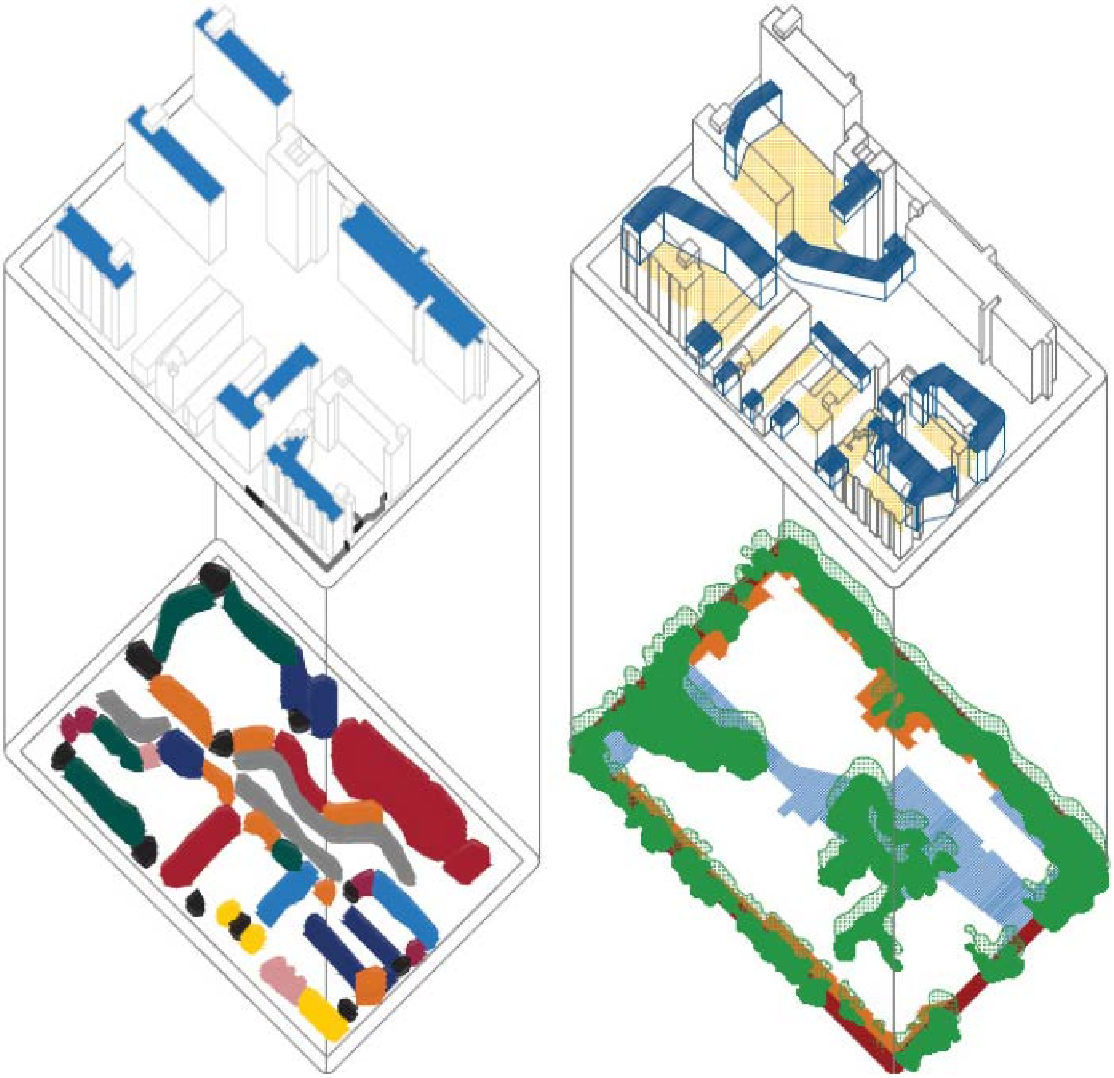
Quantifying urban energy potentials
Presenting three european research projects

Fremouw, Michiel

Publication date
2017

Document Version
Final published version

Published in
Proceedings of the Smart & Sustainable Cities and Transport Seminar



Smart & Sustainable Cities and Transport

SEMINAR

Proceedings

12 – 14 July 2017
CSIR, Pretoria, South Africa

Faculty of Engineering, Built Environment and Information Technology
CSIR
our future through science
TUDelft

Proceedings

Smart & Sustainable Cities and Transport Seminar

12 – 14 July 2017

CSIR, Pretoria, South Africa

Editors

Dr DCU Conradie CSIR, South Africa
Prof C du Plessis, University of Pretoria, South Africa
Prof AAJF van den Dobbelsteen, TUDelft, The Netherlands

Date published: July 017

EDITORS

Dr DCU Conradie CSIR, South Africa
Prof C du Plessis, University of Pretoria, South Africa
Prof AAJF van den Dobbelsteen, Delft University of Technology, The Netherlands

ISBN-10: 0-7988-5636-X
ISBN-13: 978-0-7988-5636-2

Date published: July 2017

PEER REVIEW PROCESS

A full double peer-review process was followed for the conference. This included a double peer review process for all abstracts. A double peer review of all full papers was also undertaken. All papers were reviewed by reviewers from outside their institution. Reviews were undertaken by Delft University of Technology, University of Pretoria and CSIR. The organizing committee communicated the results of these reviews to paper authors. Full papers also received final editing and quality checks before being included in the proceedings. Of the initial 19 abstracts received, 11 full papers were accepted for publication in this proceedings.

ABOUT THE CONFERENCE

The *Smart Sustainable Cities and Transport Semina*r is the result of recent formal cooperation agreements between Delft University of Technology, the University of Pretoria and CSIR. The target audience of the conference is built environment researchers and professionals, as well as government, business and non-government organisations that have an interest in smart and sustainable built environments. The main purpose of this seminar is to present original research findings and research in progress to further boost the collaboration between South African and Dutch parties working on similar themes of sustainable (re)development of cities. In particular, the aim of this seminar is to help the cities of Tshwane and Amsterdam and their respective knowledge institutes, to collaborate and learn from each other in their endeavours to become smart, resilient and sustainable.

ORGANIZING COMMITTEE

[SSC12] QUANTIFYING URBAN ENERGY POTENTIALS: PRESENTING THREE EUROPEAN RESEARCH PROJECTS

Michiel FREMOUW [1]

[1] *Department of Architectural Engineering + Technology, Faculty of Architecture and the Built Environment, Delft University of Technology, Email: m.a.fremouw@tudelft.nl*

Keywords: Energy Potential Mapping; Urban Energy Atlas; Urban Energy Transition; Renewable Energy; Built Environment

Abstract

Although more than half of the world's population now lives in cities, this trend is expected to continue and there is an increasing awareness of the need to move to a fully sustainable urban energy system, this transition process is still significantly lagging behind in many places. The yield of many renewable energy sources is directly related to the surface available for deployment. Because of this and the high density of cities, urban planners face the difficult challenge of incorporating energy based planning in their practices. The TU Delft method of Energy Potential Mapping provides the means to spatially quantify energy demand and renewable supply in the built environment in a unified way. This paper presents three current research projects that apply the EPM method in European cities: CELSIUS (smart District Heating and Cooling), City-zen (urban transition strategies) and PLANHEAT (urban DHC planning toolset).

1. Introduction

Energy is space. In the post fossil fuels world to come, this basic tenet dictates the need to investigate the relation between energy demand, renewable energy supply and their spatial characteristics. Living standards increase, the majority of the world's population now lives in urban areas, and both of these trends are expected to continue in the decades to come. In order to cope with the associated high energy demand, the high density of these areas means energy needs to be incorporated in urban planning practices.

The method of Energy Potential Mapping (EPM) (Broersma et al, 2013), developed at the chair of Climate Design & Sustainability at the TU Delft faculty of Architecture and the Built Environment, provides the means to spatially quantify sources and sinks in a unified way, thereby facilitating this integration.

2. ... ial Map ...

A ... PM is th ... energy and space: as with urba ... itself, r ... va ... ilability and concentration depend ... spatial c ... es can h ... hat quantify these potentials.

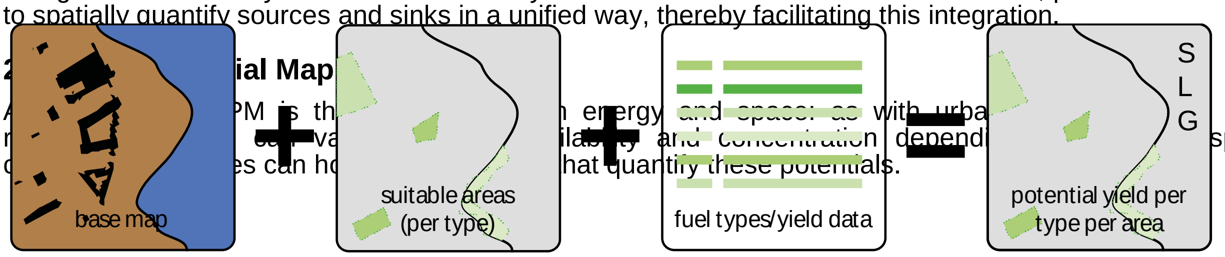


Figure 5 Basic EPM calculation for biomass (Fremouw, 2012)

A simple example is biomass (Figure 5): depending on soil, climate and agricultural practices, a certain yield per hectare can be expected in the form of tons of wood, or litres of biofuels. These can subsequently be converted into heat, motion and/or electricity, and therefore an energetic potential can be tied to an area deemed suitable for production. In denser urban areas however, competing functions will result in more complex calculations and because of the limited availability of space in cities, multiple land use may be a prerequisite for some energy sources. For solar photovoltaic potential for example, the available roof space will be the basis, and for wind energy the distance to risk objects (houses, gas pipelines, highways). The end result however will be an amount of potentially harvestable energy per hectare per year.

For urban areas, this energy can be quantified in a small number of types (both demand and supply): electric, fuels and thermal (heating and cooling). Although conversion between these types is possible (and usually quantified as part of an EPM calculation), this unified way of presenting potentials makes it easier to connect demand and supply potentials. Although strictly speaking fuels and electricity are not considered 'useful energy', final conversion of these two energy carriers is not building related, and therefore they are included instead.

EPM supports the New Stepped Strategy (Dobbelsteen *et al.*, 2012) of reducing demand, then considering exchanging, cascading and storing opportunities and finally generating the remaining required supply sustainably. The end result will be a series of demand categories and supply potentials, which can then be used to formulate an energy based plan.

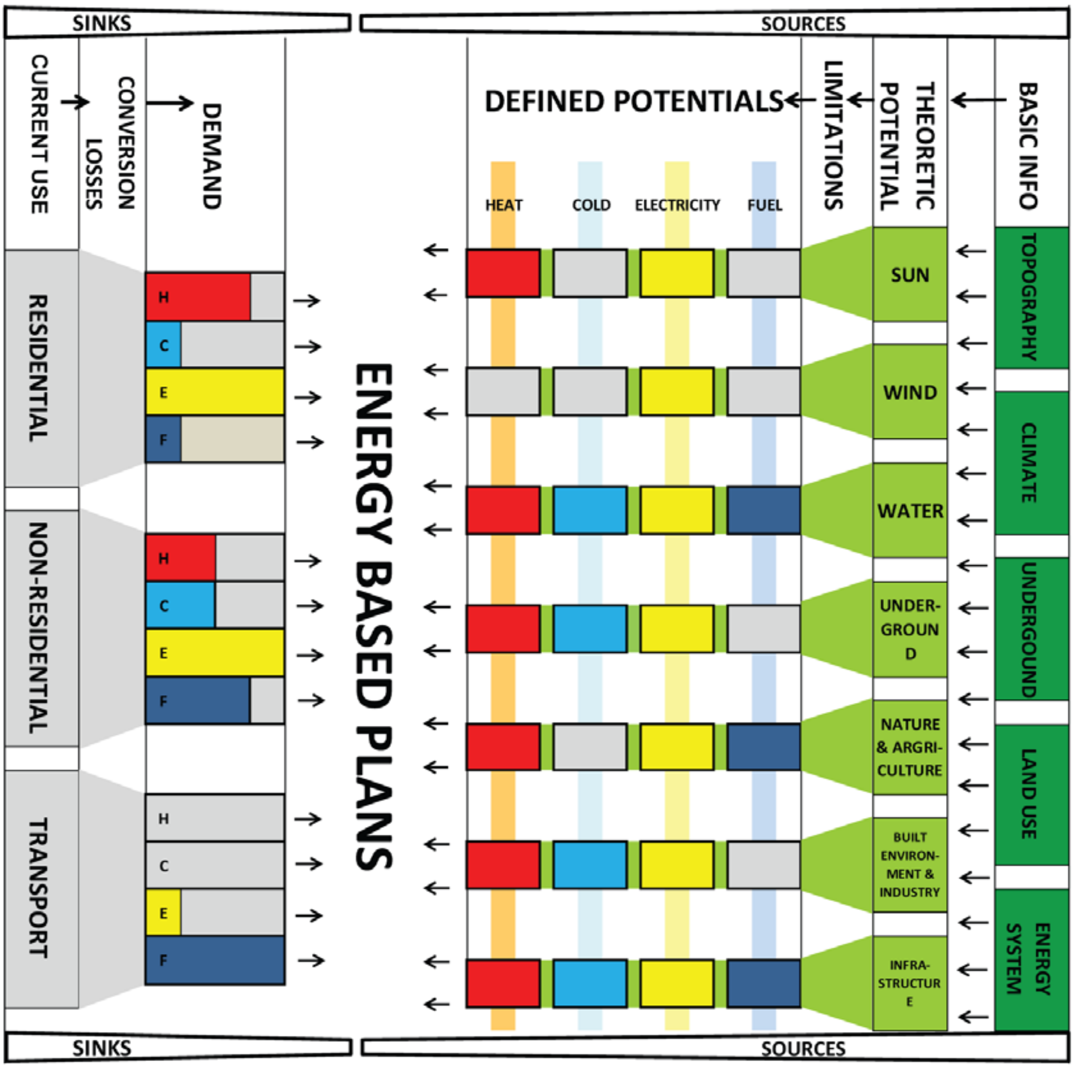


Figure 6 EPM representation (Broersma et al, 2013)

Figure 6 is a schematic representation of the EPM principle. As the horizontal orientation in the figure suggests, the intent is to make demand and supply meet in the middle, in order to facilitate urban energy planning. On the left hand side, current use (usually related to energy carriers like natural gas) is derived to calculate useful energy demand (Madureira, 2014), in order to remove technology specific conversion losses. On the right hand side, spatial and technology characteristics are applied to arrive at defined supply potentials. Both demand and supply are divided by the energy forms most common in an urban environment: Heating, Cooling, Electricity and Fuels.

An example of deriving useful demand from final consumption figures is natural gas, frequently collected remotely and transported through a large network to the end user. 'Final consumption' here does not represent the required useful energy for indoor heating, as this is measured at the front door and conversion to heat in a boiler incurs a subsequent energy loss. Furthermore, as a percentage will be related to cooking, this needs to be subtracted from the initial demand figure, in order to arrive at the (potentially low temperature) space heating component of gas consumption. For this cooking component, a high exergy source will still be required (for example biogas or electricity), however this will be a small fraction and therefore more easily manageable in an otherwise predominantly lower temperature system.

For heating purposes, a potential replacement on the (renewable) supply side would be using a ground based heat exchanger and heat pump, which is a significantly different process and therefore has different conversion losses for the same useful demand. As mentioned, in this regard the term 'final energy demand' relates to an energy carrier reaching the consumer's front door, and therefore may not represent the right consumption and production figures.

3. Urban Energy Atlas

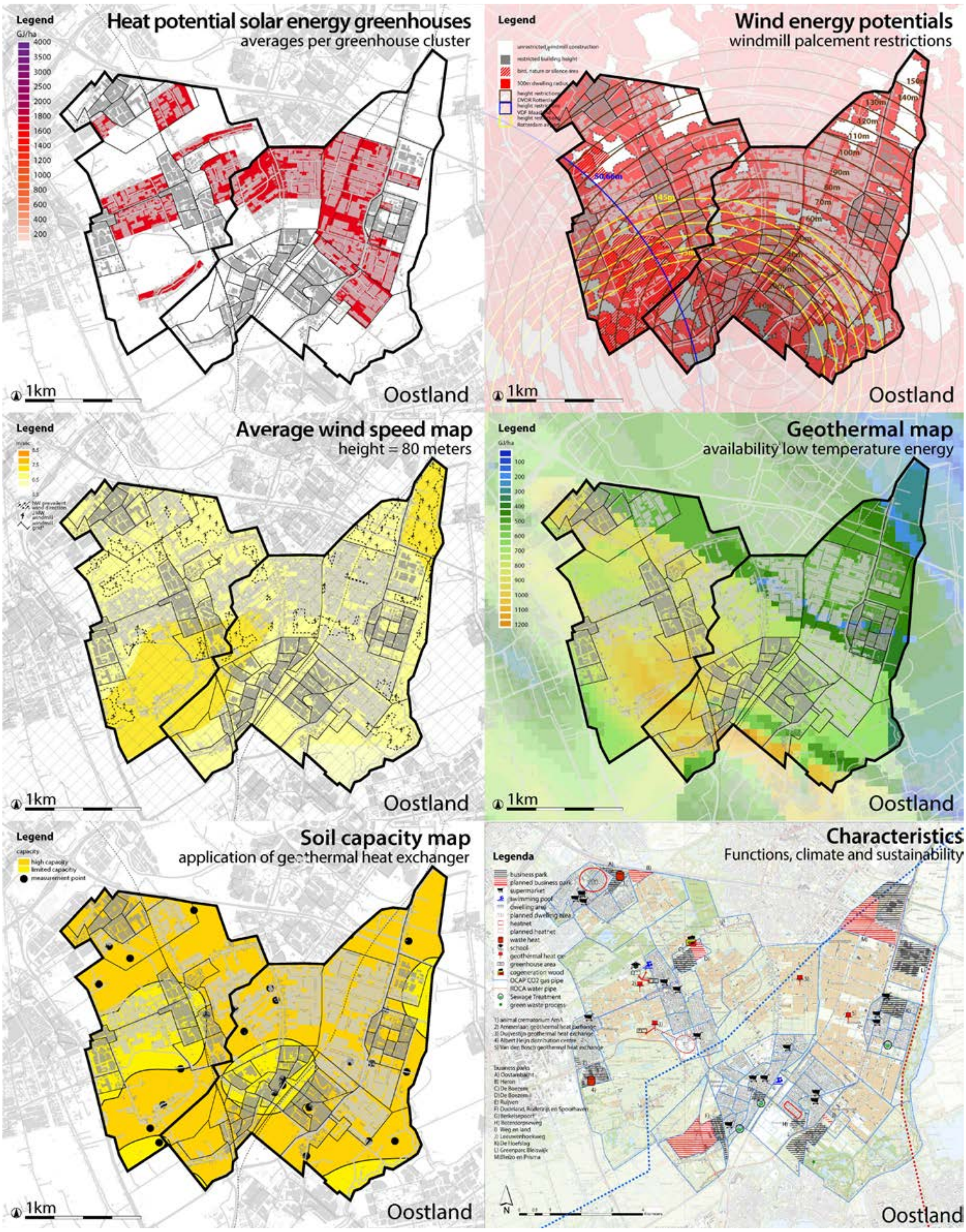


Figure 7 Selection of energy potentials of the Oostland area (Broersma et al, 2013)

The collected geospatial data can subsequently presented as a series of maps, either as separate documents using the same projection (portrayed in Figure 7), or in a combined interface. A common occurrence of this is in so-called Decision Support Tools (DSTs) or Decision Support Systems (DSS'es), which usually provide a map interface comparable to google maps, in which individual layers can be turned on and off. Visualization can be adjusted to project multiple layers of information in a single view. The ultimate goal is to provide a catalogue of energy potentials that can be projected on top of present and future energy demand, in order to shape the aforementioned energy based plans.

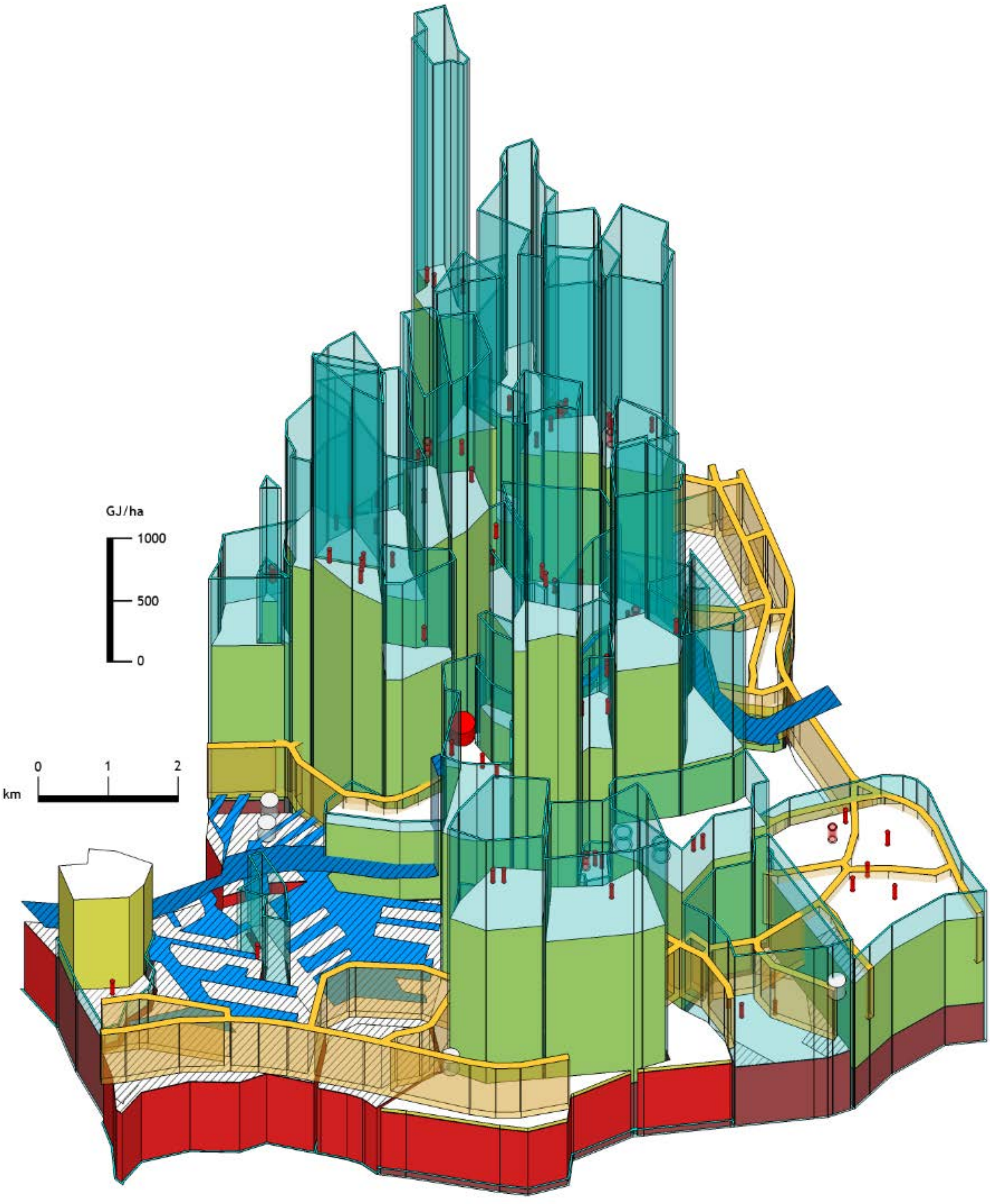


Figure 8: 3D heat map of Rotterdam (Broersma et al, 2011)

Visualisation is not limited to two dimensions. An example is the 3D heat map of Rotterdam (NL), as shown in Figure 8. Here, demand (GJ, for the visualisation normalised by area to negate neighbourhood size differences) is represented by a series of hollow cores (following the contours of neighbourhoods), which are filled by local heat potentials. Although based on a limited set of potentials, the discrepancy between demand in the high rise dominated centre and the more balanced (and sometimes surplus capable) periphery is clear, demonstrating the need for a District Heating (DH) network.

4. Applications

Since its inception over a decade ago, the EPM method has been used in many different projects, covering a wide range of scales from individual neighbourhoods to cities, regions and countries, and providing an ever increasing level of detail, source data permitting. Three currently running research projects are highlighted here, to show the various ways in which EPM principles are applied to real cities.

4.1 CELSIUS

The premise of the CELSIUS project (www.celsiuscity.eu, 2013-2018, part of the European FP7 programme) is that urban heating and cooling demand in European cities, at present still overwhelmingly supplied using fossil fuels, can easily be covered by residual and renewable sources, as well as more efficiently operating District Heating and Cooling (DHC) networks.

The project revolves around so-called demonstrators, innovative technologies at a high Technology Readiness Level (TRL) that are built and monitored in one of the five partner cities (Gothenburg (SE), Rotterdam (NL), London (UK), Cologne (DE) and Genoa (IT)), and have replication potential. CELSIUS aims to spread its knowledge and experience by actively recruiting so-called replication cities (currently numbering 65), who have expressed interest in adopting CELSIUS demonstrators and developing their HC networks using CELSIUS knowledge.

In CELSIUS, the EPM method is used to determine both suitability for and quantifiable potential in so-called replication cities, by defining spatial calculation methods for these demonstrators. An example is the Rotterdam river water cooling demonstrator, where the EU water framework directive was applied to define upper thermal exhaust limits for lakes, rivers and seas, thereby making it possible to quantify cooling potential in suitable cities (Fremouw et al, 2015).

In order to support demand (and refurbishment) quantification, pathways were mapped (Figure 9) for various types of energy demand maps, taking into consideration data availability, detail levels, privacy concerns and the advantages (and disadvantages) of different types of output.

The PLANHEAT project (discussed in section 4.3) will address these issues in greater detail, as the toolset it develops requires certain types of base data in order to operate.

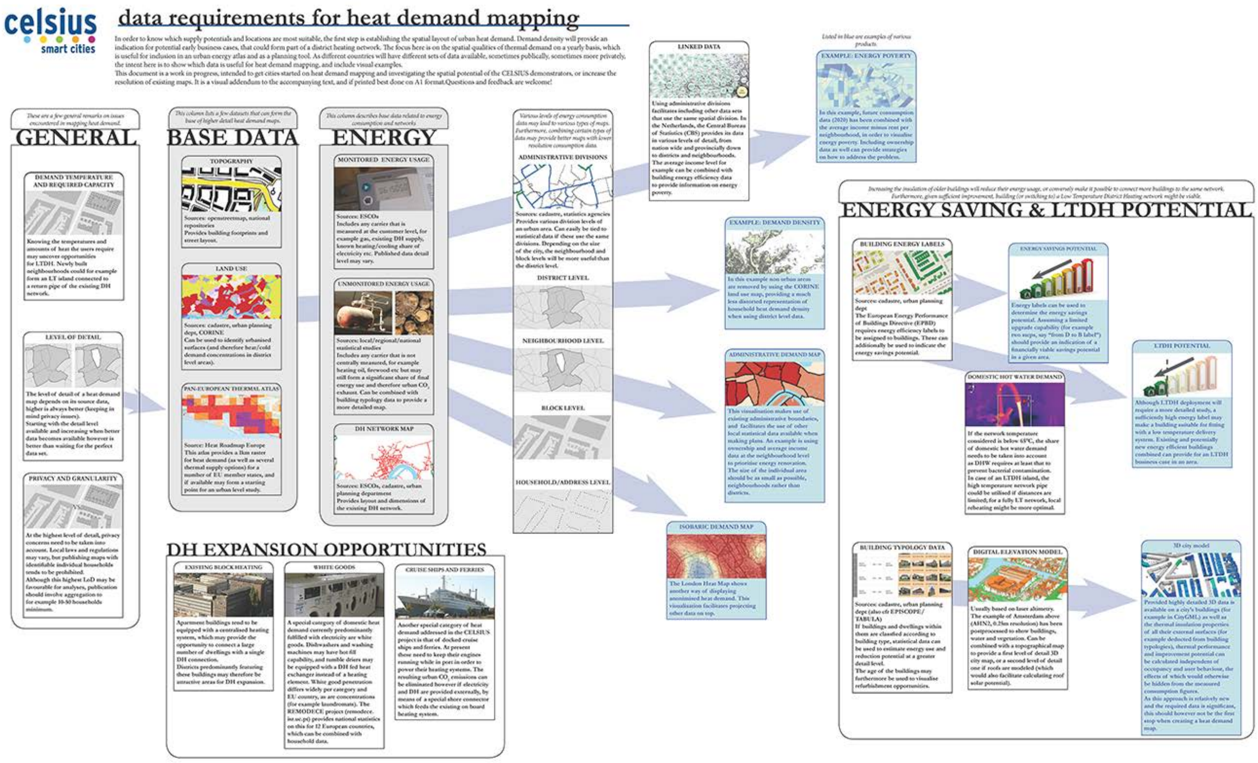


Figure 9 Mapping heat demand (Fremouw, 2015)

4.2 City-zen

The aim of the City-zen project (www.cityzen-smartcity.eu, 2014-2019, also part of the FP7 programme) is to support and accelerate sustainability targets in urban areas, with a focus on integrating building retrofit measures, the introduction of smart grids and renewables based heating and cooling. As the name suggests, involving citizens and starting at the neighbourhood scale (rather than top-down) play an important role.

Similar to the CELSIUS project, City-zen combines the development of new knowledge and tools with live test beds, in the feorm of participating cities and a dozen technological **demonstrators** with a high technology readiness level. Examples of demonstrators are a blood bank in Amsterdam which recently started using a water purification supply line to provide its cooling, and Grenoble's Vivacité, an experimental platform for collaborative energy data management.

Lead cities **Amsterdam** (NL) and **Grenoble** (FR) have ambitious sustainability targets, but owing to the ever changing priorities of the stakeholders involved (for example national and local government, citizens and businesses), the path towards these is not always certain. Furthermore, regulatory, financial and social barriers may need to be overcome in order to accomplish a larger share of the technical potential that's available in a city.

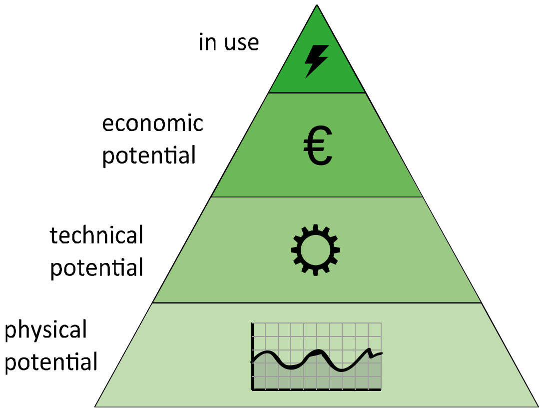


Figure 10 From theoretical potential to application (Fremouw, 2012)

Figure 10 shows a simplified energy potential pyramid, where subsequent limitations result in a much smaller share of the physical potential is actually built and operational. Although using 100% of physical potential will be impossible for various reasons, the top layer in this figure can none the less be significantly wider.

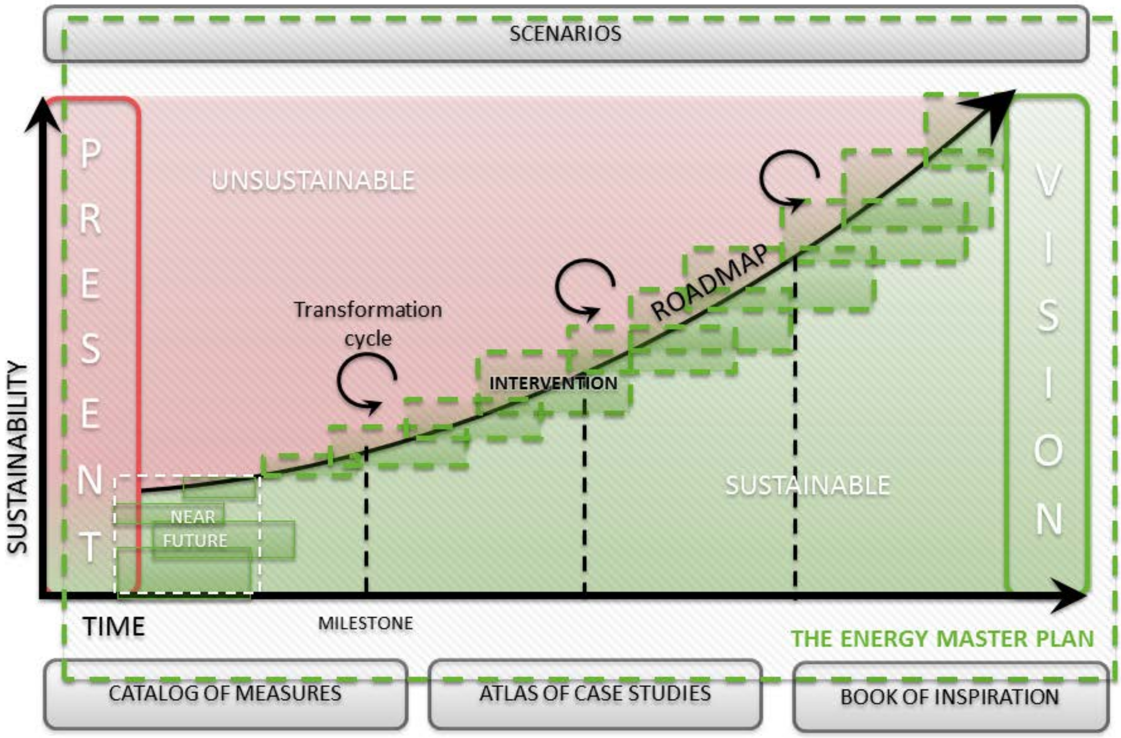


Figure 11 The City-zen methodology (Broersma & Fremouw, 2015)

The **City-zen methodology** (Dobbelsteen *et al*., 2014) aims to connect the long term sustainability targets ("visions") of cities with their present state and (energy) potentials, taking into account the long term resilience of possible solutions and emerging synergies in order to arrive at an economically viable, fully sustainable future urban energy system: the **Energy Master Plan** (EMP).

Figure 11 represents the overall structure of the EMP. Here, the EPM method and its resulting Urban Energy Atlas provide the quantified starting point (the "present" on the left) from which a **roadmap** can be built towards this vision. Owing to the long period of time covered between the present and the vision (for example 2050) and its accompanying uncertainties (for example resulting from global external factors represented here by "scenarios"), the roadmap cannot provide detailed blueprints. Rather, it deals with strategic choices and areas of interest, for example the level of retrofitting versus available residual / renewable heating and cooling (HC) sources, their temperatures and availabilities, or perhaps a stronger focus on wind energy and electrification. As time progresses, more detailed plans can be made for specific areas that fit these strategic choices, and at each milestone, progress will be evaluated, possibly followed by a readjustment of plans.

A supporting product of the City-zen project will be the **Catalog of Measures**, which aims to record common barriers encountered for various energy measures and provide the means to level them, called opportunities here. These frequently address regulatory, financial and social issues simultaneously in order to achieve both economic viability and social acceptability.

The knowledge and tools developed in the City-zen project are tested in ten so-called **roadshows**, where, after preparation, a group of City-zen experts visits a city and helps local stakeholders shape a roadmap in a week long workshop. So far, four roadshows have been organized in Belfast (IE), Dubrovnik (HR), Izmir (TR) and Menorca (ES). The next roadshow will be in partner city Amsterdam (NL), in October 2017.

4.3 PLANHEAT

The recently started and Horizon 2020 funded PLANHEAT project (www.planheat.eu, 2016-2019) aims to develop open source renewable Heating and Cooling (**HC**) **mapping, planning and simulation tools** at the urban scale. Partners from eight countries across Europe (including validation cities Antwerp (BE), Velika Gorica (HR) and Lecce (IT)) work on PLANHEAT, which focuses not just on the toolset itself, but also on solving data acquisition and management issues on the input and output sides. Even within the 28 European Union member states (EU28), the availability of source data varies significantly, and although certain base data will always be required (but usually available from a public EU wide or national database), methods and procedures are being developed to provide (sometimes lower resolution) alternative data and identify analogs, as well as both simple and complex calculation methods.

The energy potential mapping module provides calculation methods for HC demand, demand reduction and supply. When combined with the network maps that the planning and simulation modules require, this provides the layers for an Urban Heating and Cooling Atlas. The mapping module will also provide the input for the planning and simulation modules, which allow the shaping and validating of local HC plans. Special focus is placed on the Urban Heat Island (**UHI**) **effect**, and its consequences for present and future cooling demand. Satellite data will be used to assess local UHI consequences.

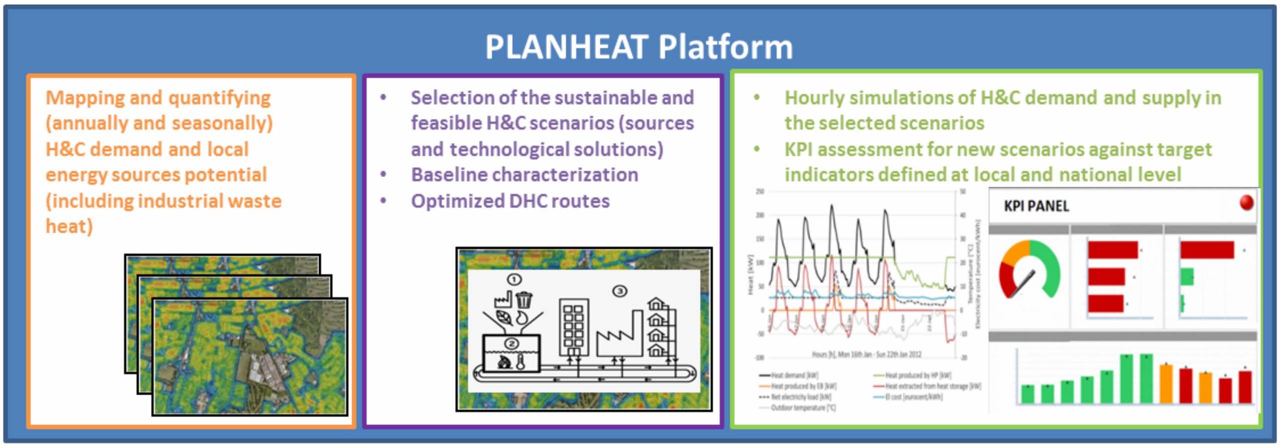


Figure 12 PLANHEAT platform structure

The end result will be an open source, interoperable and freely downloadable mapping, planning and simulation toolset for urban HC planning. During the project, **training modules** will also be developed and webinars organized to get new users started quickly. The first webinar is planned for September 2017, introducing the project and identifying data acquisition strategies.

5. Outlook

In the past decade, great strides have been made in the field of Energy Potential Mapping, starting with simple maps of opportunities ('kansenkaarten') (Dobbelsteen & Stremke 2009), and at present able to use building detail level GIS data to forecast future energy demand and calculate supply potentials for the urban and regional scale. Methods to further integrate temporal components (demand and supply curves), multiple temperature levels (see also Broersma & Fremouw, 2013) as well as strategies to deal with varying data availability and detail level and local circumstances affecting (or accelerating) transition, are currently under development.

The brief period in human history of a strong spatial separation between demand and supply that the fossil fuel age forms, will undoubtedly come to an end in the 21st century. Our continuing desire for and move toward higher levels of urbanization, and the relation between energy and space, therefore mean that for these dense urban areas, thorough energy based planning will be of paramount importance.

6. References

Broersma, S., Fremouw, M.A. & Dobbelsteen, A.A.J.F. van den (2011) Heat Mapping the Netherlands, laying the foundations for energy-based planning, Helsinki, SB11

Broersma, S., Fremouw, M.A. & Dobbelsteen, A.A.J.F. van den (2013) *Energiepotentiestudie Oostland - Met een regionale energie-analyse naar lokale duurzame ingrepen*, Delft: Delft University of Technology.

Broersma, S., Fremouw, M.A. & Dobbelsteen, A.A.J.F. van den, (2013) Energy Potential Mapping: Visualising energy characteristics for the exergetic optimisation of the built environment. Entropy, Issue 15, pp. 490-506

Broersma, S., Fremouw, M.A., (2015) The City-zen approach for urban energy master plans, Pretoria, SASBE2015

Dobbelsteen, A.A.J.F. van den & Stremke, S., (2009) *Energiepotenties Groningen – basisrapport*

Dobbelsteen, A.A.J.F. van den, Keeffe, G. & Tillie, N.M.J.D. (2012) Cities ready for energy crises - building urban energy resilience, SASBE2012

Dobbelsteen, A.J.J.F. van den, Tillie, N.M.J.D., Broersma, S. & Fremouw, M.A. (2014) The Energy Master Plan: Transition to self-sufficient city regions by means of an approach to local energy potentials, Ahmedabad, PLEA2014

Fremouw, M.A. (2012) *MUSIC: GIS based EPM and residual heat potential*

Fremouw, M.A. (2015) *CELSIUS: Data requirements for heat demand mapping*

Fremouw, M.A. (ed.) (2015) *CELSIUS: D5.7 Concepts for energy efficient and sustainable energy production*

Madureira, N.L. (2014) *Key concepts in energy*, Heidelberg, Springer, p10