end of cities as we know them.

One might argue that present-day economy has built in sufficient safety and security for the continued provision of energy and all other needs, but over the past few decades various occurrences have demonstrated that cities are very vulnerable to hampering supplies. For instance, technical failures and black-outs have rendered power plants out of operation (e.g. New York City, USA, 2006), airplane accidents have cut major high-voltage lines supplying urbanized areas (e.g. the central river region, Netherlands, 2009), natural disasters have led to the destruction of power plants (e.g. Fukushima, Japan, 2010), politically driven decisions have blocked supplies (e.g. Russia versus Ukraine, 2009 and 2014), terrorist attacks have damaged energy infrastructure (e.g. Russia, 2010), and – more 'friendly' as we know it – market price mechanisms have influenced supplies in various ways (e.g. the Gulf War effects, late 1990s).

In the past most city regions used to be self-supporting entities: think of the Mesopotamian cities, Greek City states, yet also European mediaeval regional centres. Resource cycles used to be closed, meaning that all food, water, energy and materials came from the direct environs and waste products were reused in that same vicinity. Where this evolved out of balance, cities collapsed – think of the ancient Egyptian centres and Mayan cities on the Yucatán peninsula in Mexico. We are now in an era where none of the world's cities is self-sufficient. Globalisation has made cities strongly dependent on supplies from elsewhere, and wastes are also treated in places mostly not known to citizens. As described with the examples of hampering supplies of energy, this implies cities presently are very vulnerable to failures in the system.

The inevitable conclusion of the previous is that for a secure, sustainable future, cities need to become resilient. A greater extent of self-sufficiency will help to achieve this. Supported by historic examples, city regions and metropolitan areas are still the most suited level at which sources and sinks can be solved locally. Therefore these form the scale on which the battle for sustainability will be won or lost, and the level at which cities can become resilient and even self-sufficient. However, how are we going to transform existing cities or emerging and growing metropolitan areas, with their non-sustainable systems, to sustainable ones?

A master plan for a sustainable energy system for city regions is not a luxury anymore. There is not one single solution that will provide the answer; enforced by successful examples this paper discusses one approach that may help.

2. ENERGY MASTER PLAN

For the research presented the authors based themselves on existing urban regions. Handling an existing city must entail a stepped approach, since commencing with an integrated design from scratch is impossible. The proposed Energy Master Plan will therefore be based on incremental steps of transition.

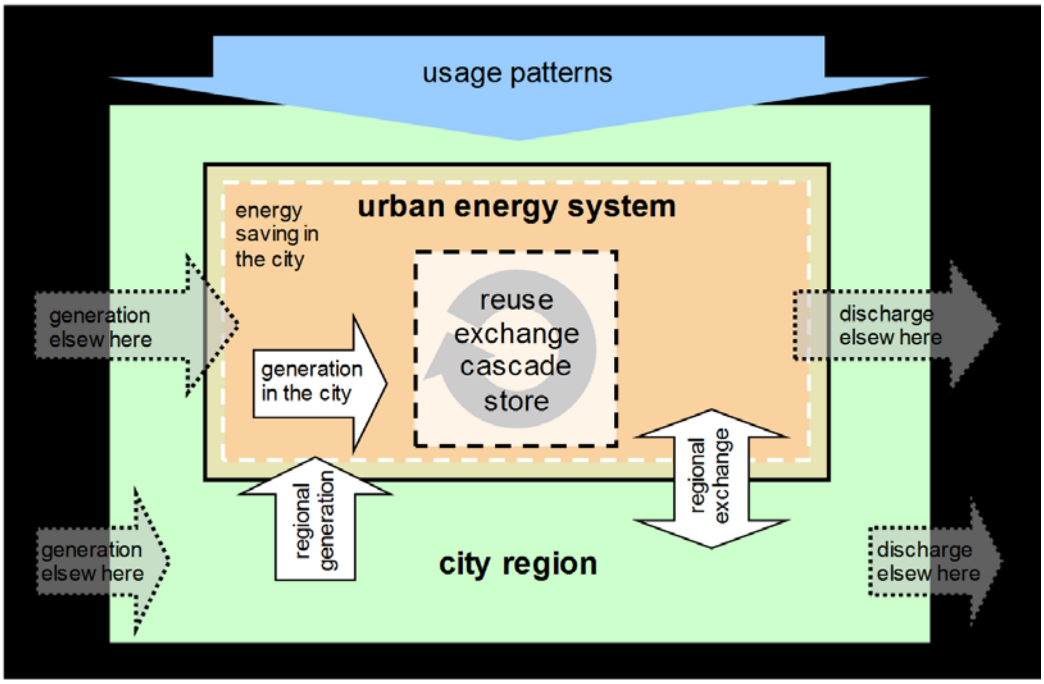

Figure 1 *Graphic depiction of the Energy Master Plan for self-sufficient cities (Dobbelsteen, 2012a)*

A quintessential basis for an effective approach to cities is formed by proper knowledge of the city's use patterns of energy: data are needed of energy consumption, production of energy and residual waste flows, to as much detail as possible. So the Energy Master Plan starts with the charting of energy consumption figures, sources, sinks and unused potentials of the studied area. Herein the method of Energy Potential Mapping discussed further on can play an essential role.

A first real step deals with the identification of demand reduction possibilities in the existing built environment. Every part of the energy demand you can reduce, means avoidance of required energy production; so it is a first step to self-sufficiency. New to be constructed buildings can already be net zero energy. Ambitious cities had better enforce that new development actually is energy-neutral, because all new non-sustainable developments add up to the already present problem. The greatest potential in most cities however lies in an improvement of the existing stock of real estate, so a meticulous analysis of the potential of energy saving in different districts and neighbourhoods, depending on the urban typology and architecture, will help make a leap forward.

A second step deals with the potential that lies within differences between supply and demand. In temperate climates with both heat and cold demands simultaneous discrepancies in demand and supply can be bridged by synergetic systems, heat exchange, cascading and intermediate storage of energy. Heat grids are already well-known in colder climates; these are usually based on high-caloric heat sources, often originating from fossil energy sources. There are however other options (as studied, for instance in the European FP7 projects CELSIUS and City-zen). Lower-temperature grids can also be deployed in order to optimize the exchange of heat (Dobbelsteen et al., 2012b), and cold grids can serve cities with a substantial demand for cooling. Energy can also be reaped from other resources' wastes, such as waste water or waste material. In these cases processing is most likely to be arranged outside the city borders. So inter-exchanging with the region becomes important here.

Finally, the remaining demand needs to be fulfilled with renewable energy, to be generated inside the city but in terms of quantity most logically outside the urbanised area, which has more space to allocate conversion techniques to produce electricity or heat. We should acknowledge that with the fossil reserves depleting, the world's energy supply needs to come from its surface ever more. This entails a competition with other forms of land use: agriculture, nature, recreation, building sites, etc. Therefore we need to become very considerate about the use of land around cities, for which Energy Potential Mapping (EPM) is a proven means to provide insight in the energy potentials locally available inside and outside the city. Taking into account the enormous quantity of energy a modern city consumes, every acre of urbanised area needs at least an acre of energy-productive land. The city's environs therefore become ever more indispensable to the modern metropolis.

3. ENERGY POTENTIAL MAPPING

As discussed, present-day urban energy systems largely rely on a controlled supply, capable of delivering high-exergy electricity and heat when and where required. Dimensioning of energy systems is mostly defined by peak demands. As the many renewable sources from sun to magma are fluctuating and/or take on a lower exergetic form (for example low-temperature heat), knowing both the spatial and temporal behaviour of urban energy demand and supply are paramount to shaping an Energy Master Plan.

The method of Energy Potential Mapping (Dobbelsteen et al., 2011; Broersma et al., 2013a), developed since 2005 at the chair of Climate Design & Sustainability at the Delft University of Technology and having gained international standing, aims to provide quantitative insight in the when and the where of these, visualising both mismatches, surpluses and shortages. The advanced 3D method (soon to be 4D, by detailed geospatial inclusion of the time factor) has been used for sustainable energy plans and forms the basis for making Dutch regions energy-neutral, in cooperation with local stakeholders, by providing them with a palet of possibilities with which they can choose and design appropriate, robust and long term sustainable measures.

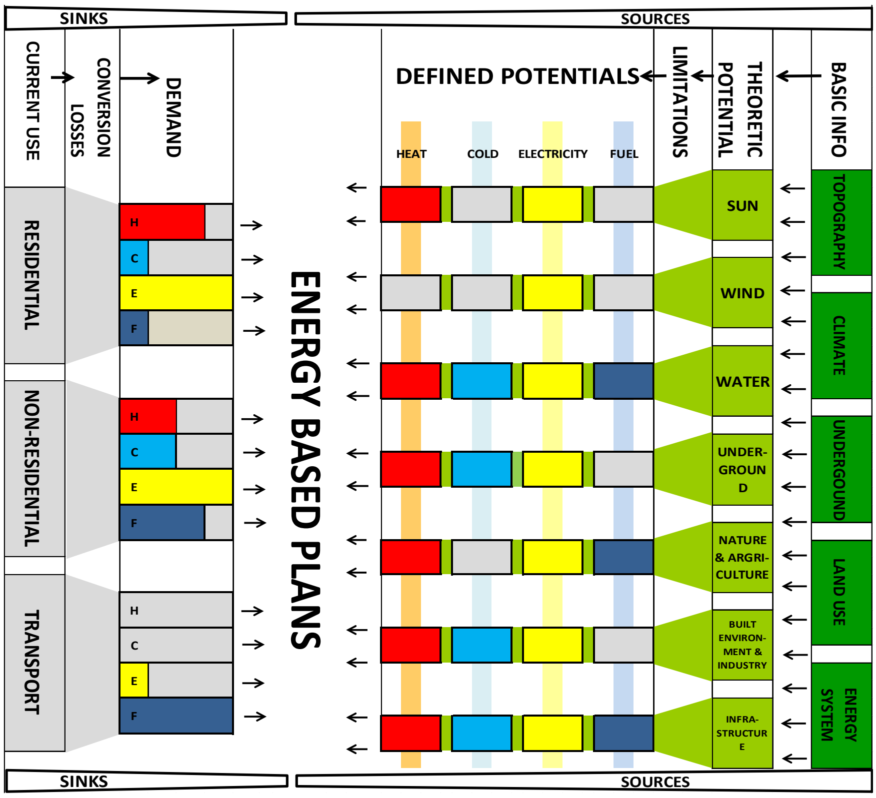

Figure 2 *Graphical explanation of the Energy Potential Mapping method, with consumers at left and potentials at right (Broersma et al., 2013)*

EPM takes into consideration conversion losses and various limitations on the demand side and theoretical renewable supply potentials in order to arrive at a more realistic potential for a chosen area, preferably while promoting multiple land use. An example would be the technical potential of photovoltaic panels on existing roofs, where the amount of solar radiation arriving at a given area is reduced by suitable roof area and orientation and expected long term PV panel performance. This can further be enhanced by structural suitability, glare issues, financial models and other local limitations and results in a detailed but realistic quantitative potential for photovoltaic electricity. Common themes on the demand side are assessing actual demand (thermal comfort, tap water heating, lighting and electricity use of appliances) from known metered figures and reduction potentials.

When combined, these form a stack of maps of many different demand and supply potential categories that provide both detailed quantified insight in and a policy-maker friendly overview of the available potentials, making it possible to arrive at a robust and realistic Energy Master Plan.

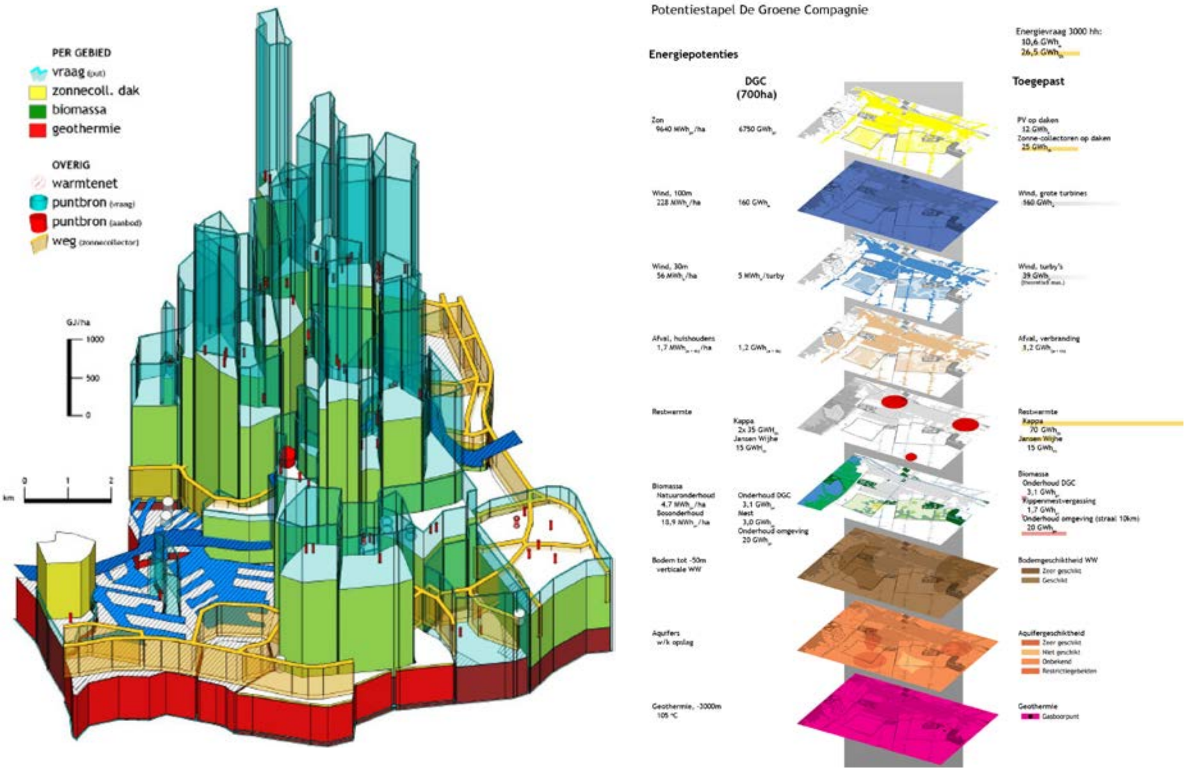

Figure 3 *(Left) Detailed 3D heat map of the central district of the city of Rotterdam: hollow cores indicate heat demands, full cores and layers are heat potentials, natural and anthropogenic (Broersma et al., 2011). (Right) Combined energy potential map stack for a neighbourhood in the Dutch town of Hoogezand-Sappemeer (Broersma et al., 2010).*

4. PRACTICAL APPLICATION IN CITY REGIONS

Rotterdam region

In the Netherlands, data are available for some 30 different housing typologies, for which average energy consumption and measures to improve energy efficiency are known. A step by step energy approach to integrate energy into spatial planning and making energy data easy accessible by EPM has proven to be a crucial part in preparing a stakeholder-based Energy Master Plan in the city.

A first step in building an Energy Master Plan was mapping the existing energy demand and reduction potentials per housing typology, which prioritised actions for policy-makers. Consequently, EPM en Heat Mapping presented the potential use of waste flows and the capacity for renewable energy generation of Rotterdam in a user-friendly format for a wide range of stakeholders as all maps were compatible to Geographical Information Systems (GIS). This meant that urban energy planning could finally be performed. Two cases will show the effect of EPM in GIS in the city. Since 2013 the Energy Atlas of Rotterdam is online. Using a 50 cm by 50 cm pixel grid, solar potentials are presented for the whole city of Rotterdam. This means that each square of 50 by 50 cm is presented with data of the feasibility of installing PV panels. The open data set is used by 2000 citizens and companies every month. Solar data are not only linked to weather data, roof angles, shading, cloud coverage etc. to get potentials as realistic as possible, but also to ownership of buildings. This way the Energy Master Plan can be translated directly into action plans. A second case is rolling out the district heating network in the city. Combining energy demand maps, heat maps, density maps and maps of existing pipelines made it possible to work with housing associations, energy companies and investors to work on a district heating master plan for the city. With threshold values agreed on by stakeholders a future district heating map could be drawn with new areas to connect, or areas to intensify, or areas where district heating was not feasible. This was a clear map for policy-makers, now translated into action plans for each area.

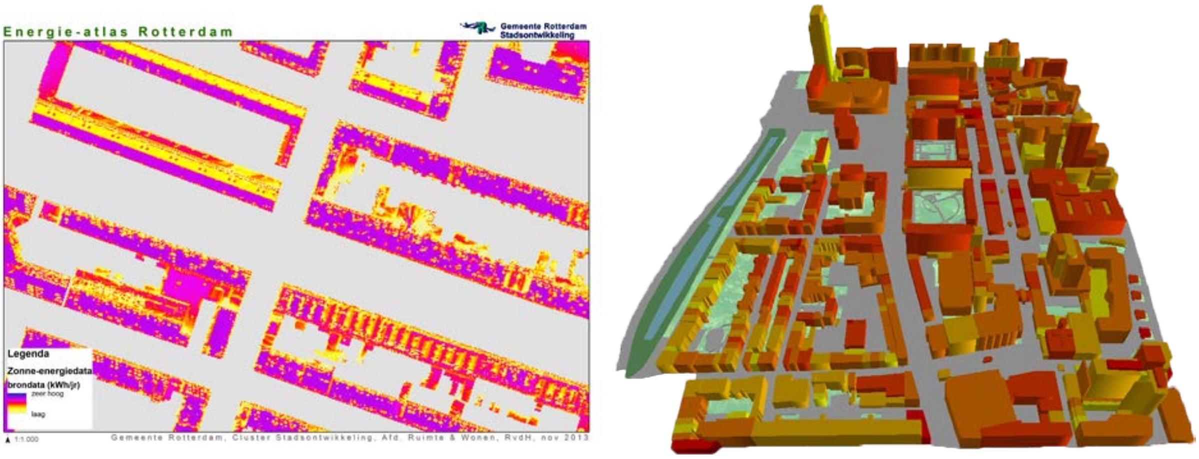

Figure 4 *(Left) 2D solar potential map in GIS of the Lijnbaan neighbourhood in Rotterdam, which can be combined with an ownership map as an example; yellow is low potential. (Right) 3D solar potential map for the same neighbourhood. Roof angles, orientation and shading are integrated in these maps; red is high potential (maps by Roland van der Heijden).*

One more important aspect of EPM is that it constituted the input for energy scenario planning methods such as GRIP, the Greenhouse Regional Inventory Protocol (Carney et al, 2009). A stakeholder-based energy scenario was the basis of the Energy Master Plan.

The energy scenario process can be run using bottom-up or top-down data. However, the internal consistency of the developed scenario pathways and their value for stakeholders will be much higher using local data as they can be directly translated into the Energy Master Plan and local actions. In short, one can state that EPM is an enabler of urban energy planning.

Oostland region

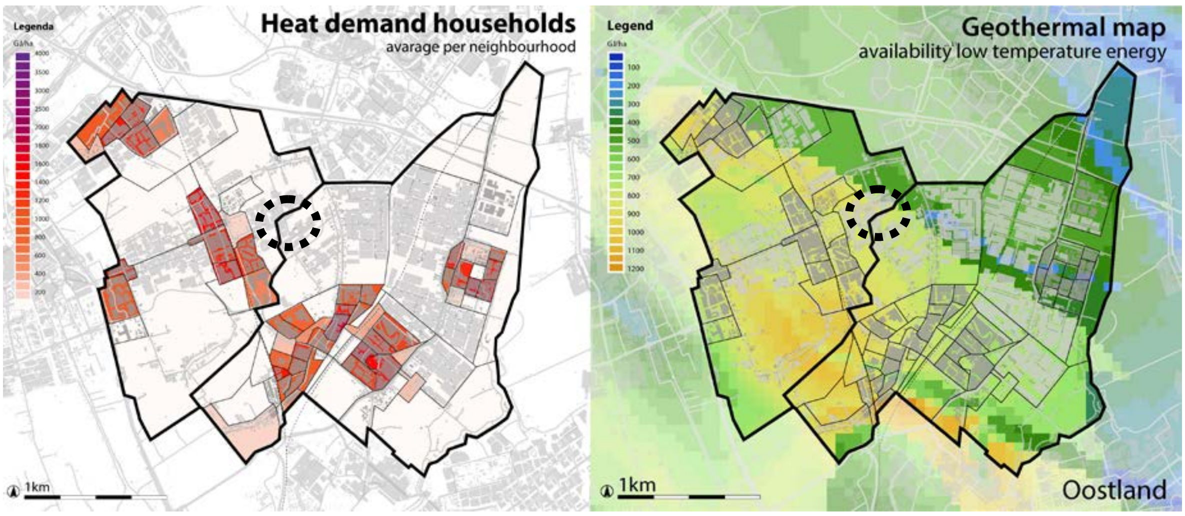

Figure 5: *Energy potential maps of heat demand of households in Oostland (left) and potentials of deep geothermal wells (right) (Broersma et al., 2013b)*

A recent regional energy study, in which the method of EPM was applied, was executed for the Dutch Oostland region (Broersma et al., 2013b). This 100 km^2 area is dominated by horticulture, spread between several smaller towns, including Pijnacker. The energy demand maps of different functions and origins as well as the various maps of sustainable potentials of the region (e.g. wind, solar, biomass, geothermal heat, thermal and electric potentials on roofs) served as the basis to expose and quantify sustainable interventions in the built environment. Figure 5 shows two examples of energy potential maps of Oostland, one of demand (left: heat demand of households) and one of supply (deep geothermal heat).

These two maps are shown here in order to explain an example of the application of EPM to a proposal of a geothermal energy cascade in the town centre of Pijnacker. The proposal is schematically shown in figure 6. The concept of a geothermal energy cascade comprises the maximised use of a geothermal energy source. This can be achieved by re-injecting the extracted hot water with the lowest possible temperature into the injection well. Different functions within the built environment can have different temperature trajectories used for heating (differences in inlet and outlet temperatures of the heating systems). If different areas, neighbourhoods or functions with consecutive temperature trajectories will be connected in series, a thermal cascade is created. Heat networks will distribute the hot water. The different districts need to have a similar heat demand too.

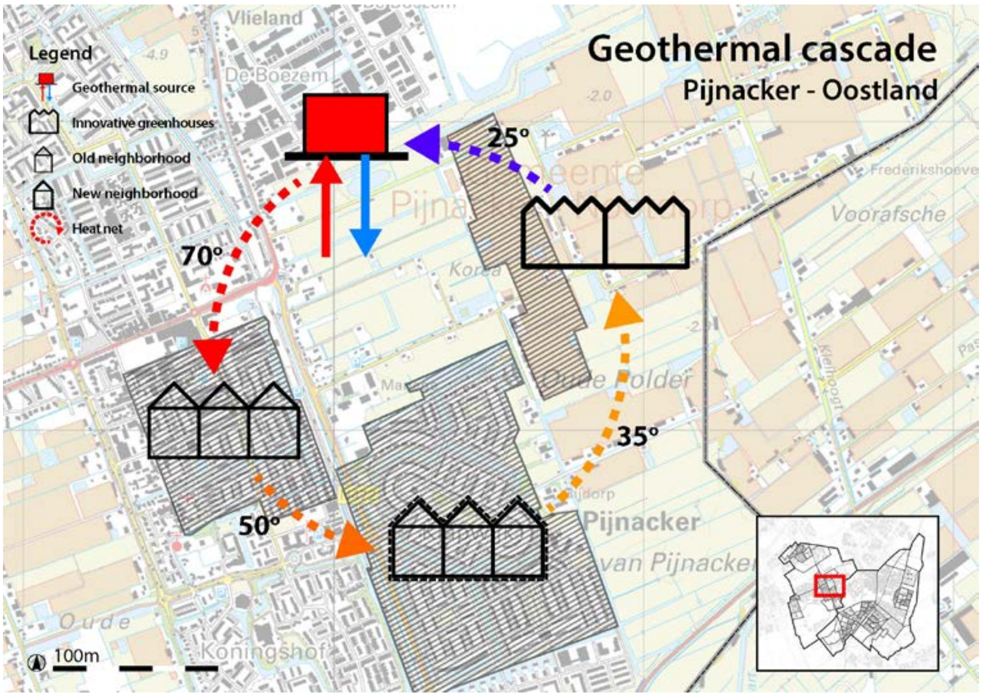

Figure 6: *Proposal of a geothermal cascade that consecutively supplies an older and newer residential area and a well-performing greenhouse area; this is based on and quantified by the energy potential maps of figure 2 (Broersma et al., 2013b).*

The centre of Pijnacker (encircled in the potential maps) has great geothermal potential. An old quarter here has a relatively high-temperature demand (~70°C inlet temperature); a significantly lower temperature could provide the adjacent newer area (~50°C inlet temperature). Adjacent to these two residential areas, a new greenhouse area is planned. If energy-efficient greenhouses are realised, very low temperatures (~35°C) will suffice. The two dashed residential areas in figure 6 have a similar heat demand. The new greenhouse area is finally dimensioned appropriately and connected by the heat supply of the cascade.

In this proposal, the present geothermal heat, at around 2000 m depth, provides a temperature of around 70°C and is re-injected at around 25°C. In the longer run, in an ideal situation, the geothermal well would be replenished by high-temperature heat in summertime, at present perhaps coming from fossil-fueled power plants, and in the future preferably from residual solar heat, won in collectors on roofs and in urban surfaces.

5. CONCLUSION

This paper discussed an approach to energetically resilient city regions, based on various energy studies that gradually led to the stepped approach, coined as the Energy Master Plan. The examples used in this paper were from the Netherlands, but the authors think the generic approach may be applied in various countries and climates, only leading to different outcomes than the relatively cool temperate climate of the Netherlands. Since this paper argued the importance of becoming energetically resilient in detail, cities anywhere across the world may profit from a generic approach that helps them to become more self-sufficient whilst maintaining the quality of life, or even increase it, when speaking of emerging or rapidly growing metropolitan areas.

The first self-sufficient city still needs to be developed, or rather: redeveloped. Many cities across the world have made vows to become climate-neutral, carbon-neutral or energy-neutral by a certain year in the nearby future, but only few of them have their energy administration up-to-date. The authors think that using the science-based approach of the Energy Master Plan, including the method of Energy Potential Mapping, will help to realise their ambitions better than using a less-rationalised approach.

By testing the approach in its full potential, flaws or specified deviations will inevitably emerge, but it is the only way to get ahead in times when old solutions do not provide an answer anymore to new challenges.

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