



PLANNING FOR CLIMATE-BENIGN CITIES – DESIGN OF A MIND MAP FOR SMART ENERGY TRANSITION

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UDC
502.15:711.4
621.311.24

Original
scientific
paper

Received:
16.01.2023
Accepted:
29.03.2023

Abstract: Local energy transition initiatives – as part of a broader climate-benign and sustainability policy – have become a focal point of future-oriented resource and environmental strategies. Place-based energy conversion however, has turned out to be a very complicated task, from both a governance and research perspective. The present study seeks to sketch out the contours of local sustainable energy planning, with a particular emphasis on (i) practical data and evidence-based information requirements, (ii) the involvement and engagement of citizens and stakeholders, and (iii) the great research potential provided by digital information technology. To that end, a comprehensive mind map for energy transition is depicted, inspired by first experiments in the city of Rotterdam.

Keywords: energy transition, climate-benign cities, local energy mind map, citizen participation, Pentagon model, diabolio model, e-compass, digital tools, local energy scenario's.

JEL classification: R00, Q59, Q40

1. Energy: The Critical Climate Factor

The policy cycle of pressing societal issues (e.g. poverty, housing, health) follows normally various stages: initial awareness, fact finding, policy plans, problem recognition by citizens, policy implementation, public responses, policy assessment, and policy adjustment/revision (Lasswell 1956; Brewer and deLeon, 1983; Nakamura, 1987; Zahariadis 2016; Cairney, 2019). It has taken several decades – since the first awareness of environmental decay (in the 1960s) till the acceptance of stringent environmental policy measures in most OECD countries (beginning of the 21st century) –, before a full-fledged environmental policy came into being, taking for granted that ‘*more may be less*’ (Schwartz 2005). It is noteworthy that the current debate on climate policy shows a similar evolutionary pattern, be it that we are still in the initial stages of the climate policy cycle.

Over the past decade it has increasingly been recognised that energy use and energy policy are critical success factors for effective climate policy. The rising popularity of the concept of climate-neutrality has prompted a critical stance on fossil fuels, witness notions like energy-neutral cities, CO₂-neutral cities, or decarbonised cities (e.g., Golubchikov 2011; Huovila et al. 2022). It is noteworthy that cities or urban agglomerations are increasingly seen as pivotal actors in achieving climate-neutrality through the mechanisms of drastic energy transition. Meanwhile, urban energy policy – with a view to a reduction in fossil fuels and an increase in general energy efficiency – has become a major responsibility of cities all over the world, as is also witnessed in the New Urban Agenda. The war in Ukraine, the rise in energy prices and the international power conflicts around oil and natural gas have made secure energy provision a prevalent item on the current policy agenda of countries and cities.

In the ‘*new urban world*’ (Kourtit 2019) it is argued that the majority of the people in our world lives in cities or urban agglomerations. The same holds for the location of economic activities. Consequently, the highest portion of energy consumption and of environmental waste is likely to be found in urban areas (United Nations, 2016). Since cities are pivotal actors in climate and energy planning, it is plausible that urban climate and energy initiatives are key in achieving a sustainable global and local development.

Since cities are seedbeds of innovative sustainability in geographical space, it is important to make a systematic typology of distinct environmental or climatological roles to be played by cities. In a study by Tillie et al. (2009) the following functional roles were specifically distinguished:

- application of renewable energy sources;
- exploitation of available energy potential;
- better use of waste streams (e.g., circular city planning; see Williams 2023);
- improvement of energy savings in buildings (e.g., insulation measures).

In the above mentioned study by Tillie et al. (2009) also a cascading energy planning for cities was advocated, starting from city level via district and

neighbourhood level to the individual building level. Each level has of course its own limitations and potentials. But it is clear that when urban energy initiatives focus on individual buildings, complex communications issues and painful negotiations with residents and households emerge (Kourtit 2021). Consequently, ultimately, successful urban energy initiatives in case of energy transition in the city call for citizen communication, citizen participation and whenever possible citizen engagement (see e.g. Beierle and Cayford 2002). *Citizen involvement* is thus one of the most prominent challenges in urban energy planning. This will be one of the corner stones in the present study.

A second prominent element in contemporary urban energy transition is formed by the potential of *digital technology* (see e.g. Rutter and Keirstead 2012; Zhang et al. 2017; Nijkamp et al. 2023), on both the supply side and the demand side, e.g. by the use of sensors, electronic measurements tool, early warning tools, smart energy dashboards, user-oriented e-compasses, and so forth. Also at the meso level of district planning new methodological tools are being introduced, such as digital energy twins. Consequently, the main challenge in modern urban energy planning is the design of interactive digitally-oriented citizen participation approaches and data-based tools at local or neighbourhood level.

The present study seeks to sketch the contours of a decentralised local energy planning system, with a particular emphasis on three glaring success factors, viz. the use of action-oriented data and information systems, the role of citizens and stakeholders in local energy initiatives, and the great possibilities offered by the use of digital information technology, including in particular smart dashboards (in the form of an e-compass) and digital twins for a 3D representation of the energy savings capacity in urban areas.

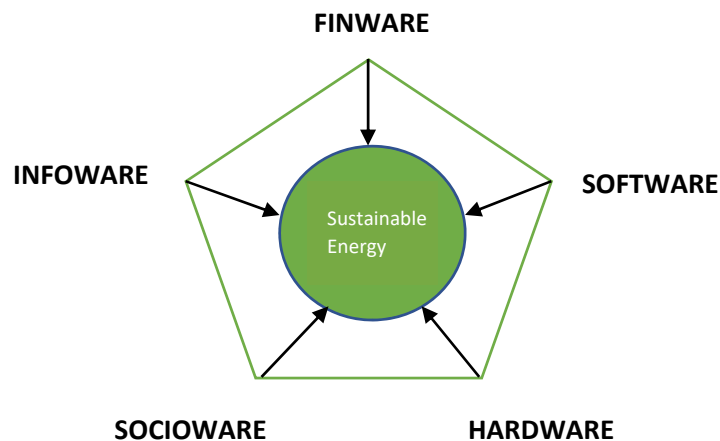
This paper is organised as follows. After the introductory Section 1, the next section (Section 2) will be devoted to setting the scene for urban energy transition, using a *Pentagon* model. Next, in Section 3 the organisation of citizen participation in urban areas is articulated, with a particular view to the relevance of the '*diabolo*' model for citizen engagement. Section 4 presents then a systematically decomposed mind map for depicting the complex energy transition arena at local level. The various components of this mind map – 7 in total – are then briefly described in Section 5, with particular emphasis on a dedicated decision support tool for energy transition at decentralised level, viz. the *e-compass*. Then, in Section 6 we address specifically the research and planning potential of smart digital technology, in particular, digital data infrastructure and digital twins. Finally, Section 7 provides some retrospective and prospective observations.

2. Urban Sustainability and Energy Transition

The awareness of cities as cornerstones for sustainable development (including energy savings) dates already back to the 1990s (see e.g. a study by Nijkamp and Perrels 1994). Urban energy has over the past decades become an important research topic (see Capello et al. 1999; Nijkamp et al. 1999; Hettinga et al. 2018). The current

drastic energy conversion plans in many cities show that sustainable energy transition is not only a technical engineering problem, but predominantly an organisational planning problem. An effective local energy initiative has to meet at least five criteria or necessary conditions (e.g., Nijkamp 2008), as is also indicated in the pentagonal picture in Figure 1.

Figure 1. An energy Pentagon model



The elements of this figure are:

- *Hardware*: technical adjustments in the building stock (e.g. dwelling insulation, combined heat & power, solar panels, etc.) (see Nijkamp et al. 2023).
- *Infoware*: inventory of citizens' perceptions and preferences (e.g. using Arnstein's (1969) preference ladder techniques), employing evidence-based information, in which the citizen is both a producer and consumer of data (the 'prosumer' concept; see e.g. O'Reilly 2017; Lammi and Pantzar 2019).
- *Finware*: the financial viability of drastic conversion measures or adjustments, raising questions on energy poverty and subsequent public support measures, especially in the energy crisis during the Russian invasion in Ukraine.
- *Socioware*: use of community sense or social capital regarding citizen awareness and common sustainable energy initiatives (e.g. common construction and management of solar panels).
- *Software*: development of advanced tools for monitoring and guiding complex energy developments (e.g. scorecard methods, energy dashboards, e-compasses etc.).

The Pentagon in Figure 1 is a generic presentation of a complex force field, but the direction it will move to depends on the relative weights of the various pentagonal objectives, ranging also from short-term concerns to long-term strategic perspectives, under conditions of uncertainty (see also Casti 2012). The presence of uncertainty is one of the biggest bottlenecks in a decentralised and citizen-oriented energy transition planning and has led to a wide range of different approaches, such

as: preference ladder methods (see e.g. Arnstein 1969), bottleneck analyses (identification of impediments to the implementation of local energy policy based on the pentagon model in Figure 1), socio-psychological motivation and incentive methods (inspired by Maslow 1970) (based e.g. on a system of bonuses or nudges to convince citizens to participate; e.g. see John and Stoker 2019), target groups approaches (based on e.g. socio-economic and cultural identities of groups of residents), or preference elicitation methods in combination with multi-criteria methods (such as the well-known MAMCA model; see e.g. Macharis et al. 2012). All such approaches to achieving an appropriate urban or local system of sustainable energy transition need solid data; uncertainty kills the confidence of citizens in drastic policy interventions. Scorecard and dashboard methods may be helpful in systematising the various information sources needed for obtaining a clear picture of reality. In the context of future-oriented energy and sustainability planning also combined energy-sustainability scenario's (including circular city scenario's) may be very helpful (see e.g. Nijkamp et al. 1999). Thus, there is a wide range of methods available that may be instrumental as decision support tools in public planning and private involvement in energy transition planning at local level. In the next section we will present a mind map to sketch out the complex fabric of digital-oriented and citizen-based local energy planning.

3. The Organisation of Citizen Participation

Modern policy theory is – in contrast to conventional quantitative-analytical approaches – no longer based on command and control measures, where governments decide what to do in order to reach prespecified goals (see e.g. the 'fixed target' approach developed by Nobel laureate Jan Tinbergen 1956). Furthermore, it has been argued by another Nobel laureate, Kenneth Arrow (1963), that in a democratic society a consistent aggregation of distinct citizens' preferences to an unambiguous collective decision is fraught with unsurmountable problems (the so-called 'impossibility theorem').

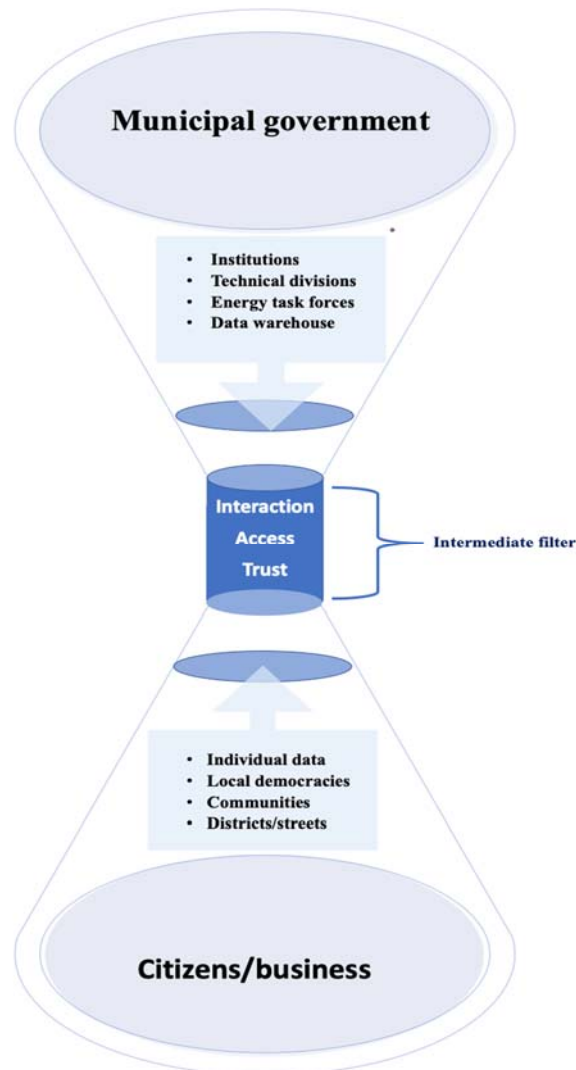
In our paper we take for granted that urban policy-making (e.g. in the urban energy field) is based on an interactive engagement of citizens or stakeholders and competent public authorities (Callahan, 2007; Fung 2006; Michels 2011). However, a direct linear translation of citizens' preferences into undisputed collective or public decisions is not feasible, whereas an unanimous acceptance by citizens of public decisions taken by (local) governments is not feasible either (see e.g. Loorbach and Rotmans 2010; Mulgan 2009).

In the present study on local energy transition initiatives it is important to explore which citizen involvement methods do exist and are applicable or suitable (see also Monnikhof and Edelenbos 2001; Van Zoonen and Hirzalla, 2018; Rowe and Frewer 2000). Examples of such initiatives (possibly oriented towards specific target groups) are:

- Local community meetings or interactive workshops.
- Focus groups of professional climate adaptation leaders and interest groups.

- Digital Information and communication apps.
- Organised meetings of stakeholders in the field.
- Bonus systems for energy-benign behaviour (e.g. vouchers, climate awards, or nudges).
- Open access to a general climate dashboard or access to a personalised e-compass.
- Early warning signals on excessive energy use (an individual ‘amber alert’).
- Involvement of citizens for interactive energy scenario design (e.g. ‘digital gaming’).
- VR (virtual reality) or AR (augmented reality) experimentation of future decentralised energy systems, e.g. through metaversal experiments (see.e.g. Joshua, 2017; (Lee et al., 2021).

Figure 2. A ‘diabolo’ model for citizen participation in urban energy transition



It is worth noting that public participation may assume different roles of citizens: the citizen as a resident, the citizen as a designer of public space, the citizen as a community partner, the citizen as a tax payer, the citizen as a recipient of public subsidies, and last but not least the citizen as a democrate voter. Thus, there is a great diversity in actors involved, in issues to be addressed, and in communication tools to be employed, so that in reality a complex public participation process is likely to emerge. There is clearly a need for a community-oriented approach to energy transition, based on what is called a ‘*new social partnership*’, defined as “people and organisations coming from some public, private and civic entities/bodies which are engaged in voluntary, mutually beneficial and innovative relations with the aim of dealing/pursuing with social goals by putting together their own resources and competencies” (see Giordana et al. 2013, p. 151).

In the context of an operational energy study, inspired by energy initiatives in the city of Rotterdam, we have introduced the notion of ‘an intermediate interactive filter system’ which comprises competent and qualified agents which form an interactive layer between government institutions and individual citizens (‘his master’s voice’). This is represented in the so-called ‘*diabolo model*’ mapped out in Figure 2 (see also Nijkamp et al. 2023).

This ‘diabolo’ model belongs to the class of interactive multi-agent decision modelling tools. It avoids a centralised tyranny of urban governance and it incorporates a balanced system for a multiversatile centralised – decentralised governance mechanism for urban energy planning – comprising a bi-directional semi-institutionalised coordination system, with the involvement of energy coaches, sustainability ambassadors or grass-root representatives in local or district councils. The agents are directly accessible – in an informal setting – by locals, while their functioning is based on mutual understanding and trust. At the same time, this intermediate filter system acts as a liaison to the official and institutionalised agencies and planning divisions under the legal competence of the city administration. Consequently, the intermediate filter system may be seen as an engagement vehicle for citizen-oriented energy process planning, through which information, views and impediments on local energy transition issues are filtered to public or municipal energy services. This filter system is also a critical factor for data collection and information provision at community or individual level, and can also effectively be employed in an advanced digital policy support setting.

4. Design of Urban Energy Transition: A Mind Map

The design of an efficient citizen-oriented local energy supply and consumption system is not an easy task. The city of Rotterdam has decided to play an active role in localised energy transition systems along three dimensions: evidence-based and open-access information, citizen participation and engagement, and use of advanced digital technology (in particular, dashboards and digital twins). For more information we refer to Willemsen et al. (2023) and Nijkamp et al. (2023).

The complexity of local or urban energy transition calls for a systematic design of this multi-faceted process comprising both the policy arena, the citizen involvement and the knowledge handling capacity (including digital technology). In the present paper this will be presented in the form of a Local Energy Mind Map Analysis (LEMMA). This mind map is sketched in Figure 3. A mind map offers generally a simplified diagrammatic representation of concepts, ideas, goals and interventions – in a tree structure – of a complex and interconnected phenomenon. In the present context the LEMMA mind map sketches four cornerstones for effective planning of sustainable energy transition, viz. the built environment material (objects), the competence of public administration (decision-making agencies), the role of residents and local business (subjects), and the steering function of appropriate information data (knowledge infrastructure). They altogether shape the contours of a Quadruple Helix model. Clearly, these four cornerstones can be further decomposed, following the decomposition principle advocated by Kourtit (2021).

Figure 3. A simplified LEMMA mind map

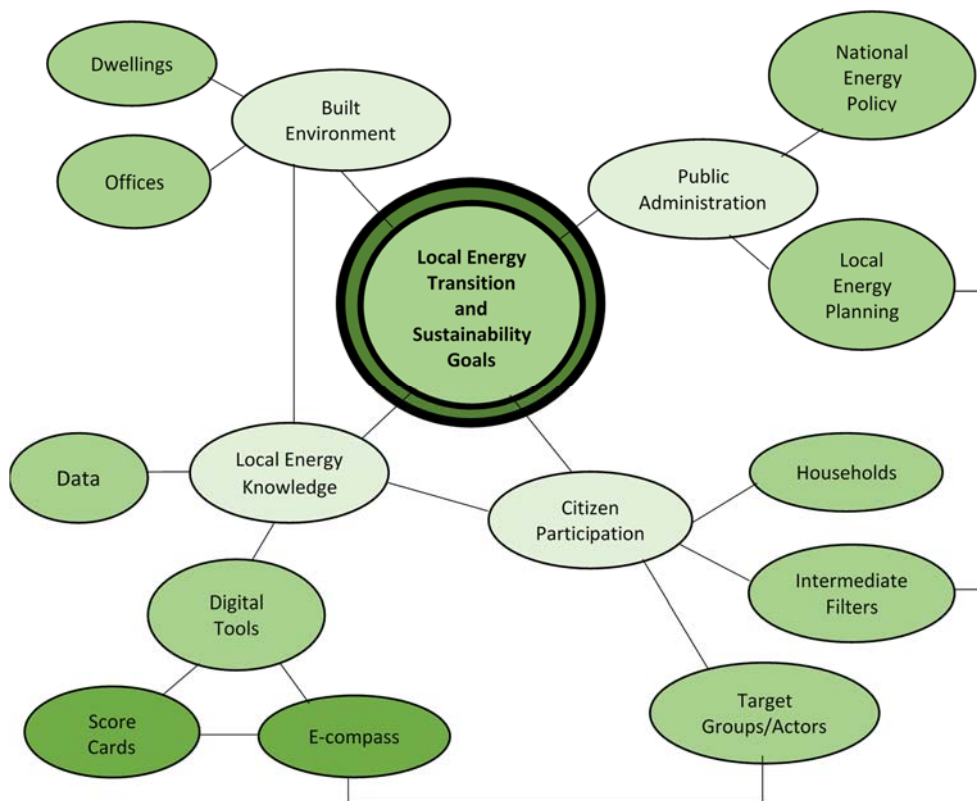
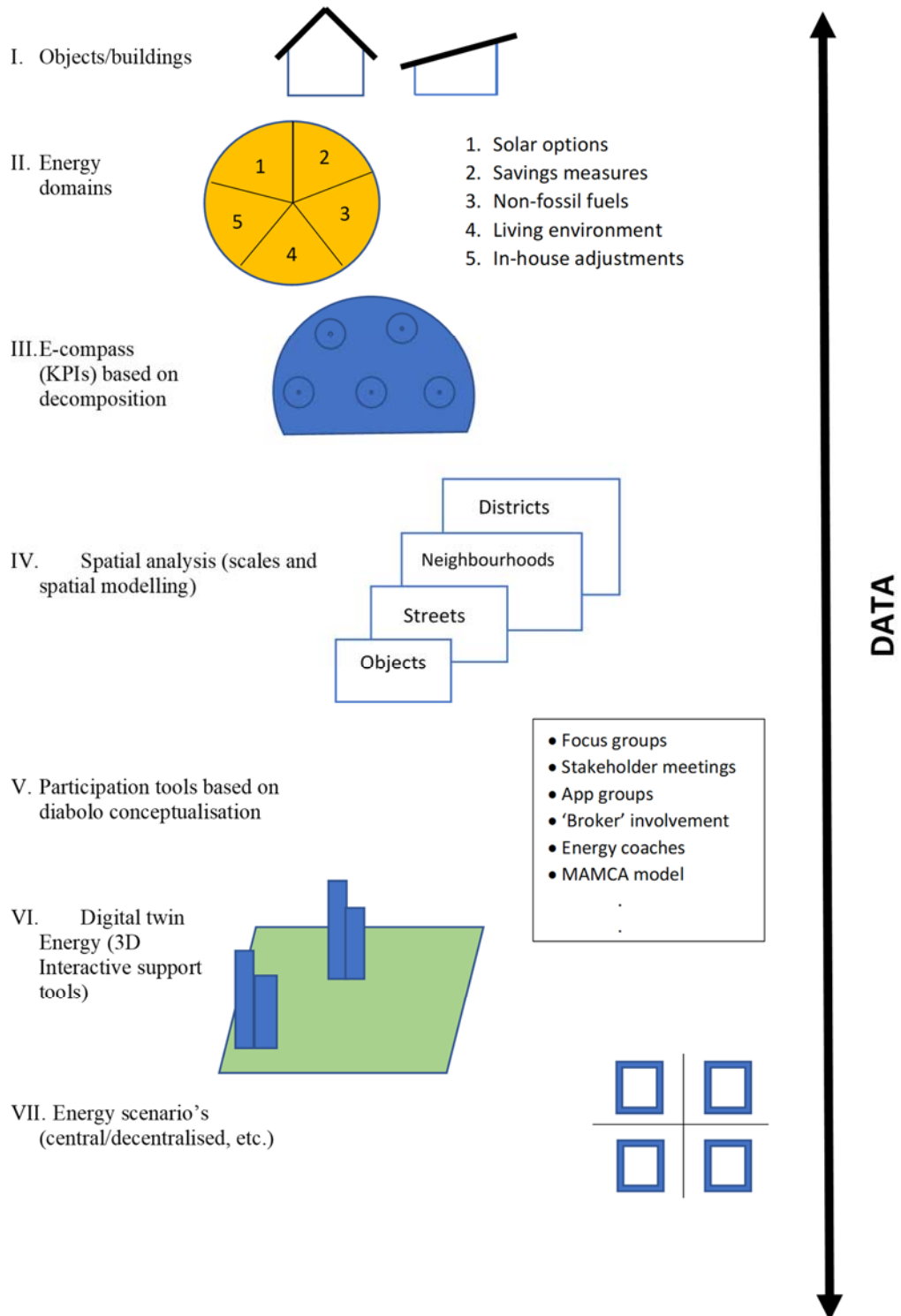


Figure 4. Decomposed design of sustainable LEMMA framework



This LEMMA mind map picture can be further transformed into a more detailed modular-structured configuration with a decomposed architecture, as is depicted in Figure 4. There are seven main constituents of this decomposed mind map:

- objects or buildings.
- energy domains.
- relevant KPIs to be included in an e-compass.
- relevant analytical scales, from microcosmic to macrocosmic spatial scales.
- citizen participation and engagement tools.
- geo-science digital tools for mapping out local energy performance (e.g. digital twins).
- Design of future-oriented energy scenario's.

These seven mind map components will now successively be discussed in the next section on a detailed LEMMA presentation.

5. Elements of a Decomposed Energy Mind Map

In the present section the 7 constituents of the decomposed LEMMA framework in Figure 4 will concisely be presented and commented on.

5.1 *Objects/buildings*

Cities have a material side (e.g. the built environment) and an intangible side (e.g. urban history or urban architectural style). In the context of urban energy transition it is worth noting that buildings (e.g. houses, factories, shopping centres, parking garages) are not only a consumer of energy, but may also act as a producer of energy. On the energy consumption side, satisfactory insulation of buildings (e.g. double glass, roof insulation) is often seen as an effective vehicle for energy-savings behaviour, while on the producer side in particular solar panels have a great energy producing potential. Especially in the present times – with an urgent need of a reduced oil and gas dependency and of a decarbonised energy provision infrastructure – it is a great challenge to find a proper and effective mix of energy savings measures, sustainable energy production measures, and non-fossil fuel energy conversion. Cities offer indeed a great potential for drastic energy transition due to their agglomeration advantages (see Capello et al. 1999), while place-specific energy action calls for district, neighbourhood or building-specific adjustments and initiatives.

5.2 *Energy domains*

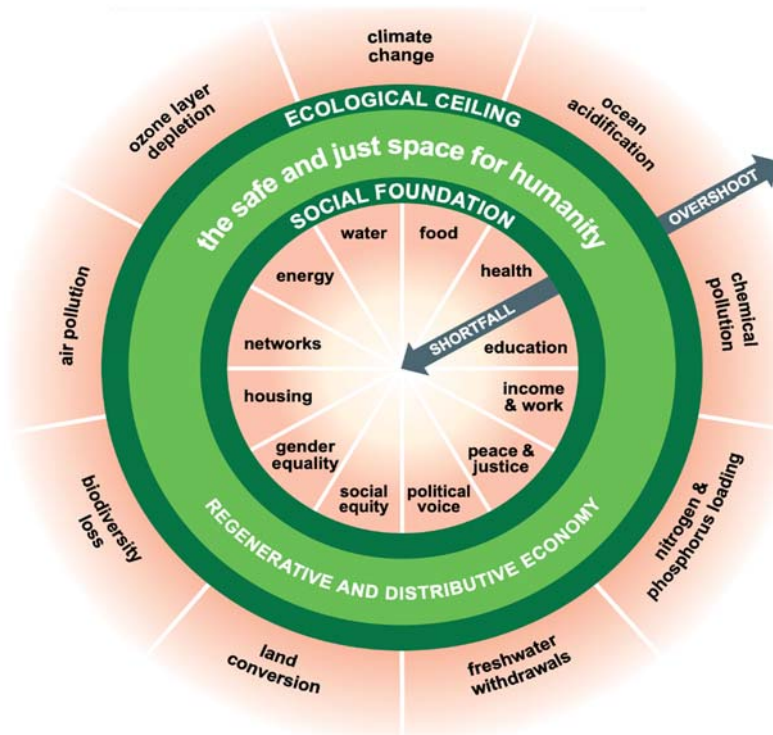
The urban energy field is multi-faceted and comprises many dimensions and components, such as use of natural gas, electricity, coal, combined heat and power, solar energy, and so forth. However, in all cases a drastic increase in energy efficiency is a sine qua non for climate-benign outcomes. Apart from technological efficiency in energy production and consumption, there is also a great potential for citizens or business life to make a real difference, in terms of direct energy use (e.g.

for heating) and indirect energy use (in the form of embodied energy in material consumption). Consequently, citizens are key actors in all urban energy domains, including also protection measures against urban heat island effects (e.g., through green cities and green neighbourhoods).

5.3 *E-compass*

Citizen involvement calls for guidelines for residents or stakeholders regarding necessary or desirable adjustments in their direct and indirect energy behaviour. To provide meaningful, transparent, and action-oriented advice, the use of scoreboards or – in a more advanced setting – smart dashboards has become very much en vogue. Examples of data-based dashboards for use in urban environmental policy and in localised corona policy can, respectively, be found in Kourtit and Nijkamp (2019) and Nijkamp and Kourtit (2022). Such dashboards are based on a limited set of relevant Key Performance Indicators (KPIs) and comprise the most critical steering and control parameters so as to achieve pre-defined objectives. In general, a dashboard is based on a modular design, and follows a strict decomposition approach containing a limited number of main indicators, sub-indicators, derived sub-indicators and so forth.

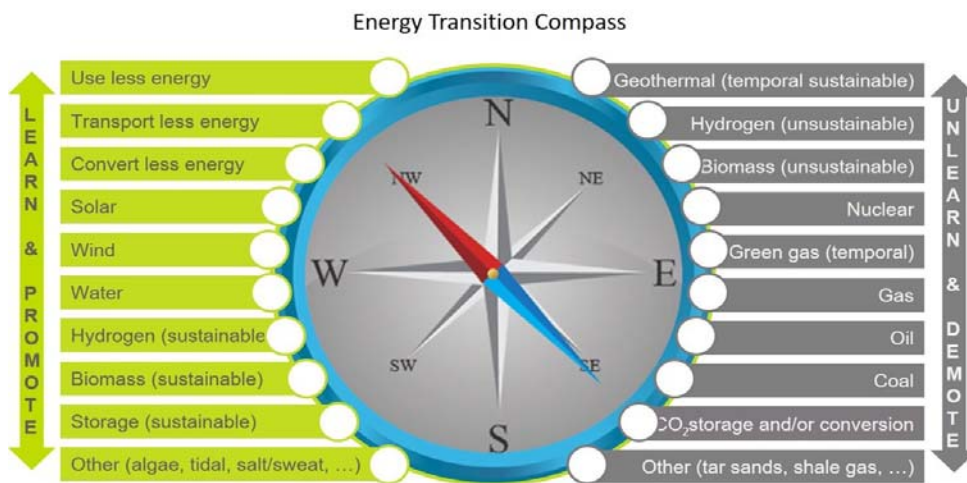
Figure 5. The Doughnut of Social and Planetary Boundaries (Raworth 2017, p.3)¹



¹ Kate Raworth (2017): <https://www.kateraworth.com/wp/wp-content/uploads/2020/04/20200416-AMS-portrait-EN-Spread-web-420x210mm.pdf>

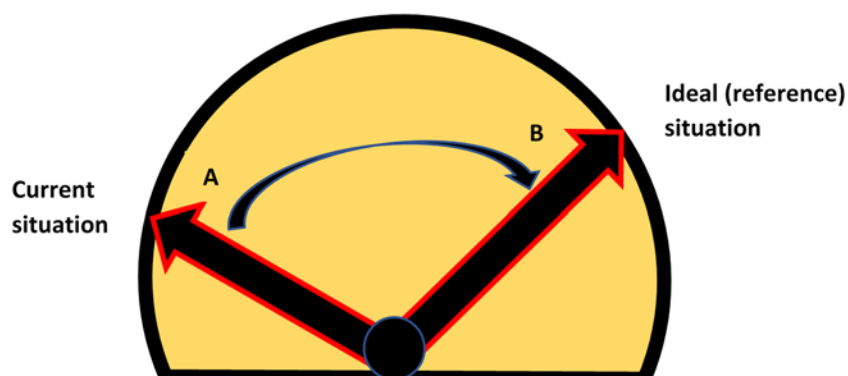
In the meantime, an avalanche of smart dashboards for an effective use in local energy planning has emerged. We offer here two illustrative examples of such dashboards. The first one presented here is a global energy function dashboard, which maps out the various general approaches for an energy-savings and climate-benign policy (see Figure 5). The local dimensions in this mechanism are less well developed and hence it is less suitable as an operational tool for local energy transition.

Figure 6. Energy Transition Compass (L. Dietvorst)²



The second example of an energy dashboard is more specific and action-oriented, and contains the ingredients for an effective local energy transition dashboard (see Figure 6). Nevertheless, it needs more citizen-oriented detail, which offers more relevant insight to residents and stakeholders on case-specific energy adjustments. We refer to Figure 7 for an illustration of an *e-compass* based on the Rotterdam case study.

Figure 7. E-compass for energy efficiency



² Louis Dietvorst: https://nl.pinterest.com/l_dietvorst/louisdietvorst/

The e-compass – as part of an energy efficiency dashboard – measures the tension between the actual energy situation in a given building or neighbourhood (A) and the ideal (or reference) situation (B). To bridge this gap, local energy planners and citizens (or owners of a real estate) need to have transparent information on the necessary trajectory from A to B, in particular from the perspective of the five dimensions mentioned in the Pentagon in Figure 1, viz. *finware*, *software*, *hardware*, *socio-ware*, and *infloware*. Thus, the e-compass is not just a simple ‘energy-efficiency thermometer’; it includes – through a systematic decomposition – also the relevant background information and empirical data that are needed to inform citizens and to obtain the citizens’ support or acceptance as well as to lay the foundation for balanced energy transition decisions by competent authorities. The e-compass is thus a critical decision tool in citizen-oriented local energy planning.

5.4 Spatial analysis (scales and modelling)

Adequate knowledge and actionable information is a necessary condition for successful local energy transition. However, such information is scale-specific and may range from individual attributes at the level of dwellings or occupants to relevant information on energy infrastructure at street or district level. Clearly, individual-specific data are subjected to strict privacy regulations regarding collection, storage and use. The scale of data also determines the type of modelling of urban energy systems, on both the supply (including infrastructure) and the demand (including behavioural) side of the complex urban energy spectrum (see e.g. Donaghy et al. 2021). Spatial energy modelling is increasingly becoming a major research challenge, in particular in the context of citizen participation strategies and of the unprecedented potential of smart digital technology in the energy field.

5.5 Citizen participation tools

The field of energy transition touches immediately the interests of residents. However, to digest all diversified opinions and interests in a comprehensive evidence-based platform for effective planning has turned out to be a harsh task, and therefore in Section 3 we have proposed the use of the diablo model as a tool for designing and analysing an operational citizen involvement approach. As mentioned, the actual citizen engagement vehicles are numerous, but an evidence-based and quantitative-statistical analysis of views and choices of a large number of residents is fraught with many difficulties. A promising and often tested model for preference elicitation of many actors is the so-called MAMCA model (see Macharis et al. 2012). The MAMCA (Multi-Actor Multi-Criteria Analysis) model is able to capture the priorities (or preference rankings) of a large group of relevant actors regarding a set of choice alternatives. The MAMCA approach is based on the following principles. An actor is confronted with a countable choice set of several discrete alternatives, each characterised by a measurable set of relevant attributes or characteristics (criteria). The evaluation results can be seen in a single view – supported by digital techniques (e.g., digital twin, dashboards) – that takes into account the interests and

preferences of various stakeholder groups. Furthermore, the MAMCA framework provides also information on problems and perspectives of other groups so as to create transparency and awareness in order to look for compromises and to come to a sustainable agreement. In the next section we will provide a brief overview on the modern digital techniques in recent geographical and planning studies.

5.6 Digital support tools and 3D digital twins energy

Over the past decades we have witnessed a rising popularity of geo-science inspired support tools for spatial planning, ranging from traditional GIS techniques to modern digital twin techniques. All such approaches are data-driven and have demonstrated their usefulness in numerous studies (see e.g. Craglia et al. 2021). These digital methods are also increasingly advocated and applied in local energy planning issues. To highlight the particular importance of these digital methodologies, we will in a separate section (Section 6) explain the development of and the potential of this advanced approach in more detail.

5.7 Local energy scenario's

The field of local energy planning is full of uncertainties on future developments. These uncertainties may relate to the supply side (e.g. fossil fuel dependence), geo-political determinants (e.g. war situations, like in Ukraine), climatological requirements, behavioural adjustments (e.g. climate-benign life styles), or political interests. To cope with such uncertainties often use is made of future scenario's (see Nijkamp et al. 1999; Nunes et al. 2000; van der Heijden 2005). Such scenario's may be wide-ranging, from energy consumer responses to technological breakthroughs. From the perspective of local (neighbourhood or dwelling level) energy planning, scenario's incorporating behavioural responses based on citizen engagement are extremely important as signposts for a balanced and sustainable energy transition. In particular, the integration of digital support tools (such as interactive 3D viewers) and citizen engagement approaches (e.g. by means of smart dashboards) may be of great relevance for localised sustainable energy planning. It will also form a major analytical tool for energy transition strategies in the city of Rotterdam.

6. From Spatial Data Infrastructure to Digital Twin Infrastructure

This section will address in general the prominent merits of the use of digital support tools in local (energy) planning (see also Lawrence et al. 2017). In the 1990s, already a discussion started on how to bring together public data by law (Open Data), Open Standards and information technology. The initiatives of FGDC (Federal Geographic Data Committee) in the USA – followed by Inspire in Europe – are nice examples of large projects to address and support societal questions by means of a data-driven approach (see for an overview Masser and Cromptoets 2018).

There are several reasons why the next step in the discussion on data infrastructures became then pertinent. An important reason is the enormous growth

in data. Thanks to sensors we are able to measure geographical processes above and below the surface in almost every second. But we are also able to give an extra information content to such data. We can collect from a geo-science perspective also the height and the depth, i.e. 3D. Buildings, but also the soil, become nowadays part of our data infrastructure. The traditional GIS-based systems were no longer capable of storing – and making accessible – these new data sets. That explains why a new concept has been brought to the table: Digital Twinning (Craglia and Scholten 2019).

Digital twinning bridges the gap between the physical and the digital world by bringing real world data and models into a virtual environment. Over the last few decades, there has been a strong increase in data collection and storage capacity. A digital twin provides a platform to bring big data from different sources together in a single and structured place. Such a virtual replica of the physical world can facilitate data-driven working and can lead to more efficient decision-making and asset management in an ever-digitizing society.

The concept of digital twinning is meanwhile being applied in numerous sectors and industries, including aerospace engineering, manufacturing, healthcare, urban and environmental planning, construction and smart cities. Consequently, definitions for a digital twin may vary quite substantially (Barricelli et al. 2019). From an academic perspective, digital twinning is often explained in terms of an intelligent system allowing for continuous interaction, communication and synchronization between the digital twin, its physical counterpart and the surrounding environment; it frequently includes a predictive or time-based element (Grieves 2015). So, a digital twin is not just incorporating data, but the integrated data set allows data modelers to integrate their models in order to simulate the behavior of the digital twin.

In the built environment, digital twins are starting to receive more interest, being mainly useful for inspection purposes (Pan and Zhang 2021) and predictive maintenance, especially when combined with sensor data and model results (Khajavi et al 2019). Building information models (BIMs) play in this context an important role, as these models contain detailed information on the properties of all components of a building from an architectural angle (Rafiee et al. 2014). Digital twinning of buildings and constructions using a BIM is increasingly applied in architecture, engineering and construction (Lu et al. 2019, Menassa 2021).

The aforementioned examples feature digital twins of a single physical system. However, the continuous improvement in data processing techniques, cloud computing, artificial intelligence, sensor technologies and 3D modeling algorithms open up the opportunity to develop increasingly more advanced digital twin infrastructures and applications. A logical next step lies in the development of comprehensive digital twins that bring together data from multiple physical systems. An example of this upscaling is Digital Twins for the Physical Living Environment (DTFL, Geonovum 2022), which integrate geospatial data of physical and geographic objects on a regional scale along with data on the dynamic processes (e.g. through sensor data) that are taking place.

Although digital twinning of a single building or construction using BIM receives more and more attention, the incorporation of BIMs in the wider context of a DTFL system remains relatively unexplored. Importing a BIM into a DTFL is challenging, as it requires accurate geospatial positioning of the BIM. This is of course complicated, as BIMs are often stand-alone models that lack geo-referencing. Bringing a BIM into a DTFL can have great added value for a material construction or infrastructure object. For example, relations can then be established between model results and factors like sub-surface, weather or real-time traffic flows. Also, it can facilitate assessing the impact of a planned construction work on the external living environment.

In the context of urban energy transition, digital twins can be used to model and optimize the performance of energy systems in the city at any geographical scale. As mentioned before, we need then empirical measurements and policy actions at different levels. For the discussion and decisions on energy measures, the object (dwelling, factory, shop, etc.) is the most appropriate level of analysis (like for a BIM). However, for the neighborhood level we also need to have all possible data of the digital twin for a better understanding of e.g. the influence of the sun or wind, the HCS (hot-cold storage) in the subsurface, or solar panels at the neighborhood level (Hettinga et al. 2018). Overall, the use of digital twin infrastructure can help cities plan and implement their energy transition in a more efficient, cost-effective and democratic way.

7. Concluding Remarks

Local energy planning has become a prominent task of urban policy-making agencies. Developing and assessing new energy transition strategies geared toward a strict climate-neutrality, a decarbonised economy and a circular production and consumption structure calls for innovative adaptation measures involving various (internal and external) stakeholders with a view to gaining trust in public policy based on transparency and consistency. Such an adjustment approach does not only require due engineering expertise (as sketched in Figure 1), but also a clear consideration of socio-economic disparities, age and gender differences, housing demands, infrastructure, logistics provisions, environmental sustainability and general local wellbeing. Such conditions need novel insights and balanced energy transition policy strategies to ensure the necessary technical, socio-economic and policy support mechanisms ranging from the urban to neighbourhood level. In a study by UKCIP the following principles have been formulated for a good urban adaptation strategy in the context of climate change³:

- work in partnership
- understand risks and thresholds
- frame and communicate smart objectives/outcomes
- manage climate and non-climate risks using a balanced approach

³ Source: <https://www.ukcip.org.uk/about-adaptation/>

- focus on actions to manage priority climate risks
- address risks associated with today's climate variability and extremes
- use adaptive management to cope with uncertainty
- recognise the value of no/low regrets and win-win adaptation options
- avoid actions that limit future adaptations
- review the continued effectiveness of adaptation decisions.

Clearly, these guidelines hold in general for climate adaptation strategies, but have an almost equal relevance for drastic energy transition in the context of environmental and climatological concerns, at both global and local levels.

The task of local authorities – in tandem with place-based communities – is to develop future-proof residential areas. A critical success factor in this context will be the use of advanced digital technology, at the level of both individual citizens and houses as well as at the meso- or macro-level of strategic sustainability and energy planning. The experiences in Rotterdam have demonstrated that the mix of advanced digital tools, citizen engagement, operational data supply systems and interactive policy strategies may in principle lead to successful sustainable energy outcomes at urban and neighbourhood level.

Acknowledgement

The authors recognise a research grant of Royal Dutch Shell, in cooperation with the city of Rotterdam, for undertaking this work.

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PLANIRANJE KLIMATSKI-BENIGNIH GRADOVA – DIZAJN MAPE UMA ZA PAMETNU ENERGETSKU TRANZICIJU

Apstrakt: Lokalne inicijative za energetska tranziciju – kao deo šire klimatski benigne politike i politike održivosti – postale su fokusna tačka strategija za resurse i životnu sredinu orijentisanih na budućnost. Međutim, pokazalo se da je konverzija energije zasnovana na lokaciji veoma komplikovan zadatak, kako iz perspektive upravljanja, tako i iz perspektive istraživanja. Ova studija nastoji da skicira konture lokalnog održivog energetske planiranja, sa posebnim naglaskom na (i) praktične podatke i zahteve za informacijama zasnovanim na dokazima, (ii) uključivanje i angažovanje građana i zainteresovanih strana, i (iii) veliki istraživački potencijal koji pruža digitalna informaciona tehnologija. U tom cilju, prikazana je sveobuhvatna mapa uma za energetska tranziciju, inspirisana prvim eksperimentima u gradu Roterdamu.

Ključne reči: energetska tranzicija, klimatski benigni gradovi, lokalna energetska mapa uma, učešće građana, model Pentagona, dijablo model, e-kompas, digitalni alati, lokalni energetska scenario.

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