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The City of Flows: Urban Planning of Environmental Flows

Editor

Rob Roggema

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Editorial

City of Flows: The Need for Design-Led Research to Urban Metabolism

Rob Roggema [1,2]

[1] Office for Adaptive Planning and Design, Cittaideale, 6707 LC Wageningen, The Netherlands; E-Mail: rob@cittaideale.eu
[2] Knowledge Centre NoorderRuimte, Hanze University Groningen, 9747 AS Groningen, The Netherlands

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Abstract
The design of cities has long ignored the flows that shape the city. Water has been the most visible one, but energy and materials were invisible and/or taken for granted. A little over 50 years ago, Abel Wolman was the first to illuminate the role of water flows in the urban fabric. It has long been a search for quantitative data while the flows were mostly seen as separated entities. The fact they invisibly formed the way the city appears has been neglected for many years. In this thematic issue the "city of flows" is seen as a design task. It aims to bring to the fore the role flows can play to be consciously used to make spatial decisions in how and where certain uses and infrastructure is located. Efficient and sustainable.

Keywords
energy; food; food-energy-water nexus; nexus thinking; urban flows; urban metabolism; urban planning; water

Issue
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1. Introduction: Brief History of Urban Metabolism

When we think about flows in the city the term urban metabolism is often used. Like our body, the city is seen as an organism which requires resources to function, and the way these resources are used to serve all different functions of the city, and to which waste flows this leads, determines the metabolism of the body, and translated to urban flows, the urban metabolism. The first to point at the role that a flow, in this case the flow of water, plays in the urban fabric was Abel Wolman. He calculated the size of the water flows that flew through the city and discussed how this flow could be managed more efficiently and more sustainable (Wolman, 1965). Some decades later the discussion about pollution of the urban environment led to the need to understand the urban pollutants better and their influence on the flows of the city. Air could be polluted and could pollute soils and water, polluted water could pollute food systems and have a profound impact on human health. It was therefore essential to develop understanding about how these flows in the city behaved, how big they were and how they influenced the quality of life, and how they produced waste streams in the form of pollution. An important insight was offered when urban flows became part of an ecological conceptual model (Van Leeuwen, 1981). In this model the aims for a sustainable management of flows in the city was established. In a so-called eco-device model (Figure 1) the incoming and outgoing flows were symbolized, as well as the flows that were prevented from entering the area or leaving. This way, an abstraction of the flows of water, energy and materials could be given, and determine if the system was performing ecologically well or not.

This abstract model has been modified and further elaborated in order to illustrate the flows in greater detail and also show the external factors of the system, such as climate change, that determine the context of the "extended urban metabolism model" (Newman, 1999). Though Peter Newman has put the model in practice, especially in traffic and mobility plans, working with the parameters in an integrated way to create a spatial perspective remained a challenge. Jón Kristinsson invented a three-dimensional model (Figure 2, left) in which, for every layer, the specific flows were symbolized as in or outgoing flows, which could re-enter the system at an-

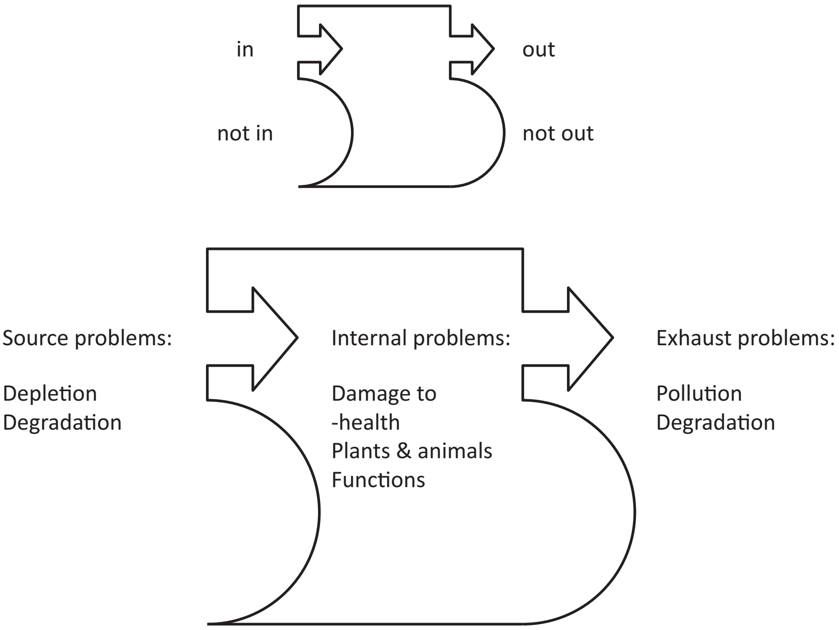

Figure 1. Eco-device model (IN–Not IN; OUT–not OUT). Source: After Van Leeuwen (1981).

other level. This way a comprehensive 3D-model of a city could be drawn, and the city seen as an ecosystem itself (Tomásek, 1979). The levels Kristinsson determined were the abiotic, biotic, urban and atmospheric layers (Kristinsson, 2012). Nowadays, more layers could and should be added to this systemic image (Figure 2, right), as demonstrated by van Timmeren and Henriquez (2015). The exchange of flows between more layers will open up the possibilities to close cycles and become a more sustainable urban ecosystem. A direct link can be established here with thinking that takes place around the theme of Smart Cities.

The ecosystem model is reduced to few levels (earth, city, networks) in the new model (new linkages and potentials to connect and exchange flows, materials, streams), and lacks the (a)biotic layers at all. When these would be integrated in the model a more comprehensive model would emerge, hence consist of the abiotic, biotic, user, interface, address, network, city, cloud and earth layers.

Where most of Kristinsson's (2012) work focuses on the building itself, trying to optimize the indoor climate and direct environment of the building using technological innovations that make use of the different available

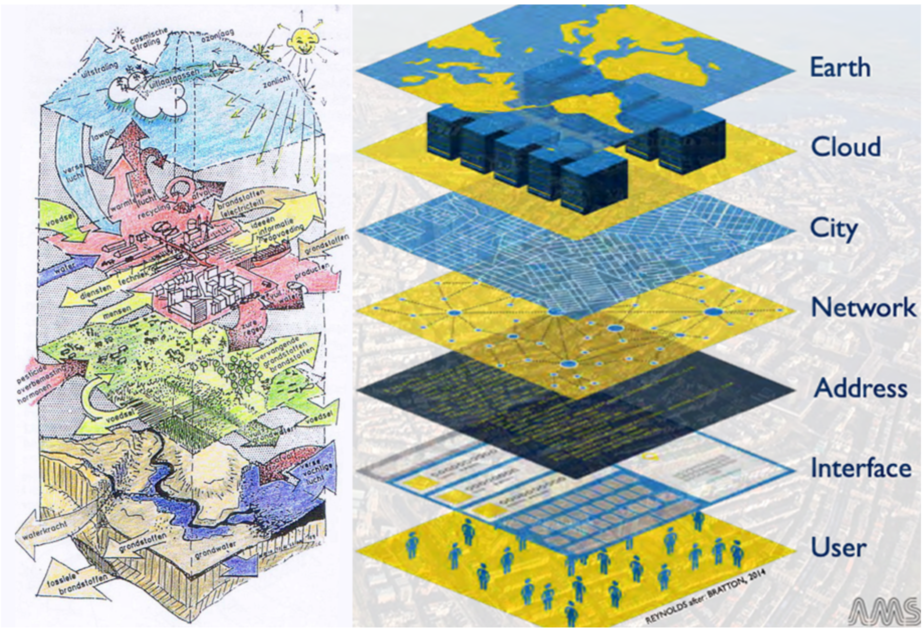

Figure 2. Kristinsson's (2012) 3D-model of the city as an ecosystem (left); van Timmeren and Henriquez' (2015) "the Stack" layers including recent digital additions (right).

flows in the vicinity and aim to close resource and waste cycles as good as possible, "until the good (urban) traveler leaves no trace", at the scale of the city as a whole additional connections, exchange and gains can be harvested. In the Rotterdam Biennale 2014, curated by Dirk Sijmons, this has been investigated (Figure 3) under the title *Urban by Nature* (Brugmans & Strien, 2014), and design-led projects have shown that large benefits can be by connecting the waste streams of certain flows to the resource demands of others at the regional urban scale (Gemeente Rotterdam, IABR, FABRIC, JCFO, & TNO, 2014).

Overlooking 50-odd years of scientific research, thinking, academic education, designing and innovating around the topic of urban flows, several aspects presented themselves as key components. The quantification of urban flows, the ambition to close cycles and minimize waste flows, the systemic approach, and the implications for the spatial configuration of the city are recurring subjects. However, the dominance which could be expected of design-led approaches did not come to total fruition. At the end of the day urban flows must be quantified, in order to assess their performance and this seems the dominant paradigm. Instead of looking at the size of flows only, ore aspects require synergy, something that can be easily achieved through design. The synergies between livability, design, urban flows, assessment tools and sustainability has been extensively investigated (Tillie, 2018). Implementation of synergetic thinking should now be a priority, and it is necessary that the integration and sustainability of urban flow systems should shape the city. Consciously, and not as an invisible unexpected add-on to our cities. Integrated urban flows should be designed to lead to attractive places, in which the brilliance of the systems has become visible, can be witnessed and experienced by residents, and where new resources are celebrated.

2. Thinking in Nexuses

So far, the majority of academic work has been oriented towards quantification of flows, assessment tools, and determining what one flow needs from another to operate? Do we have enough water for bioenergy, how much electricity is needed for desalination? These types of questions are mainstream, often focusing on only one urban flow. In recent decades the energy-water nexus has received the majority of the attention, as can be witnessed by a broad range, but not exhaustive, of literature shown here (Bauer, Philbrick, & Vallario, 2014; Byers, Hall, & Amezaga, 2014; Connor & Koncagül, 2014; Cooley & Wilkinson, 2012; Davies, Kyle, & Edmonds, 2013; Gleick, 1994; Halstead, Kober, & van der Zwaan, 2014; Henthorne, 2009; Inhaber, 2004; Kohli & Frenken, 2011; Koulouri & Moccia, 2014; Lavelle & Grose, 2013; Macknick, Newmark, Heath, & Hallett, 2012; Macknick, Sattler, Averyt, Clemmer, & Rogers, 2012; Mielke, Diaz Anadon, & Narayanamurti, 2010; Mitra & Bhattacharya, 2012; Plappaly & Lienhard, 2012; Radcliffe, 2018; Rodriguez, Delgado, DeLaquil, & Sohns, 2013; Sanders & Webber, 2013; Spang, Moomaw, Gallagher, Kirshen, & Marks, 2014; Stiegel et al., 2009; US

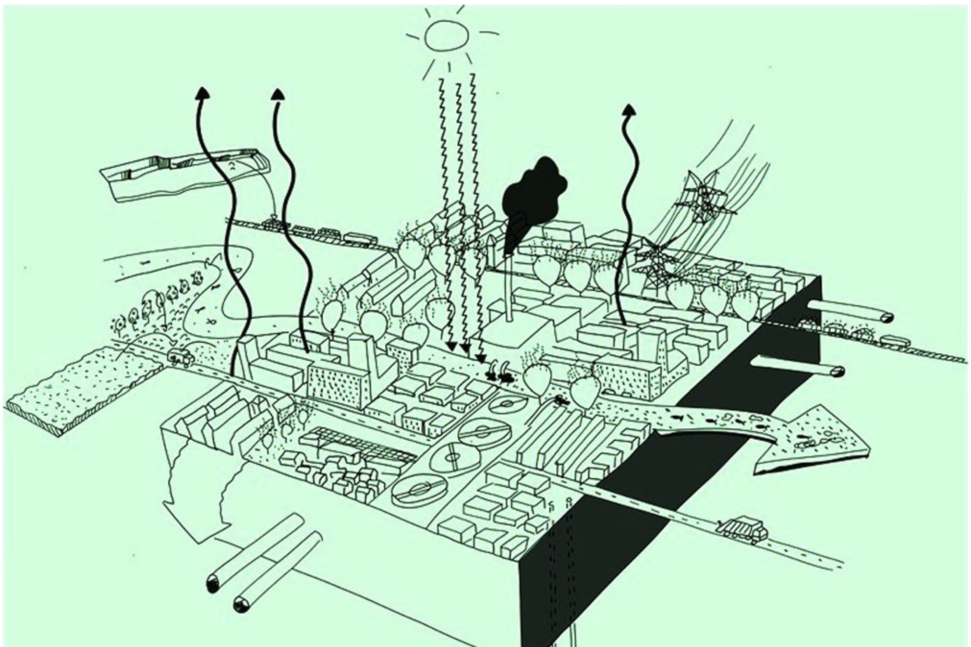

Figure 3. Urban metabolism model. Source: Dirk Sijmons/Jutta Raith (Gemeente Rotterdam et al., 2014).

Department of Energy, 2006; Wang, 2013; Water in the West, 2013; Webber, 2008; World Energy Council, 2010).

The nexus of water and food has been investigated in the agricultural literature, while the energy-food nexus is less well researched (ISIS, 2013; WISIONS, 2007) and very few linkages are made between food, energy and water and ecosystems (UNECE & KTH, 2014).

Only recently integrated thinking about water, energy and food emerged as the food-energy-water nexus (Barrett, 2014; Bazilian et al., 2011; Bizikova, Roy, Swanson, Venema, & McCandless, 2013; BMU, 2012; Ferroukhi et al., 2015; Flammini, Puri, Pluschke, & Dubois, 2014; Granit et al., 2013; Hanlon et al., 2013; Hoff, 2011; Mohtar & Daher, 2012, 2013; Shannak, Mabrey, & Vittorio, 2018; SEI, 2011; World Economic Forum, 2011). Especially after the Bonn2011 meeting the research agenda sparked, and new investigations occurred and reached the academic journals. The majority of these research outputs are focus on quantifying the flows, developing assessment tools and/or aim to define the relationship quantitively between two or more of the flows. The implications of different sizes, relationships and amounts of flows for the city are less well researched. A design-led approach is rare, and this may be one of the reasons it is very difficult to amend the systems of water, energy and food to establish more integrated, sustainable and resilient urban systems (GIZ & ICLEI, 2014).

3. The Thematic Issue

The focus on quantification of urban flows is, on the one hand, needed to understand what we are talking in the first place. It does matter with how much water we have to deal in the city, how much energy is required, or how much food must be grown to feed the population. However, on the other hand understand quantity only is not enough. Reduced amounts of flows must also be integrated in the spatial context of the city, towns and landscape. Therefore, this thematic issue of Urban Planning features articles that illuminate the possibilities of design-led approaches to inclusion of urban flows in the city. To set the scene, Roggema (2019) starts with sketching the current context of disruptive developments, which influence the context and the spatial options in the city. The space available and the amounts of networks for unexpected change determines the adaptivity of systems, and the possibility to introduce counterintuitive solutions. Yan and Roggema (2019) focus on design-led approaches for the food-energy-water nexus, and integrate spatial, governance and appraisal aspects of the nexus. Han and Keeffe (2019) focus on a very interesting flow, the move of urban forests through the city. In their article, Galan and Perrotti (2019) highlight the opportunities for sustainable metabolism at the regional level. The way people can be involved and given a larger stake in their consumption of basic flows is the subject in McLean and Roggema (2019), while a different perspective on governance to improve urban metabolism, increasing accountability in strategic planning, is given in Zengerling (2019).

This thematic issue brings together insights and perspectives on the “city of flows”, an orientation on the possibilities to change the spatial design for the city as a result of choices made for flow systems. This design-led thinking is, so-far, underestimated in realizing a resilient system of flows in urban environments. Even in acquiring academic outputs for this thematic issue, it proved to be not easy to collect an abundant number of articles. There is still a long way to go, especially because the quantification, assessing and defining of urban flows will not easily lead to implementation, and hence to a more resilient and sustainable city. The way design approaches can visualize solutions and propose unprecedented and innovative solutions is unmet by most current published research.

4. Conclusion: Future?

State of the art literature shows that most research focuses recently on the food-energy-water nexus. While in building research materials form a substantial body of knowledge, the use of waste and materials at the urban design level is not very common. Therefore, it is suggested to add and integrate these flows to the model. Finally, the rapid development of data collection, analysis, data-driven design and the use of data in planning our cities (Smart Cities), would justify starting thinking about integrating data in the urban metabolism model, despite data being often non-physical.

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About the Author

Rob Roggema (PhD) is Professor of Sustainable Spatial Transformations at the Knowledge Centre Noorderruimte, Hanze University Groningen. He is a landscape architect and an internationally renowned design-expert on sustainable urbanism, climate adaptation, energy landscapes and urban agriculture. He has previously held positions at universities in the Netherlands and Australia, State and Municipal governments and design consultancies. Rob developed the Swarm Planning concept, a dynamic way of planning the city for future adaptation to the impacts of climate change.le of urban planning and architecture in the daily lives of asylum seekers and their future trajectories.

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Article

Design for Disruption: Creating Anti-Fragile Urban Delta Landscapes

Rob Roggema [1,2]

[1] Office for Adaptive Planning and Design, Cittaideale, 6707 LC Wageningen, The Netherlands; E-Mail: rob@cittaideale.eu
[2] Knowledge Centre NoorderRuimte, Hanze University Groningen, 9747 AS Groningen, The Netherlands

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Abstract
In this article three different responses are taken as the starting point how different types of disruption could be dealt with. These responses—repair, bounce back and grow stronger—are combined with three disruptions (sea level rise, storm surge and heavy rainfall), and then tested in three case studies. The result of the investigation is that anti-fragility (grow stronger) is a preferential approach to create delta landscapes that become stronger under influence of a disruption. Anti-fragility is for this research subdivided in three main characteristics, abundance of networks, adaptivity and counterintuitivity, which are used to analyse the three case study propositions. The type of response, type of disruption, characteristic of anti-fragility and the qualities of the case study area itself determine the design proposition and the outcome. In all cases this approach has led to a stronger and safer landscape. The concept of anti-fragility impacts on the period before a disruption, during and also after the disruptive impact. This gives it a better point of departure in dealing with uncertain or unprecedented hazards and disruptions.

Keywords
anti-fragility; delta landscape; disruption; intervention; coast; resilience

Issue
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1. Introduction

Though many areas suffer from the impact of climate change, deltas and coasts are seen as belonging to the most vulnerable areas in the world (Balica, Wright, & Van der Meulen, 2012; Climate Institute, n.d.; Meijer & Nijhuis, 2014). These areas are at risk of climate impacts such as sea level rise, storm surges and cyclones, and they also are the areas with largest population concentrations and economic prosperity, which places these areas at an increased vulnerability level. When a disruption occurs in deltas and coasts several responses are used to recover: repair, bounce back or grow stronger.

1.1. Repair

The dominant response is repairing damage after the disruption and rebuild the city. In this option defensive structures such as dams, seawalls are built, aiming to protect as many assets in the urban landscape by excluding disruption. Barriers are raised to keep the external impact away from the city. However, this equilibrium is setup for disaster. Eventually, even the strongest protective system is not strong enough to withstand unprecedented impacts, hence future disruptions will require rebuilding again. Good examples of this approach are the Dutch Deltaworks (Rietveld, Rietveld, & Habets, 2017) and the Thames Barrier (Kendrick, 1988), but also the Rebuild by Design (Ovink & Boeijenga, 2018) after hurricane Sandy hit New York belongs in a way to this category, though rebuilding in New York takes place by creating more resilient and soft defensive structures.

1.2. Bounce Back

The second approach to deal with disruption is to design a city that can keep performing its basic functions (e.g., ecological resilience; Gunderson & Holling, 2002) and bounces back (e.g., 'engineered' resilience; O'Hare & White, 2013). The concept of resilience is used to describe how cities and regions could embed security and risk management features into their built environment and governance systems as part of a broader drive towards more safe and sustainable communities (Coaffee & Bosher, 2008). Measures are taken both to resist disruption as to recover rapidly afterwards (Coaffee, 2008). Resilience shows similarities to relational understanding of spatiality (Massey, 2005) as both put emphasis on fluidity, reflexivity, contingency, connectivity, multiplicity and poly-vocality (Davoudi & Strange, 2009). Place is seen as complex interconnected socio-spatial systems with unpredictable feedback processes at multiple scales and timeframes (Davoudi, 2012). A more resilient urban environment for instance planned under an interpretive regime reducing the 'will to order', discourages fixity and rigidity (Davoudi, 2011).

1.3. Grow Stronger

The third response is less used. The concept of anti-fragility (Taleb, 2012), a theory focusing on how systems can become stronger under stress, could be beneficial for deltas confronted with disruptions. This concept will be further explored how it can be of use in spatial design in this article.

Each of these responses have their (dis)advantages, depending on the type of disruption and the context in which it takes place. In this article the problem will be defined first. Following this, three types of potentially disruptive developments for deltas will be described. In Section 4 the concept of anti-fragility is further elaborated on and three key characteristics, networks, adaptivity and counterintuitivity, are defined. These characteristics are then used to test the impact of three disruptions in three case studies and investigate whether they can grow anti-fragility in spatial planning. The article ends with drawing conclusions and formulate several recommendations.

2. Problem Statement

The sustainable urban development model is under threat of a range of developments of economic, social, environmental and spatial nature (European Union, 2011, pp. vi), terrorism (Marcuse, 2006; Rossi-Hansberg, 2004) and climate change (Carter et al., 2015; De Sherbinin, Schiller, & Pulsipher, 2007; Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013). While it is common to see disasters as 'causes', and the destruction of the built environment as 'effects', the intricate links between cities and disasters cannot be described by a unidirectional cause-and-effect relationship. The city–disasters nexus is a bidirectional relationship, which constantly shapes and is shaped by other processes, such as climate change (Wamsler & Brink, 2016). The majority of current responses applied in cities focus on protection, safety and security, or disaster risk reduction (DRR). This leads to a controlled but narrow equilibrium. If developments work out a little different than projected, a protective approach will not suffice, as city influences the disaster as much as the other way around and this will 'undermine' the well-meant protection which only prevents one direction: the impact of the disaster on the city. Instead of being the victim of external factors, the city should enhance its holistic capacity to not only deal with multiple and different complexities resulting from external disruptions, but also minimise its influence on the genesis of disasters. Additionally, it would be even more interesting if the quality, safety, prosperity and beauty of deltas improves when a disruption occurs. This bidirectional relationship of decreasing negative impact of disruptions and at the same time increasing the strength and quality of the delta requires urban design solutions, which can turn threats into benefits. Design-led research (Roggema, 2016) can provide insights how to use the power a disruption brings to make deltas stronger. The goal therefore is to find mechanisms that increase the quality of urbanised deltas as result of the disruption.

3. Disruptive Developments in Deltas

In general, delta areas are under threat of three main potentially disruptive impacts: sea level rise, storm surges and heavy rainfall during storms, cyclones or hurricanes.

3.1. Sea Level Rise

Due to a complex of factors sea level is rising and will continue to rise in an accelerated fashion (Kopp et al., 2016; Nerem et al., 2018; Vermeer & Rahmstorf, 2009; Walsh et al., 2014, p. 45). Due to sea level rise coastal zones are under threat of inundation and flooding. One of the most recent integral predictions for change in global sea level estimates that in a worst-case scenario the level will increase with 2.5m by the end of the century (NOAA, 2017) or as much as 3–3.5m for most of the United States (Climate Central, 2017). The vulnerability of deltas and coastal zones for sea level rise is the elevation: it is obvious that lower lying land is more vulnerable for sea level rise than higher elevations.

3.2. Storm Surges

Add significant extra risks, leading to higher costs and large spatial impact on land use (Neumann et al., 2015). For several hurricanes in the United States the surge has been estimated and ranges between almost 10m (Katrina), to 7m (Ike) and 2–4m for Charley and Irene (Weather.Gov, n.d.). In Norway, calculations show that a storm surge triples or multiply fivefold sea level rise (Norwegian Directorate for Civil Protection, 2017). These examples illustrate that different contexts imply other additional water levels attacking the coast. It is clear that centimetres of sea level rise often lead to meters of surge.

The vulnerability of deltas and coast is in this case the level at which coastal protection can take away wave and surge energy.

3.3. Heavy Rainfall

Tropical cyclones or hurricanes, when they make landfall, come along with torrential rain and contribute for more than 50% to extreme precipitation events both with regards to Atlantic tropical cyclones (Aryal, Villarini, Zhang, & Vecchi, 2018) as the Indian Ocean cases (Lang, 2018). Hopkins and Holland (1997) found similar results for East Coast Australia, and Taiwan (Chen, Tan, & Shih, 2013). The vulnerability of deltas and coast for heavy rainfall is determined by the spatial capacity in landscapes and cities to temporarily store large amounts of water. Often this capacity is far below the required space causing flooding.

In Section 5, these disruptions will be used to investigate whether the three case studies could grow stronger by using anti-fragile spatial interventions.

4. Anti-Fragility

Systems vary in their ability to deal with stress, ranging from being fragile and degrading under stress, be robust and remain unchanged during stress, or to be anti-fragile and improve while suffering stress (Johnson & Gheorghe, 2013). A fragile object is an object, which perturbations can only harm, damage or break. Something is robust if events, perturbations, volatility, disorder cannot harm it. At the same time, nothing can benefit from it. Resilience is the capacity of a system, to absorb a shock without breaking, perhaps deforming but then rebounding to its previous condition. Therefore, in the case of resilience as well as robustness, time ultimately leaves the object or the system unchanged (Blečić & Cecchini, 2017). Anti-fragility is beyond resilience or robustness. The resilient system resists shocks and stays the same; the anti-fragile benefits from shocks, thrive and grow when exposed to volatility, randomness, disorder and stressors, and it loves adventure, risk, and uncertainty (Taleb, 2012, pp. 21–22). An anti-fragile system creates opportunities to learn from small mistakes, trial-end-error, to deal with new challenges, to improve and innovate. Anti-fragility means that mistakes have reversible consequences and we can learn from them. In this situation there are more upside than downside effects from random events (non-linear gains), as losses from mistakes are small, while a positive option may appear that supports development (Platje, 2015).

In order to find general criteria for an anti-fragile development, the opposite of the criteria defined for fragile planning (Blečić & Cecchini, 2017, p. 6) is combined with anti-fragile criteria (Johnson & Gheorghe, 2013):

- A global idea for future direction that must be clear and operates as a general guideline, stimulate novelty and allow for disorder;
- Self-organising elements at the local scale towards that general direction;
- Redundancy through creating space that is not allocated for any specific use, e.g., absorption zones;
- Only few guiding rules for order in place, stimulate tipping points to emerge;
- Multi-functionality, simultaneity and mixed uses, for a selected and limited number of system states, e.g., certain mixes of use;
- Environments that allow for surprise and counter-intuitive feedback;
- Equally divided resources over the area;
- Similar spatial qualities everywhere.

These criteria can be interpreted and combined with each other to formulate three conditions for anti-fragility to emerge: an abundance of networks (Roggema & Stremke, 2012), high level of adaptivity (Roggema, 2012a; Roggema & Van den Dobbelsteen, 2012) and application of counterintuitive design principles (Roggema, in press). Each of these contain their own set of elements and properties that could support deltas and coasts in dealing with disruptions.

4.1. Abundance of Networks

If a system contains more intense networks of water, energy, mobility, communication, social, trade, etc., this implies there will be more connections, more hubs and nodes, hence higher connectivity. This makes the system very flexible and adaptive, as for every connection several alternatives are in operation and can be used whenever needed. A fine network also guarantees that resources and spatial quality can be spread evenly over the system; there is no core that has preferential access or rights. At the same time the nodes that are connected with most other nodes is the place where gravity moves towards: more people, more movement, more exchange and higher values will be realised in these places. When the network is fine, this implies multi-functionality and mixed land use, as on a relatively small area highly connected and less connected nodes exist next to each other and give reason for busy and quiet connections, and differences in land-use. Under threat of disruptions such rich networks can grow in functionality, for instance when connections can take up roles they didn't have before (new transport routes when others are flooded, and squares becoming water storage or roads waterways).

4.2. Adaptivity

An adaptive landscape is one that has the spatial and functional options to change whenever necessary. The transformation of places from a certain use to another, or spaces that are made redundant in order to accommodate sudden needs, such as for capturing and store water, increase the possibility to adjust to new and unprecedented impacts. The general direction for the future is established and should be supported by the residents of the area, but this general direction contains the freedom and flexibility to realise different future spatial constellations, which is ben built up from its smaller spatial elements. The space is created for self-organisation as to find the right mix of functions and spaces required at every given moment. Some functions emerge, while others diminish, and spaces constantly transform. Disruptions will enforce these transformations and changes to adjust according the demands posed by the type of disruption. For instance, accelerated sea level rise would require the use of absorption zones where the rising water can find its space as to increase the safety levels. In the design of these coastal zones the inclusion of spatial redundancy needs to provide these zones.

4.3. Counterintuitivity

Counterintuitive solutions are necessary to counteract unprecedented disruptions. If these novel disruptions are treated with the same solutions as former problems were solved, it is almost certain they will not suffice to prevent the new disruption from impacting the land. Therefore, the design process should be organised in a way it gives space to think outside the box and invent new propositions that are different from the business as usual policies that have been used in the past. These counterintuitive solutions can stimulate emergence of unexpected developments, tipping points that turn spatial configuration around in order to create the space for self-organised transformations that make the landscape stronger than before. This way the disruption becomes the initiator of a new, stronger, landscape. For instance, if storm surges threaten the coast the business as usual solution would be to strengthen and heighten the seawall. However, this solution would only increase the risk, as future storm surges could be more severe than expected and cause a disaster. A counterintuitive solution could be to allow seawater in the hinterland from the beginning as to bypass the risk and create a stronger, more beautiful landscape with the seawater as an integral part of it.

5. Case Studies

In this article three case studies are taken to illustrate the mechanisms how the quality, strength and/or safety of delta landscapes can be increased. In every case study one major possible disruption is taken as the entrance point for the design propositions. Subsequently it will be described how the delta landscape could become stronger as result of the disruption. Therefore, the three main characteristics of anti-fragility are used to analyse the qualities of the design propositions. Finally, for each case study it will be discussed whether the spatial propositions could be beneficial beyond the major disruption defined at the beginning. Each of the case studies, Double Defence (Roggema, Van den Dobbelsteen, & Stegenga, 2006), the Sydney Barrier Reef (Roggema, 2017) and the Floodable Eemsdelta (Roggema, 2012b), is used to retrospectively illustrate the potential of antifragility avant-la-lettre.

5.1. Double Defence

The Double Defence project (see Figure 1) is located in the northern part of the Netherlands. The north shores and the Wadden Sea are currently under threat of sea level rise and storm surges. This area is very vulnerable because it is low lying and the high ecological values of its tidal flats, which, under accelerated sea level rise, might drown. Storm surges could attack the coastal protection, which has, compared to other parts of the Netherlands, a lower safety level.

The proposed response to these potential disruptions is to introduce a second row of barrier islands in front of the existing ones. Because of the new islands a storm surge is not only prevented from harming the coastline, which is miles further away, it also adds a huge amount of extra sediment, such as clay and sand particles to the area behind and in between the existing and new islands. Because the islands create a more tranquil maritime environment, these particles get the chance to sink down and build up existing or new sandbanks. This enhances the wetland ecosystem of the Wadden Sea, not only in quantity but also in quality. Instead the existing islands and sandbanks are threatened of washing away during a storm surge, the new islands provide the incentive for more and new ecological area to emerge.

The introduction of an extra row barrier islands starts a new development of land-genesis. The main, long-term objective is clear, whilst the specific shape of the wetlands is dependent on the interaction of the storm surge, amount of sediment, existing sandbanks and wave strength and direction. The shape of the New Wadden will emerge under influence of the currents and available sediments, and constantly change shape. This adaptivity is possible because the area is effectively an extensive absorption zone where water, wind and sand self-organise the build-up of new sandbanks, and use the redundant space as needed. The introduction of the new islands is counterintuitive. The regular solution in this case would be to protect the existing islands by strengthening the beach and dune systems or add sand in the system to feed the build-up of sandbanks. The result of the antifragile proposition is that a rich nature emerges, which by its land-forming increases the safety of the entire northern part of the Netherlands.

On the new islands, opportunities for new uses, such as recreation, urban living, agriculture and renewable energy generation arise. At the same time, the existing hinterland, due to its better protection, could explore new developments and become a place for food supply, urban living, water retention and high-tech industrial activities, which would be under serious scrutiny if the design intervention would not be effectuated.

Figure 1. Plan for Double Defence (Roggema et al., 2006).

Double Defence is a project that deals predominantly with storm surges, uses adaptability and counterintuitivity to develop a proposition that strengthens the delta landscape.

5.2. Sydney Barrier Reef

The Sydney Barrier Reef (see Figure 2) is a proposition for the coastal zone of Eastern Australia, between Newcastle and Wollongong. The current situation is not suitable for reef development but in the future that will change, as temperatures in the southern Pacific will rise and eventually create a suitable environment for a barrier reef. Accompanying higher temperatures moving south is the emergence of cyclones moving further away from the equator (Sharmila & Walsh, 2018). These cyclones, similar to recent ones hitting Queensland, will impact the New South Wales (NSW) coastline in the future. The main disruption in the Sydney region is therefore the rise in temperatures of the ocean, as this will cause cyclones to move further south and cause storm surges, severe wind and rainfall. At the same time the Great Barrier Reef (GBR) in the northern parts of the southern Pacific will warm up and this causes bleaching of the reef. In recent years up to 50% of the GBR has suffered from this process, and it is expected that with further rise in temperatures the acidity of the ocean will increase, and the reef will come under further pressure.

The proposition to deal with several of these problems at the same time is to create the conditions in front Sydney's coast for the development of a barrier reef. A natural reef can grow on artificial materials such as shipwrecks or abandoned oilrigs, turning the problematic abandoned rigs into an advantage. The future Sydney Barrier Reef protects the coast against the impact of storm surges accompanying cyclones but forms also a refuge for the GBR. The first tropical fish and coral have been spotted in front of the Sydney coast (Booth & Sear, 2018), which makes it opportune to provide the right habitat for more of these species.

The introduction of the artificial elements that form the basis for tropical reef development is counterintuitive, as the normal response to more intense storms would be to replenish the beaches, and try to strengthen the coastal protection structures, while at the same time all efforts would be put to rescuing the GBR. Accepting the new normal and invent a solution that could solve multiple problems at once gives the NSW-coast a high level of adaptivity. The design of the underwater landscape is detailed in a way it will protect the coast, but also allow for emergent developments, such as higher sea levels, more or less sediments and other coastal dynamics, should they occur. The few driving forces of this coastal system, such as the distance from the coast, the gaps in between parts of the reef and the exact positioning of the sunken materials, determine the spatial reorientation of this redundant absorption zone. Once the artificial basis is created the growth of natural reef takes place in a self-organising way. This way the global direction for the NSW-coast is understood, but at the same time the freedom to deal with change and uncertainty will allow the system to develop in a fitting way.

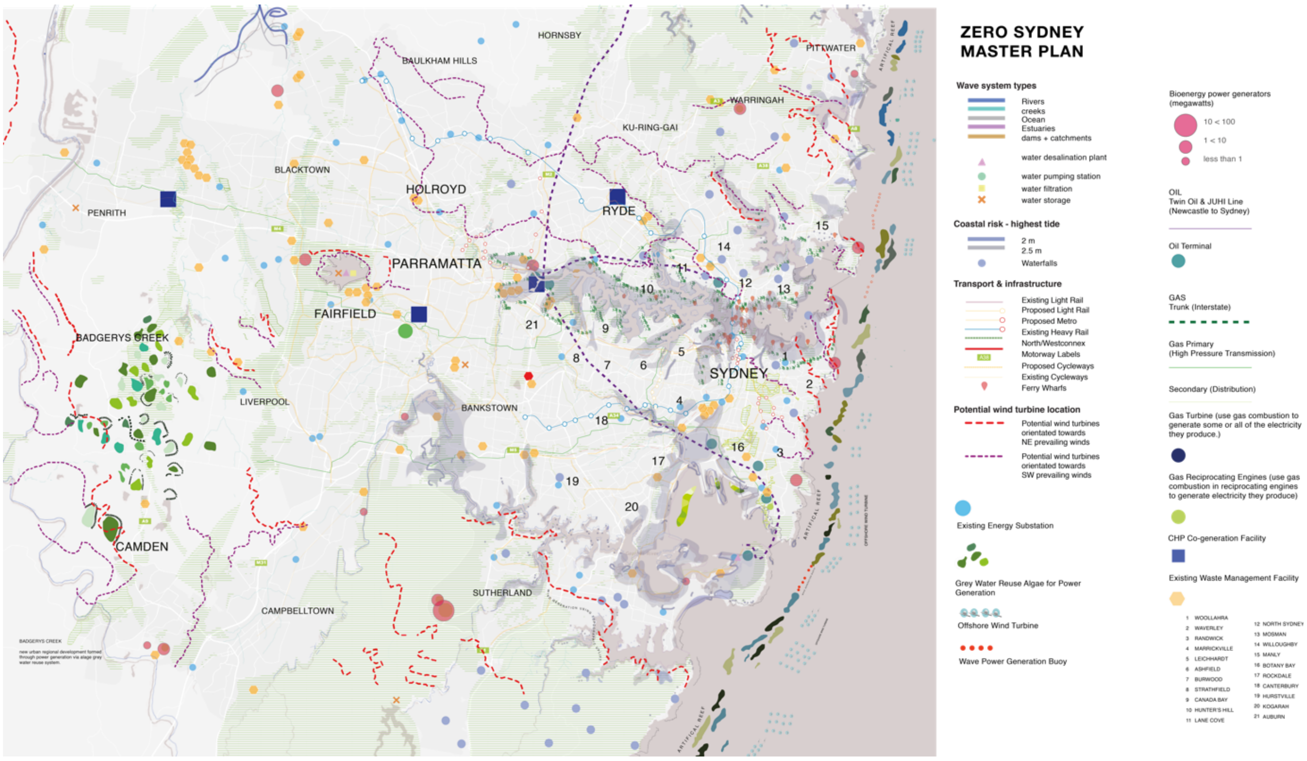

Figure 2. Sydney Barrier Reef (Roggema, 2017).

The introduction of a Sydney Barrier Reef implies several other advantages. In normal weather the gaps in between the reef parts form little tunnels hence will amplify the surge and cause better surfing conditions at the coast. These gaps are therefore designed in a way they exactly will have the most impact at the most popular surf beaches. In between these gaps wave power 'plants' are proposed, which will emerge from the sea when stronger storm surges occur. This way renewable energy is generated and at the same time the reef is 'closed off' so it increases safety levels. An additional benefit from sinking shipwrecks and oilrigs is they are excellent dive sites. Together with the colourful reef itself these sites are very attractive for tourism.

The proposition of the Sydney Barrier Reef predominantly deals with the impacts of storm surges through cyclones and, to a lesser extent, sea level rise. The main disruption is the rise in temperature which is used as an opportunity in this project. It allows for a counterintuitive and adaptive solution.

5.3. Floodable Eemsdelta

The Eemsdelta region is located in the northeast of the Netherlands. It is a historically valuable area where until 1000AC people used to live on artificial hills, created by piling up their own waste, amidst a tidal flat. Once the residents started diking the land a coherent system of coastal protection emerged up to the point they started to make their own land and reclaimed this from the sea by introducing a wooden structure system in the sea that was capable of capturing sediment and this way grew above sea levels and became new land. This region is now under threat of accelerated sea level rise and occasional storm surges.

The proposed intervention in this landscape is to create consciously a hole in the coastal protection system. This way, a Floodable Eemsdelta (see Figure 3) will emerge over time. The water will enter the hinterland and fill up the landscape as high as the sea level will rise. This implies a twofold mechanism. The first element is that it doesn't matter how fast sea level rise happens. At every stage of a sea level rise the landscape is ready and used to the water in the local environment. Secondly, an eventual disaster, e.g., a dike breech, will not happen due to the hole that has been there forever. This way people in the Eemsdelta region can predict the future circumstances they will live in. As a matter of fact, the water increases the quality of living in the area, and provides an abundant resource for cooling, against drought and other uses. A second intervention optimally profits from the seawater. Applying the historic system of land reclamation, also in this landscape wooden structures are proposed that will capture sand and clay sediments hence grow the ground level of the landscape. Once the wooden structures are in place, poles and to them floating houses can be attached. This way the houses are prepared for coming seawater, they won't float away, and the residents are certain of the most beautiful (and safe) landscape to live in.

In normal situations sea level rise will be dealt with by increasing the protective seawall and increase its height and strength. To purposely make a gap in the dike is, especially in the Netherlands, counterintuitive. Using a sim-

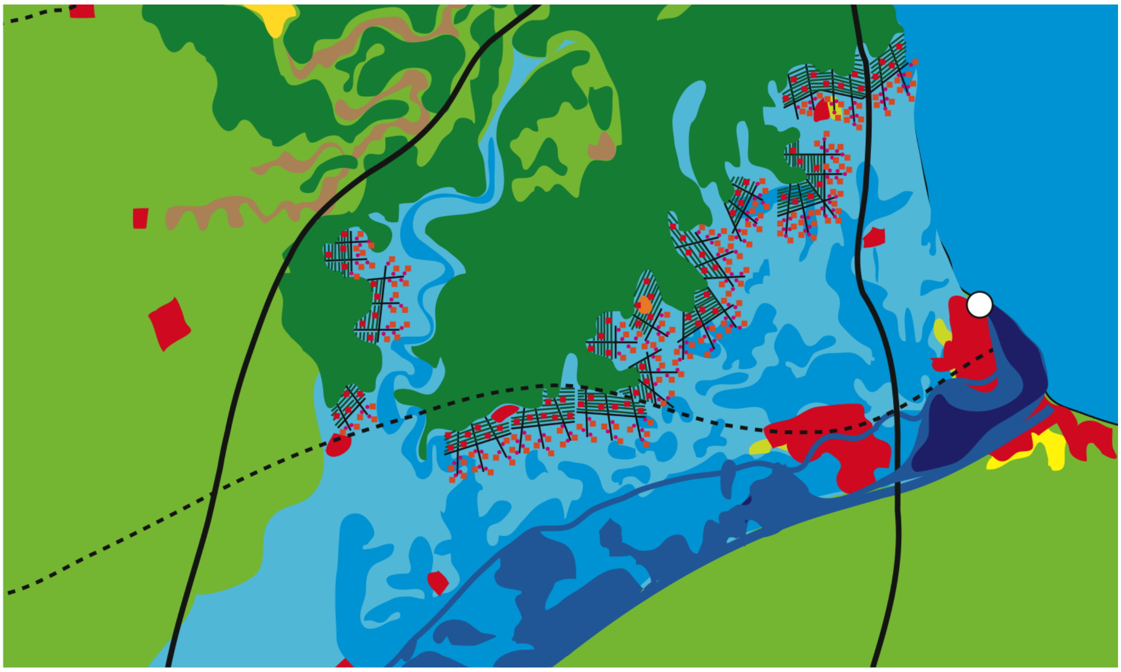

Figure 3. Floodable Eemsdelta (Roggema & Van den Dobbelsteen, 2012).

ilar principle as applied in the Sand Engine (Stive et al., 2013), the incoming water enforces the landscape behind the dike to adjust and adapt. This delta landscape self-organises its components to make sure the typology of housing and their location is chosen in safe places. Because the water will flow to the lowest point, after the inlet the main direction of how the landscape will evolve is clear. In detail natural processes such as wind speed and direction, the amount and type of sediment, the shape of contour lines are the few guiding principles that determine the exact land forming, the build-up of new soil and where new housing can be developed. The entire zone under influence of the water is redundant and functions as an absorption zone, in which many different developments can be accommodated. The pace of sea level rise is not relevant, as the area is always prepared for any change in sea level.

Besides accommodating sea level rise in a secure way, this proposition also creates the absorption zone for collecting and storing seawater during and after a storm surge, as well as the impact of heavy rainfall in the landscape itself.

The Floodable Eemsdelta project predominantly focuses on disruptive sea level rise and to a lesser extent storm surges and heavy rainfall, using an unorthodox and counterintuitive approach in which an entire landscape provides the space to adapt to constantly changing circumstances.

6. Conclusions

In this article three possible responses to disruptions in delta landscapes are identified: repair, bounce back and grow stronger. The latter one is the most interesting, though less researched one. If a system can improve its quality and gets stronger this is called anti-fragility. In this article it is illustrated that delta landscapes, under threat of multiple possible disruptions, such as sea level rise, storm surges or heavy rainfall, all benefit from using the anti-fragility concept as design approach. Each of the case studies show an increase in quality and strength if antifragile characteristics, such as adaptivity, counterintuitivity and, in these case studies to a lesser extent, abundant networks are used in the design propositions. The Double Defence project enhances the size and quality of the natural wetlands of the Wadden Sea, at the same time increasing the safety level of the coast. The Sydney Barrier Reef increases the protection of the coast and simultaneously creates new tropical habitat for fish and coral. Moreover, it forms a refuge for the threatened species of the GBR. The Floodable Eemsdelta increases the quality of the living environment once the seawater enters the hinterland, at the same time bypassing the threat of a dike breaking through.

As illustrated in the case studies the characteristics of anti-fragility not only help these delta and coastal landscapes to bounce back after a disruption, they use the disruptive impacts as a mean to improve and grow. Because anti-fragility makes systems stronger under stress it is seen as a concept that goes beyond resilience, which aims to keep the system functioning during a disruption. In this sense designing an anti-fragile delta firstly anticipates the disruption, secondly it creates a stronger environment during the disruption, so the landscape can keep its basic functions, and thirdly design in an antifragile way results in higher qualities in the area afterwards. Anti-fragility is therefore having effect before, during and after a disruption, while resilience is mainly active during the disruption and the robust approach aims to prevent a disruption before it happens.

The notice that an anti-fragile system gets stronger under stress is appealing. Anti-fragility is used in several disciplines, such as IT, organisational theory and business, but the application in spatial design is novel. In this article three main drivers of an antifragile landscape are presented. A delta landscape becomes more stronger before, during and after a disruption if abundant networks and regenerative nodes are apparent, the adaptive capacity is large and counterintuitive ideas and concepts are used in the design. The case studies resemble a broad range of anti-fragile characteristics. Resorting under the main concepts of network abundance, adaptivity and counterintuitivity, detailed qualifications used to design an antifragile landscape are, amongst others: spatial redundancy in absorption zones, counterintuitive interventions, self-organisation, multiple uses and spaces, allow for disorder, few guiding rules, tipping points and novel solutions. These aspects are used in the design of the case studies, though not often made explicit.

Applying the concept of anti-fragility in delta and coastal landscapes supports these landscapes to constantly improve. The bidirectional relationship between cities (urbanised deltas) and disasters can be turned into a symbiotic relationship by using the antifragile concept. Instead of the urban landscape causing disruptions and then suffer from it, anti-fragility enhances the quality of the urban landscape by which the disruption will be less severe and uses the disruption subsequently to grow stronger. When urban landscapes increase the abundance of its networks, improve the adaptability and use counterintuitivity in the design process, the overall quality of the area will grow. This way urban and landscape designers have influence on establishing this symbiotic relationship by applying these principles in designs for delta landscapes.

In this article three different elements have been taken as the starting point for investigating the use of anti-fragility in landscape urbanism in deltas and coastal zones. The type of response (repair, bounce back and grow stronger) is combined with the type of disruption (sea level rise, storm surge and heavy rainfall) for three antifragile characteristics (abundance of networks, adaptivity and counterintuitivity), in three case studies (Double Defence, Sydney Barrier Reef and Floodable Eemsdelta). The typical constellation and combinatory of these elements determine the specific design task and the design propositions. This system of linking the type of response, disruption, antifragile characteristics and the area qualities could be used in every situation to propose design solutions that support the area to become safer and stronger.

Conflict of Interests

The author declares no conflict of interests.

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About the Author

Rob Roggema (PhD) is Professor of Sustainable Spatial Transformations at the Knowledge Centre Noorderruimte, Hanze University Groningen. He is a landscape architect and an internationally renowned design-expert on sustainable urbanism, climate adaptation, energy landscapes and urban agriculture. He has previously held positions at universities in the Netherlands and Australia, State and Municipal governments and design consultancies. Rob developed the Swarm Planning concept, a dynamic way of planning the city for future adaptation to the impacts of climate change.

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Article

Developing a Design-Led Approach for the Food-Energy-Water Nexus in Cities

Wanglin Yan [1,2,]* and Rob Roggema [3,4]

[1] Faculty of Environment and Information Studies, Keio University, 252–0816 Kanagawa, Japan; E-Mail: yan@sfc.keio.ac.jp
[2] Graduate School of Media and Governance, Keio University, 252–0816 Kanagawa, Japan
[3] Office for Adaptive Planning and Design, Cittaideale, 6706 LC Wageningen, The Netherlands; E-Mail: rob@cittaideale.eu
[4] Knowledge Centre NoorderRuimte, Hanze University Groningen, 9747 AS Groningen, The Netherlands

* Corresponding author

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Abstract
Urban communities are particularly vulnerable to the future demand for food, energy and water, and this vulnerability is further exacerbated by the onset of climate change at local. Solutions need to be found in urban spaces. This article based around urban design practice sees urban agriculture as a key facilitator of nexus thinking, needing water and energy to be productive. Working directly with Urban Living Labs, the project team will co-design new food futures through *the moveable nexus*, a participatory design support platform to mobilize natural and social resources by integrating multi-disciplinary knowledge and technology. *The moveable nexus* is co-developed incrementally through a series of design workshops moving around living labs with the engagement of stakeholders. The methodology and the platform will be shared outside the teams so that the knowledge can be mobilized locally and globally.

Keywords
energy; food; moveable nexus; nexus thinking; participatory design; urban design; water

Issue
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1. Introduction

This is a century of cities (Nature, 2010). More than 50% of the world's population lives in cities, and this number is expected to reach 68% in 2050 (UN, 2018). As a result, the demand for food, energy and water (collectively referred to as FEW) as well as land is expected to increase even more, leading to concerns about crossing critical thresholds of capacity at all scales (Hoff, 2011), and eventually exceeding planetary limits (Steffen et al., 2015). In developing countries, it can be a challenge to shelter an adequate quantity and quality of FEW from environmental pollution and ecological system degradation (Abdul, Shrestha, Pandey, & Anal, 2017; NDRC, 2008; Siddiqi & Anadon, 2011). In developed countries, where the social infrastructure is generally well-developed and living environment is maintained, FEW issues are not typically discussed as day-to-day concerns. Citizens mostly see FEW provisions as a given, and often do not show any particular interest except the bills, although both in regular times as well as in preparation for disasters and accidents governments and urban utility sectors are constantly challenged to be able to provide stable, sustainable and prevalent FEW services (Romero-lankao, Mcphearson, & Davidson, 2017). Recently, with progressing climate change, aging population, and deteriorating infrastructure, there is a growing awareness of risks to the sustainability of FEW in cities (IPCC, 2014; Moss et al., 2010), in the developed world (IRENA, 2015; White, Wutich, Larson, & Lant, 2015).

Sustainability of cities has been studied for long. However, the prevailing model of urban sustainability is too narrow (Powell, 2016). Planners and designer often work on sustainability, driven by specific techniques such as a smart energy system, the Edible City (Bohn & Viljoen, 2011), or design of green paths and rooftop gardens (Engelhard, 2010), etc., motivated by professional skills. Policy makers usually address single issues in a single administrative division even though the social, economic and ecological factors that present as problems of sustainability are in fact intertwined at all scales (Powell, 2016) and across sectors. The awareness of a nexus in FEW sectors is often weak. In fact, FEW are highly intertwined, even parametrically related. There are tradeoffs and synergistic effects (Haase, Haase, & Rink, 2014; Vogt et al., 2010). This situation is referred to as the FEW-nexus. Due to the connectedness of FEW in social and ecological systems, a nexus approach could improve sustainability in general terms and, as a result, has attracted attention as a way to challenge the complex urban issues related to the status quo (Liu et al., 2018). The idea can be traced to works by Ignacy Sachs in the late 1970s and early 1980s, in particular with reference to the food and energy nexus at the United Nations University Food-Energy Program (Sachs, 1980, 1988). The World Bank worked on the food, water and trade nexus (McCalla, 1997) and later replaced the idea with new concepts, including virtual water, at the Kyoto World Water Forum in 2003 (Allan, 2003a; Merrett, 2003). The importance of the three nexus pillars of FEW was officially recognized at the first Nexus Conference in Bonn, Germany, 2011 (Hoff, 2011), making that year Nexus Year One. Since then, our understanding on the nexus has been seriously improved. The essence of the nexus thinking is about doing more with less by improving the efficiency of investment in resources and land-use (Hoff, 2011; Kurian & Ardakanian, 2015; Martínez-Martínez & Calvo, 2010). Understanding and acting upon this concept is central to diminishing the human footprint on planetary boundaries (Kurian & Ardakanian, 2015). However, “the application and implementation of a nexus approach is in its infancy” (Liu et al., 2018). This is particularly true in urban contexts. Most research is focused on the supply side of the equation, namely on how to secure FEW resources in response to a growing global demand. Few studies delve deeply into urban space and design solutions from the perspective of end users and consumers.

Working on sustainable solutions for FEW requires a strategic understanding of the urban nexus. The European Union initiated the Urban Nexus Project in FP7 (the 7th Framework Program, funded by the EU Research Funding 2007–2013) from 2011 to 2014. The project examined urban issues through a nexus approach and published a series of reports. The major finding of the project is that FEW in cities is not only an issue of resources but also of land use, resilience, and eventually the quality of life of a city’s urban populace (Urban Nexus, 2013a, 2013b, 2013c). FEW is a wicked problem in consideration of the complexity of cities and related to many urban problems. However, governmental sectors or utility agencies typically treat the problems as independent issues (Bettencourt & West, 2010), and it is rare food, water and energy is dealt with together. Each sector generally has its own system, making it difficult to act in a broad and integrated way. When it comes to the environment, some argue that considerable efforts have already been made and that efficient resource use has been achieved so there is little room for further improvements.

Design-led approaches have the potential to break that mold. Design is by its nature a trans-disciplinary approach to problem solving, which draws upon logic, imagination, intuition, and systemic reasoning in order to explore potential innovative solutions to problems (Kimbell, 2011). Designers explore concrete integrations of knowledge that will combine theory with practice for new productive purposes (Buchanan, 2010), integrating the opinions and needs of multiple stakeholders. In spite of the romantic image that design is a highly personal process, in most cases design proposals are in fact the culmination of shared knowledge and consensus on a specific issue (Kimbell, 2012). These advantages make a design-led approach particularly appropriate to addressing wicked problems. The integration of FEW is not yet mainstream. and there is no established design methodology in practice. The nexus approach with regards to FEW in particular was not common in urban planning and design because of the complexity of the problem per se, the uncertainty of outcomes, and the difficulty of communication between scientific research and design as it is practiced.

This article proposes a design-led approach through the concept of the moveable nexus. The goal is to mobilize natural and social resources in urban spaces with integrated technology and knowledge in order to uncover and carry out FEW management innovations. It is also a response to the Sustainable Urban Global Initiative (SUGI) by the Belmont Forum and the Joint Programming Initiative Urban Europe in their call for the FEW-nexus (SUGI, 2016). In their words they ask us “to move stakeholders to action through dialogue from a sector oriented technocratic approach to one that recognizes more diverse viewpoints and rationalities” (SUGI, 2016). The moveable nexus is a methodology that helps designers and practitioners structuring the procedures, knowledge and techniques in design practices with regards to FEW. It is also a moveable platform to deliver the accumulated methods and techniques across cities and countries with regards to practice. We will discuss the essence of the moveable nexus concept, and the planned method for its development through the Belmont Forum joint research project. In Section 2 we will describe the key issues of urban FEW. In Section 3 we look at the components of the moveable nexus. In Section 4 we describe the procedure for implementation, and finally offer preliminary conclusions in Section 5.

2. Key Issues in Urban FEW-Nexus

2.1. The Challenges to Modern Cities

Cities are premised upon high population concentrations, accompanied by the conversion of land, originally used for FEW, into industrial activity. The rationality of modern cities was economic efficiency rather than the quality of life. The role of FEW was not diminished in the urbanization process but was dispersed and decentralized. Citizens enjoy greater convenience in daily life, but they become more remote from FEW resources (Loftus, 2009), causing a metabolic rift (McClintock, 2010; Sanyé-Mengual, Anguelovski, Oliver-Solà, Montero, & Rieradevall, 2016; Tornaghi, 2014). The limits of development and growth become manifest. Increasing climate change disasters and environmental pressures cast shadows on the sustainability of the conventional development model and in many ways force us to look back to basic concepts. Our cities will be not sustainable if we cannot step away from our path dependency in multiple aspects of our urban life (Bai, 2018; Romero-lankao et al., 2017).

2.1.1. Cities Are Gluttons for Resources

As an example, depending on the definition of urban areas, about 50% of the world's urban population consumed two-thirds of the total energy used globally, and are responsible for more than 70% of energy-related carbon dioxide emissions (Nature, 2010). Estimates of energy consumption by urban buildings and industry range between 37% and 86% and estimates of gasoline and diesel consumption attributed to US urban areas range between 37% and 77% (Parshall et al., 2010). In most countries, citizens are dedicated to driving, especially those living in suburbia. People rely on cars to meet their basic needs. Families prefer a large house in a new subdivision at the edge of town because they can get there by car. A job across town, remote from where people live and not served by public transit, is just as good as a job nearer to home even if there is a time and financial cost trade-off. Finally, cities become the major driving force to global warming and climate change risks because of the intensity of agglomeration. In light of the recently adopted Paris Agreement on climate change it is necessary to cut global CO_2 emissions by 50% by 2030, and by 80% by 2050, in order to limit global average temperature rising to 2°C or less by the end of this century (Rogelj et al., 2016), recently more ambitious to 1.5°C (IPCC, 2018). The path towards this goal is clouded but there is no time to wait. Cities, as the most prosperous places on the planet, and as the most intensive contributor to CO_2 emissions, will need to play a key role in emission reduction (World Bank, 2018). Viewed from the other side, the high concentration of production and consumption patterns in cities offers opportunities for human society to improve economic efficiency through transformative actions.

2.1.2. Cities Are Vulnerable

Our cities, and the systems that support them, have not been designed to address the FEW-nexus. Modern cities were established on a modernist understanding of urban life as an essentialist reality separate from rural life, and urban planning distinctly separated local agricultures as obsolete in a futuristic and normative understanding of the city (Barthel & Isendahl, 2013). Zoning systems exclude farmland and farming activity in urbanized areas, encouraging land owners to convert their lands to industrial, commercial or residential uses in many cities (Yokohari & Amati, 2005). Consequently, FEW are transported from distant places, while indicators such as food mileage (Tanaka, 2003), CO_2 emissions (Munksgaard, Pedersen, & Wien, 2000), and virtual water (Allan, 2003a, 2003b) usage steadily rise. Food, water and energy, from production to distribution to consumption and waste treatment are operated by different sectors. Moreover, as currently organized, the relationships between food, water, and energy are not yet mutually beneficial. Instead, they typically exhaust one another. Routinely, urban dwellers are enjoying the conveniences of urban living, and fulfill every need easily, from clothing to food and housing. Superficially, it seems as if FEW can be obtained easily as long as it is paid for. However, accessibility to FEW is in fact dependent on intensive infrastructure, a complicated supply chain of goods, and personal mobility. The intense concentration of populations, consumption activities, critical infrastructures, and social needs in metropolises assume that every part of that infrastructure will continue to work effectively into the future, with very little redundancy (Yan & Galloway, 2017). That implies that they are more vulnerable to natural hazards than distributed systems (Artioli, Acuto, & McArthur, 2017; Carpenter et al., 2015).

2.1.3. Cities Are Tarnishing

In the last century, in a surge of industrialization and urbanization, massive numbers of people migrated to cities from rural areas in search of a better life. This is now a global and continuing process. However, urban life has not spontaneously improved even as cities grow and their economies thrive. We have witnessed the winners and losers in the past decades of globalization and automatization. A majority of residents suffer from long distance commuting, traffic congestion and heavy workloads in megacities. Slums, crimes and poverty are synonymous in some cities. There is considerable overlap between the 1.1 billion poor people who lack access to adequate water and food, and the 1.5 billion who are without access to electricity (and to some extent the 1 billion slum dwellers in the developing world's cities) (Hoff, 2011). The situation in the so-called developed world is getting worse because of aging and other problems. For instance, the number of people living in food deserts is rising—around one million in the UK (The

Guardian, 2018), more than 7 million in Japan (Choi & Suzuki, 2013), and even more in the USA (Walker, Keane, & Burke, 2010). The cause can generally be attributed to handicaps, unaffordability or aging (Lawson, 2016). This is an entirely new challenge for the provision of quality FEW services in a period of growing inequality.

2.2. The Essence of Nexus Thinking in Urban Design

Nowadays, cities are considered places for better life though, as aforementioned, challenges toward sustainability are crucial too. It's true from the global perspective that FEW resources are indispensable for survival, and their conservation and efficient use are necessary for the sustainability of society. However, there exist gaps in awareness of the severity of the issue and the roles of stakeholders at human scales. FEW resources are tangible, and the nexus can be thought to be most inherently visible in nature and in rural communities, simply because the resources are used more directly in both life and work in these locations. Once FEW resources are delivered to cities where they are separated into sectors such as food, water services, electricity, and gas. For urban residents, FEW provides the basis of living, as well as the services provided by governments and businesses. The connection is less immediate, however. Very often, citizens have only been approached as either "receivers" or "users" which implies a passive role. They are not aware of the interrelations of food, water, and energy, and therefore will not change their behavior. To date, most of the FEW researches have been conducted at the macro-level. Accordingly, the urban basis for nexus policy and analysis remains weak (Artioli et al., 2017). Urban plans rarely address the FEW-nexus directly except to assume that continuing access to each aspect will be assured without any special additional measure. Because of this path dependency it can be said that the assessment tools, models, and policy recommendations of many planners seldom build on the nexus of FEW resources. Conventional planning, design, and governance systems struggle to meet the supreme position that cities have taken, namely as the most prosperous places in the modern world.

FEW-nexus thinking provides a tool to rethink the fundamental needs of human society, production and consumption, demand and supply, and cost and benefits etc. Instead of defining FEW as resource security, the FEW-nexus in cities should integrate its components into urban space and by doing so, turn the supportive aspect into a mainstream element that could create new opportunities (Kurian & Ardakanian, 2015). The essence of nexus thinking can be found in three guiding principles (Hoff, 2011):

1. Invest in ecosystem systems to secure FEW provisions;
2. Create more with fewer environmental costs;
3. Ensure accessibility to food, water and energy to all residents.

Implementation of these principles relies on finding solutions to the question: where, how, and who will produce food for cities?

2.2.1. Where—The Relationship of Production and Consumption

Typically, modern cities spread over wide areas. Spatially speaking, sustainability research and policymaking should shift focus from city centers to urban regions and global networks of production, consumption and distribution (Powell, 2016). In San Francisco, most of the carbon emissions associated with the consumption of goods by residents, firms and governments in 2008 were created outside the city's limits—elsewhere in the USA or overseas—"yet municipal sustainability initiatives target only the metropolitan area" (Powell, 2016).

Nexus thinking recognizes that production, distribution and consumption crosses both scales and places. The FEW-nexus is nested in multiple spatial scales (Verburg, Mertz, Erb, Haberl, & Wu, 2013). The extent of the potential of local production for local consumption depends on how and to what extent the distances between production and consumption can be reduced. This does not mean that every place should be self-sufficient and independent. Every city is unique in its land, its people, and its relationships to its ecosystems (Stead & Pojani, 2018; Thomas et al., 2018). Resources and flows are similarly different in every city and area around the world. Trading is still an efficient way to mobilize local resources and add value to commodities (FAO & UNEP, 1999). The question is to find an appropriate scale to work at with regards to the provision of FEW to all communities. Depending on location it may be regional or entirely local.

Regarding scale, the singular problem is how to scale up small activities to have large impacts. Various initiatives can be seen around the world that make use of FEW linkages, such as solar sharing, small hydropower generation, local production for local consumption, plant factories, community gardens, urban farming, and so on (Hussey & Pittock, 2012). Many of these are unsustainable as they are designed for a small number of people or are on a small scale and lack support. A design-led approach leads naturally enough to designed solutions, evaluates marginal benefits, and presents mechanisms that can be used to actualize the ideas. The proposition of the design-led approach is to propel a synchronized outcome, developing symbiotic relationships between FEW. Instead of siloed concepts from production to consumption, stakeholders should emerge as prosumers. These persons and groups collectively will own urban spaces and co-design circular solutions at different urban scales.

2.2.2. How—The Relationship between Costs and Benefits

Costs and benefits are the most critical aspects for sustainability. However, this is not an issue of profit or costs itself. For instance, car dependent life brings us convenience while causing the bulk of CO_2 emissions (Farr, 2012, p. 23). It is a personal lifestyle, and in some ways a representation of moral value (Al-Saidi & Elagib, 2017). Reducing environmental costs while keeping the same lifestyle requires awareness of and contribution to common values (Ames & Hershock, 2015), and especially a desire for the sustainability of society. As noted previously the largest portion of CO_2 emissions in San Francisco came from food and beverages produced outside the city center, where the consumers actually live (Bettencourt & West, 2010). Activities for sustainability happen every day and everywhere. Planners make city forms and transportation systems; designers work on buildings; citizens make home gardens; farmers devote to organic farming etc. Some are commercial-based while mostly might be not. Many of them enhance ecosystem services (Costanza et al., 1997) and contribute to shaping a common shared value (Gómez-Baggethun & Barton, 2013; Haase et al., 2014; Tratalos, Fuller, Warren, Davies, & Gaston, 2007). These values are not always clear to the people themselves, as it is a collective creation, made by local decisions. How to include new practices in planning and design so the quality and benefits can be expressed clearly (and visually) to all of residents of a city remains an unsatisfied challenge.

For urban residents, on the other hand, FEW themes appear as (private or public) services of the social infrastructure. Citizens seldom see the hidden sides of the workings of government or businesses. People generally tend to be most strongly interested in daily life and work issues affecting their own families, neighborhoods, cities and regions, and have less interest in things that are not short-term or connected to their own immediate benefit. In fact, most modern cities were established on centralized energy, water supply and treatment systems, and the maintenance of the infrastructure involves enormous costs. Consumers are usually not able to get the direct experience of FEW resources being physically interconnected. This leads to severe constraints for integrated urban FEW designs, especially in cities with high disaster risks, and drastic demographic or industrial shrinkage.

The second principle of nexus thinking is to create more with less. We do not yet know how easy or difficult it is to replace centralized infrastructure with small scale distributed systems. Smart cities and smart communities are popularly experimented with (City of Chicago, 2009; Gondhalekar & Ramsauer, 2017; Townsend, 2013; Wolsink, 2012) and may eventually lead to useful conclusions, but that time is still somewhere in the future. Most of the tests are technology-oriented, and focus on energy (Wongbumru & Bart, 2014). Some look to water (Venkatesh, Chan, & Brattebø, 2014), and few focuses on food or FEW-nexus themes (Gondhalekar & Ramsauer, 2017; Wolsink, 2012). To go further we will need a mechanism to ensure the natural costs are paid and to ensure that choices are beneficial to both ecosystems and human beings, individuals and businesses. The nexus approach tries to establish such a win-win approach in which urban resilience, citizens' health and accesebility to resources could be shaped as the common value outpacing the costs.

2.2.3. Who—Relationship between Working and Living

With the Industrial Revolution, the main source of wealth moved from the countryside into the city (Cusinato, 2016). Urban living has served as a symbol of material wealth so that younger people continuously migrate from the countryside, especially in developing countries (The Economist, 2011). In fact, the wealth of modern cities was built on the marginal effect of cheap labor forces and external costs to the environment. In many cities around the world, and especially in the West, cities have been designed according to a zoning plan that separates working and living places in order to preserve efficiency of land use. FEW systems under this regime are centralized and work at large scales. However, this established working-living style is collapsing because of globalization and automatization. Factories are moving away from expensive cities where there are cheaper natural and human resources, leaving polluted vacant land behind, as in the cases of Belfast or Detroit. New business may continuously emerge in place of the old but there is a tendency to require a different kind of worker, if not an outright reduction in the number of people needed for the enterprise. What can be done in a city without jobs? What to do with massive numbers of vacant houses, void lands, and decayed infrastructure in an aging and shrinking society (Thieme & Kovacs, 2015)? FEW offers some thoughts. For instance, feeding the city through urban agriculture has been widely discussed (Moreno-Peñaranda, 2011; Morgan, 2009; Mougeot, 2000; Tornaghi, 2014), and practiced popularly from rooftops (Engelhard, 2010; Whittinghill & Rowe, 2012), home gardens (Barthel & Isendahl, 2013), formal landscapes (Bohn & Viljoen, 2011) and shared farmland in peri-urban areas (Hara, Mcphearson, Sampei, & Mcgrath, 2018; Meeus & Gulinck, 2008; Mok et al., 2014). It is too much to say that urban farming will solve the problem of job migration that has taken place as a result of globalization, however it is not impossible that the use of FEW-nexus planning could set the stage for an alternative form of future urbanism, where work and life are more closely inter-related, along with FEW production and use.

Taking this idea further, urban sustainability can be understood not merely an issue of environmental conservation but the future of urbanism and urbanized civilization. Cities, as the dominant settlements, the home of most people on this planet, should not only be a place for work but also for living and fulfillment. FEW, both as a fundamental demand and as an infrastructure, could be not only the provisioning service but also a carrier of social ecological memories in cities even by practicing FEW nearby small scales (Andersson & Barthel, 2016;

von Heland, 2011). Mobilizing the related FEW potentials could work as a trigger for urban regeneration, wealth redistribution and the improvement of well-being. The design-led nexus approach will integrate the nexus principles with urbanism, such as producing local consuming local in practice. Following on that work, design solutions will be transferred to action programs for the UN Sustainable Development Goals (SDGs) with the cooperation of producers that aim for the balance of beneficial economic effects and environment, citizens in search of a better living environment, and governments that seek to provide efficient public services.

3. Design-Led Nexus Approach

The design-led approach aims to develop FEW solutions in cities to mobilize the potential of natural resources at multiple scales, improving the efficiency of land and resources, delivering services to all who require it. There is no such thing as a one-size-fits-all solution to any problem amidst the diversity of local and global contexts. Therefore, design itself should be a process of learning, integration and communication. The moveable nexus is such a concept within this philosophy.

3.1. The Concept of the Moveable Nexus

Research and design practice on food, water, and energy by sector are not new. Rich knowledge is accumulated in each discipline. A huge amount of research has been conducted on the nexus-pairs of food–energy (FE), energy–water (EW; IRENA, 2015; Varbanov, 2014) and food–water (FW; White et al., 2015), climatic impacts (Carpenter et al., 2015; Johansson, Schmid Neset, & Linnér, 2010; White et al., 2015) or the three pillars of FEW (Endo & Oh, 2018; Endo, Tsurita, Burnett, & Orencio, 2014).

> While nexus literature is long on determination and ambition, it is short on grounded evidence on the essential elements of FEW security, such as operational definitions that help to link research and practice, particularly within urban systems. (Romero-lankao & Gnatz, 2016)

Most of the previous studies view FEW issues from the supply side of resources, investigating the scientific mechanisms of material flows, predicting the increase of FEW risks associated with population growth and development. Typical examples include the survey of ecological resource availability (Daher & Mohtar, 2015), urban metabolism modeling of production, consumption and disposal (Bazilian et al., 2011), shifting to a low-carbon circular economy (Bears, 2017; Bhaduri, Ringler, Dombrowski, Mohtar, & Scheumann, 2015), and reducing external inputs from outside the region while encouraging local production for local consumption (Siddiqi & Anadon, 2011). However, scientific knowledge is not popularly applied in many of the design practices linked to the creation of the built world. Similarly, with some notable exceptions such as the Living Building Challenge, architects design buildings to save and manage energy, or work on the redevelopment of urban neighborhoods to improve livability. Landscape architects work on urban landscapes, urban agriculture and green infrastructure to create the feeling of a greener urban life. City planners study land use policy to improve efficiency of transportation and distribution. Quite often, participatory design in the literature is introduced as a kind of event-driven professional and educational activity, lacking the ability to transfer the gained knowledge to a large scale of practice. With regards to the FEW-nexus, each profession has a kind of limitation of scope that needs to be bridged both in breadth and in scale.

The moveable nexus is considered as an innovative methodological package for FEW management and utilization that make use of the spatial, temporal, and service linkages of natural and social resources. As the illustration in Figure 1, the package offers an indication as to how to practice nexus thinking in a way that will lead to its integration with urban planning, architectural design, and environmental policy studies. Ultimately it is a communication platform that can be moved to a design site with the support of scientific data and knowledge.

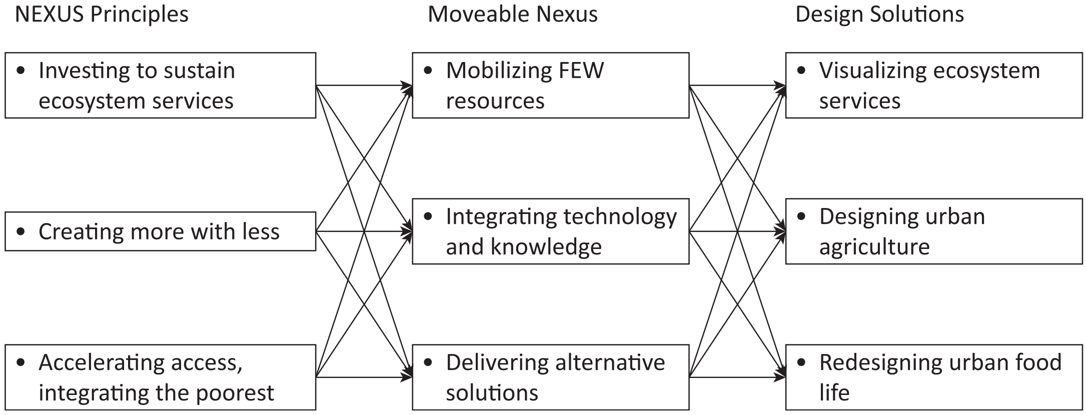

Figure 1. Principle of nexus thinking and moveable nexus. Source: authors.

3.2. The Development of the Moveable Nexus

The moveable nexus consists of design methods, evaluation tools, and participation mechanisms that can be used in design practice. The guiding principles for the development are described below.

3.2.1. Design Methods

The application of FEW-nexus and urban agriculture in cities could take a diversity of forms, including technology or policy, buildings or landscape, commercial products or public engagement programs. Design methods at the moveable nexus provide guiding procedures to explore solutions with stakeholders. The procedures of the design method construction consist, in general, of the following steps, as shown in Figure 2:

1. Inventorying FEW-related existing or potential resources and availability of space for urban agriculture, including rooftops, vacant houses, or abandoned, improperly used or void lands;
2. Designing solutions to improve the efficiency of land and space use for food production and ecosystem services with less energy and water consumption by integration of FEW technology and knowledge;
3. Composing the nexus matrices that mobilize the material and flows of resources cross sectors and disciplines in the social-ecological context;
4. Evaluating the environmental costs and the added benefits of the solutions through the enhancement of spatial, temporal and service connections among specific social-ecological systems;
5. Delivering the alternatives of solutions to and reiterate the design process with stakeholders.

This is co-design and a reflexive process with stakeholders. The inventory includes natural, social, financial, and industrial aspects. The mobilization of resources implies the activation and connection of existing and potential capitals across industrial, administrative and academic boundaries with more flows and services.

3.2.2. Evaluation Tools

The evaluation of design solutions is a tricky issue. There exists a long list of indicators to assess the impact of human activities on the environment, such as the most typical ones, food mileage (f), CO_2 emissions (e), virtual water use (w), Ecological Footprint (EF), etc. However, no such an indicator could properly describe the interaction of FEW.

EF (Wackernagel & Rees, 1998) converts the CO_2 emission in human consumption to land area equivalent to the area of forest demanded for absorbing the correspondent emission. We propose an indicator few-print which express the quantity of FEW resources to be consumed and the flow—that is, the service—among the three layers. The few-print is a combination of food

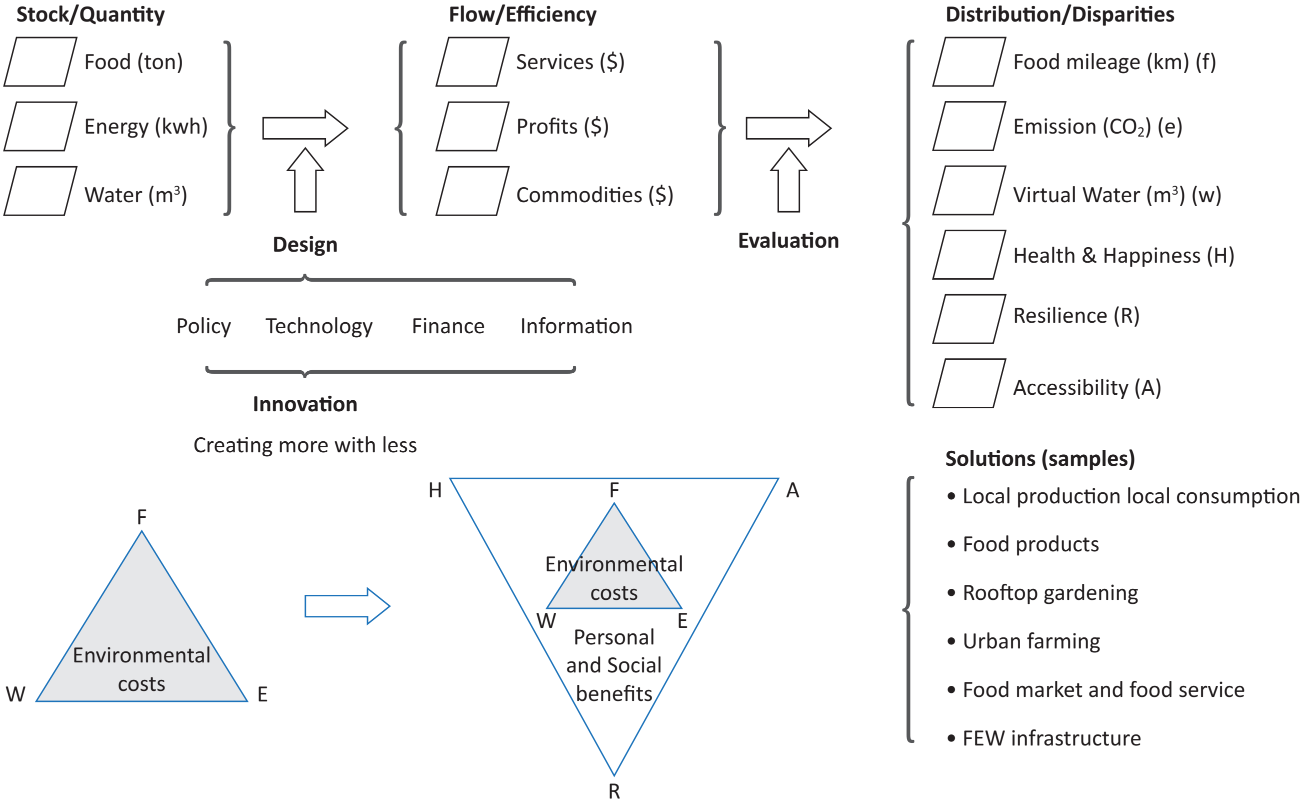

Figure 2. Framework of the moveable nexus. Source: authors.

mileage (f), CO_2 emissions (e), virtual water use (w). It also represents the ambition of nexus thinking: creating more with less.

On the other hand, the functions of urban agriculture are multifaced. People enjoy home gardens or shared farming not necessarily for the CO_2 reduction but rather for other benefits, such as education, health, culture and communication etc. Similarly, some new issues can emerge from the process, such as a reduced few-print that goes along with reduced accessibility to those resources by the residents of an area. Investors might also pursue common shared values with the public on urban agriculture and ecosystem services rather than on food production itself. Therefore, in addition to few-print, we incorporate three social indicators in perspective of citizens' quality of life: health and happiness (H), accessibility (A) and resilience (R), collectively referred to as HAR. Although each indicator has been intensively studied (for health and happiness see Groenfeldt, 2006; Urban Nexus, 2013a; for accessibility see Walker et al., 2010; for resilience see Magis, 2010; Mitchell, & Harris, 2012) the trade-offs and synergistic effects with environmental factors have not been examined.

The development of the few-print and HAR is a complex process in design. The numbers might mean different things as scales change from household, to city block to neighborhood, to the city and bioregion. The indicators of the moveable nexus in this way may not be perfect tools to judge the quality of solutions but more appropriate for communication. Stakeholders will need to understand the trade-off and synergy of different solutions at different scales so that each partner could rethink the relationships about costs and benefits, and their behavior.

3.2.3. Participation Mechanisms

Involving users in urban design and development has long been a core concept though practice is often different between social contexts (Bergvall-Kåreborn, Howcroft, Ståhlbröst, & Melander, 2010). "Through engagement with a product or service over time and space", Kimbell (2012) says, "the user or stakeholder continues to be involved in constituting what a design becomes". Designers explore concrete integrations of knowledge that will combine theory with practice for new productive purposes (Buchanan, 2010). "Design with users, design by users or design for users are popularly advocated within areas like innovation and product development" (Bjögvinsson, Ehn, & Hillgren, 2012; Wahl & Baxter, 2008). However, how to sustainably involve stakeholders especially over the long term is not easy for any participatory project. There are examples, however, that tend to be self-selecting groups who have bought into a larger goal. The community involvement of residents in Freiburg, who collectively built their eco town over decades. People who move to Freiburg did so in order to be part of that process (Freiburg, 2018). Bringing otherwise regular people into design is a more challenging task.

In the moveable nexus, the participatory mechanisms are the collaboration process of four type of partners: intermediate support organizations, the local community, experts in spatial planning, and public or private sectors. Each partner owes specific resources and advantages such as physical spaces, skills, knowledge, financial or regulative options. Our understanding is that intermediate support organisations, mostly driven by local actors, play a key role to connect stakeholders together.

The engagement of the multiple stakeholders is conducted through a series of design workshops in the moveable nexus. All of the stakeholders incorporate equity into every stage of design process, from research to formulation (Powell, 2016). During the workshop, design experts visualize resources and produce solutions. Local community gain awareness of the issues and co-create the shared values. Private or public sectors could be inspired and then turn the plan and design into political and business actions.

The design workshops will be informed with scientific evidence. The moveable nexus provides a platform for communication and learning of stakeholders, in which the FEW resources and evaluation indicators aforementioned are installed. As the results, the design solutions incorporate the wishes and intentions of all of the participants and then fits a variety of action plans and projects, while enriching the physical and social resources that are unique to the region.

Finally, the moveable nexus itself is co-developed incrementally with stakeholders through the processes in practice. Urban Living Labs (ULLs) are used as a platform to implement/accommodate the contents of the moveable nexus and secure the sustainability of the practice.

3.3. Urban Living Lab for Practice

ULLs are initiatives that focus on the collaboration of multiple stakeholders (government, industry, research institutions and communities) in different stages of the research, development and innovation process (Thinyane, Terzoli, Thinyane, Hansen, & Gumbo, 2012). It is also a recommendation of funding agencies such as JPI Europe Urban. Over the decades, the concept of living labs has become widely accepted in design practice with design thinking and system thinking (Kimbell, 2011), shifting design from design "things" to design "Things" (Bjögvinsson et al., 2012). Compared with regards to its popularity to open innovation, lead users, public health, IT tools, user-driven design (Bergvall-Kåreborn, Holst, & Ståhlbröst, 2009), it has only a limited success. Voytenko, McCormick, Evans and Schliwa (2016) surveyed five living lab projects granted by JPI Europe Urban and concluded that the concept was mostly used to secure funding. There remain many questions about the impacts and effectiveness of ULLs both in their own geographical domain and more broadly at regional and national scales. For example, how do ULLs evaluate their own impacts? How do they build on feedback results and findings of evaluation to improve their activities and impacts? These questions are reminiscent of the problems outlined in Section 2. Researchers, designers and stakeholders have difficulties in communication with each other because of the gaps between scientists and citizens, long-term global goals and the short-term personal interests on sustainable issues as well as FEW issues. Answering the questions need a collaboration network working on common issues with a designated scheme.

The moveable nexus by its nature requires the bioregion-specific collaboration of stakeholders. On the other hands, the methodology and platform of the moveable nexus could be applied everywhere for the researcher, designers and practitioner who share common understanding. An ULL could be an existing one run by cooperative stakeholders or a new one initiated by researchers. With the support of a living lab, researchers could work strategically with stakeholders to co-design long-term strategies for urban productivity in light of changing contexts. The living labs created in research areas could be part of a global network for comparative studies.

Therefore, the moveable nexus and ULLs are complementary ideas each other. The former provides contents while the latter has advantages of practical platforms with stakeholders. The moveable nexus could also help ULL to move around with the shared contents, thereby enabling global deployment. In this sense, the moveable nexus could add new values to ULLs with integrated solutions for urban FEW managements.

4. Implementation

4.1. Research Sites

The moveable nexus was proposed as the core concept of the project “The Moveable Nexus: Design-Led Urban Food-Energy-Water Management Innovations in New Boundary Condition of Change” (M-NEX) granted by Belmont Forum and JPI Europe Urban. The purpose of the project is to show how topics and issues of FEW that span across diverse regions in the world can be studied within a uniform concept. A research consortium with seven organizations in six countries (Australia, Japan, the Netherlands, Qatar, UK, USA) has been established, with its study areas being Sydney, Tokyo–Yokohama, Amsterdam, Doha, Belfast, Detroit correspondently.

The geographical features, bioregional differences and social themes of every study area are summarized in Table 1. The cities differ in terms of geographical features, bioregions and societal conditions, but from the table it is clear all cities are mature and share several common concerns in terms of sustainability in their urban areas. The project will take the complex sustainability challenges of its involved cities, and communicate FEW design solutions in concrete, visual, and physical ways to stakeholders and residents. This will deepen the understanding of FEW and promote consensus-building on actions plans for future cities.

Each country team will determine the research contents in consideration of the local needs and proceed collaboratively. For example, the UK team (Belfast) will work on design of food factories, while the Dutch team (TUD) will focus on energy planning in FEW-nexus. All of the teams will learn from each other and study the potential to incorporate FEW-management into their own cities. Ultimately, they will deliver their research findings, policy recommendations and technical innovations, such as implementation of FEW at a University campus (Doha), revitalization of a post-industrial city (Detroit), and future FEW strategies for consumption-oriented cities (Tokyo-Yokohama, Sydney).

4.2. Working with ULLs

Each team builds an ULL in the study area, hold stakeholder and community design workshops, consider local FEW-topics, and develop solutions. The ULL in each city is featured with the local social and bioregional context.

4.2.1. Belfast

Northern Ireland has generally weak infrastructure and a very poor natural gas network due to the recent civil strife known as ‘the Troubles’. In supply side of food, a strong reliance on imported food due to heavily industrialized and dense beef and dairy farming, very little arable agriculture. On the other hands, a strong dependence on the car due to poor public transportation in conjunction with poor diets due to food poverty, leads to increasingly prevalent issues surrounding obesity and diabetes. The Belfast Living Lab is based in the designated Urban Villages project. This project funded by the Northern Ireland Assembly works in 5 of the most deprived neighborhoods in Northern Ireland, to facilitate sustainable development of these at risky groups.

4.2.2. Tokyo

The 2011 earthquake and tsunami in Tohoku revealed the vulnerability of modern cities. Many areas in Japanese cities were built in the twentieth-century postwar period of high economic growth and are now approaching a time when infrastructure and other upgrades will be needed. Japanese cities are also facing declining birthrates and aging of the population and becoming more compact, even as they face rapid changes on the spatial and temporal dimensions in terms of the supply and demand for FEW (Moreno-Peñaranda, 2011). The Tokyo Living Lab is going to work in cooperation with WISE Living Lab, a community-based project initiated by Yokohama City and Tokyu Corporation since 2012 in which WISE represents an acronym of Wellness; Intelligent and ICT (Information and Communication Technology); Sustainable and smart; and Ecology, energy, economy. In the summer of 2018 the Japanese government selected 29 municipalities as pilot SDGs model

Table 1. Overview of characteristics of partner cities and case study projects.

Partner City	**Belfast (BEL)**	**Doha (DOH)**	**Detroit (DET)**	**Sydney (SYD)**	**Tokyo (TOK)**	**Amsterdam (AMS)**
Main thematic	Divided city	Food security	Vacancy and Capacity building	Urban Development process	Ageing and disaster risk	Co-creation of spatial
Climate	Maritime	Desert	Continental	Subtropical	Subtropical	Maritime
Bioregion	Northern Ireland Bioregion	Arabian Desert Bioregion	Great Lakes Basin Bioregion	Sydney Basin Bioregion	Kanto Plain Bioregion	Atlantic Mixed Forest Bioregion
Scale	Neighbourhood	Precinct: Uni-campus	Metropolitan region	Large Greenfield: 3rd City	Roof / vacant land	Neighbourhood
FEW-focus	F: Diet E: Algae W: Flood	F: Local plantation lowering UHI E: Solar W: Drought, reuse	F: Urban production E: Waste to energy W: Great Lakes Basin	F: Regional food-bowl E: Large and small hydro W: Heat	F: Food in urban roof / rural E: Solar panel W: Water-river basin	F: High tech, vertical E: Wind & integrated renewables W: flood, controlled
Motto	'The Aquaponic city'	'The urban water machine'	'The post-industrial city'	'The fridge city'	'WISE city'	'The circular city'
Take away	Technologies	People Engagement	Regional synergies Scalar Cascades	Far future design	Regional integration	Design with flows for far future
Goal	Existing technologies in the city	Expanding the effectiveness of food production in the city with minimal water availability	How to overcome jurisdictional barriers	Using landscape as cooling machine through plantation, crops and water	Close FEW cycles at river basin level	Close FEW cycles at city level
Data	Baseline data	Place based data (QU campus)	Regional jurisdictional data	Regional landscape data	Building and land use data	Flows of FEW data
Method for workshop	Roadshow	Design workshop	Large scale spatial drawing	Creative COCD	GIS modelling	Stakeholder co-design
Paradigm shifts	2050–2080	2050–2100	2035–2070	2030–2060	2040–2080	2040–2070
Outputs	Part I of few-print Advanced FEW Technologies in the city into the future	Part II of few-print Community gardens and permaculture, for higher scales	Part III of few-print Jurisdictional system, Visualizing Cascading systems and scales	Part IV of few-print FEW-urban landscapes	Part V of few-print FEW-integration in local community	Part VI of few-print Energy cascading / REAP for Food and Water

projects including Yokohama City, started to tackle these issues (Cabinet, 2018). The M-NEX Japan Team is designing new management systems to secure the accessibility of urban FEW in the Tokyo-Yokohama metropolitan area plus sustainable improvements in the quality of life, and the necessary infrastructure to support all of that.

4.2.3. Sydney

It is foreseen the Sydney region will be confronted with a rapid increase in population in the next 20–30 years (Greater Sydney Commission, 2018). The number of people will almost double and reach a total of approximately 8 million people. To cope with this enormous change the regional planning authority (Greater Sydney Commission) has presented the region as a metropolis of three cities: the old Harbour city in the East, the central Parramatta river city and the newly to be developed Western Parkland city around the new Badgerys Creek airport (Greater Sydney Commission, 2018). The Sydney Living Lab will be the new Western Parkland City, around the new Airport of Badgerys Creek. The task is to explore what new type of city could emerge here, given the fact that current development processes often not lead to a very smart, resilient and sustainable outcomes, as these neighborhoods tend to have sparse green and trees, maximized housing space on plots, people commuting to the city and spend large amount on energy because of the need of air conditioners.

4.2.4. Doha

Qatar has limited water resources; the climate is too hot and dry for much agriculture; dust storms are a serious threat. It has the highest per capita emissions of carbon dioxide in the world because of free electricity and the reliance on energy-intensive desalination for potable water. Qatar is extremely vulnerable to rising sea levels and rising temperatures due to climate change. A recent embargo by neighboring states including Saudi Arabia, a major food supplier of Qatar, has heightened the necessity for more efficient and resilient food systems and supplies. The Doha Living Lab will be built on the existing Edible and Regenerative Campus project as well as on ongoing research and networks at Qatar University related to the FEW-nexus such as new food crops, halophytes and micro algae and reuse of water, etc., under the theme of the ”The Urban Water Machine” with the engagement of all the University communities.

4.2.5. Detroit

Referred to globally as an example of post-industrial shrinking cities, Detroit has suffered from chronic socioeconomic and race segregation coupled with income inequality that amplified de-population of the central city. The urban footprint of Detroit is vast (143mi^2) in area and designed in parallel with the emergence of the automobile and models of single-family car ownership. Currently 22mi^2 acres of vacant residential and commercial land within the municipal limits. Extensive area of land is characterized as brownfields. While USDA (United States Department of Agriculture) metrics for food deserts point to a crisis of food access within Detroit, multiple alternative sources are emerging within the urban agricultural space. Community, NGO and larger organizations are undertaking urban agriculture practices and food hub production is increasing. This context is ripe for FEW-nexus based analysis. Which may assist stakeholders in catalyzing change while identifying multiple collateral benefits to water and biomass-linked processing practices. The M-NEX Detroit will work with the U-M Detroit Center as a Living Lab partner. Located in the heart of the city’s Cultural Center, the U-M Detroit Center serves as a gateway for University and urban communities to utilize each other’s learning, research and cultural activities.

4.2.6. Amsterdam

Amsterdam is dealing with climate adaptation issues and with the ambition to become climate neutral by 2050, as well as natural gas free. The city is still strongly reliant on food supply from elsewhere, as only a small share comes from the region. Schiphol Airport is a collection point of waste (food, water, materials), which is treated or incinerated elsewhere, far away. The Amsterdam Institute for Advanced Metropolitan Solutions (AMS) has The Circular City as one of their three key themes. AMS, an institute by TU Delft, Wageningen University and MIT, collaborates with the City of Amsterdam and local stakeholders, using the city as living lab for the transition to a sustainable future. The M-NEX Amsterdam is going to work in cooperation with the AMS Institute, the Amsterdam Institute for AMS. The M-NEX Living Lab will be selected and elaborated with AMS Institute and the City of Amsterdam, involving stakeholders from the city, public, private and individual to work together.

4.3. The Collaborative Scheme

The moveable nexus shall be developed incrementally through a series of design workshops at the above six living labs with all of the partners (see Figure 3). The project engagement will consist of six stakeholder workshops, one in each living lab that engage with key aspects of the FEW, in a bioregional context. This international workshop coincides with one of the (six) participatory workshops in each city. The international team will participate in this workshop and bring their particular skills and knowledge to it. Each of these international workshops has their own focus. The first workshop in Belfast (BEL) focuses on the creating an Initial vision on the technical food systems and the city. In the second workshop in Doha (DOH) the focus is on the city farm, stakeholder participation and urban agriculture. Workshop three (Detroit, DET) focuses on climate futures, de-

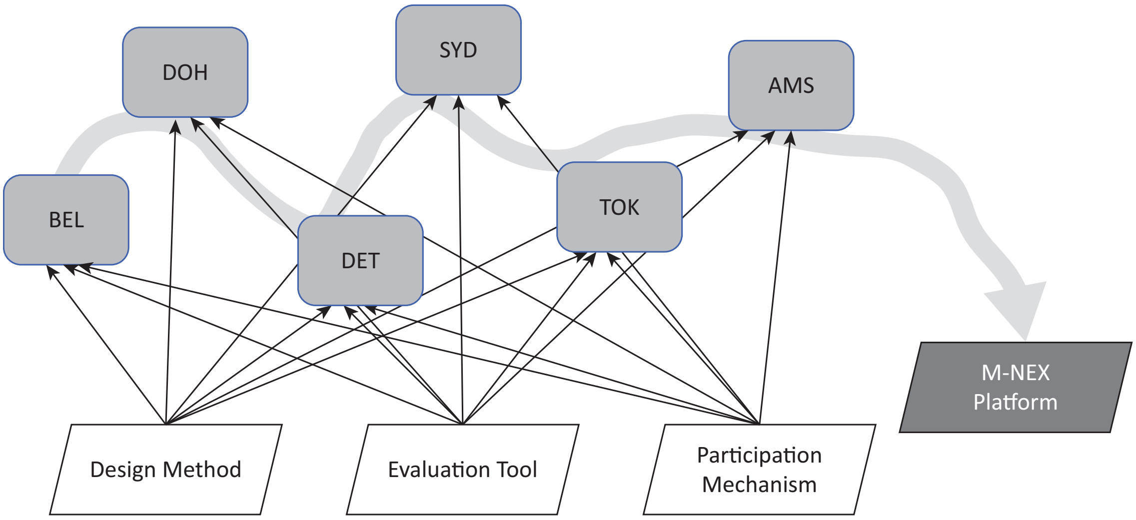

Figure 3. Scheme for the implementation of the moveable nexus.

velopment of regional scenarios and resilience in light of a changing climate. Workshop four (Sydney, SYD) focuses on building Integration, integrating FEW-technologies at user scale. Workshop five (Tokyo, TOK) focuses on stocks and flows for regional planning and the nested neighborhood. And the final workshop (Amsterdam, AMS) focuses on implementation, from strategy to tactics. Each team will bring its own topics to the international design workshop, and the teams together will refine them and build common design methods, evaluation indicators, and co-creation mechanisms. The teams will bring what they have learned back to their countries, put them into practice in their local Living Labs and undertake action toward the next international workshop. Finally, the knowledge obtained at each workshop will be integrated and provided as expertise and solutions from the M-NEX Project at each level, from building to neighborhood, city, and region.

5. Conclusions

The fact that environmental issues are indeed global in nature, gives reason to international collaborative research. Meanwhile, environmental problems are complex and require interdisciplinary efforts. With this awareness, the nexus approach is increasingly important. An enormous amount of effort is needed to create multinational and multi-sectoral research frameworks. Key issues to establish real integrative plans, projects and programs are the use of design-led methods and approaches, the implementation of early assessments, e.g., during the planning process and not afterwards, and finally the early, e.g., from the beginning, co-creative involvement of stakeholders and citizens in the planning and design phase of projects. The essence of the moveable nexus, the design-led approach is to facilitate the further integration of FEW in cities in an accessible way. Design is appealing to many and makes it possible to visualize solutions and possible outcomes of the benefits of each FEW-part being each other’s resource and service, so everyone can understand these abstract relationships hence be involved. It also makes it possible to assess the propositions at a very early stage, and this holds the opportunity to amend projects during the planning stage rather than after realization. Huge costs can be prevented.

The moveable nexus is defined with three meanings correspondent to the nexus thinking and the SUGI call:

1. To mobilize social and natural resources to create more with less for all the needed with design solutions;
2. To move stakeholders to action through cross sectoral dialogue with informed platform of M-NEX;
3. To move around local and global to the needed with the support of guiding principles and informed platforms.

Unlike the conventional approaches of research and practice, which try to deliver established knowledge and tools to users, the construction of the moveable nexus itself is through a series of design workshops which are open to any stakeholders. The three components of the moveable nexus shall be developed reflexively through engagement of stakeholders. The open idea has much adaptivity and applicability to diverse contexts while we should also keep mind the challenges in practices crossing cities (Stead, 2012; Stead & Pojani, 2018).

The concept of the moveable platform, the incremental development process, and the participatory workshops in a row are flexible to different research sites. It shares similar concept with urban living labs while the former focuses on contents and the latter has advantage of participatory platform. The collaboration of these approaches will create synergetic effects and demonstrate solutions for urban sustainability.

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Conflict of Interests

The authors declare no conflict of interest.

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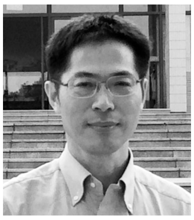
About the Authors



Wanglin Yan (PhD) is Professor at the Faculty of Environmental Information Studies, Keio University, and head of Program for Environmental Design and Governance at the Graduate School of Media and Governance of the same university. Prof. Yan is a distinguished scholar in Environmental and Geo-informational Science for urban and regional planning by multi-disciplinary and transdisciplinary approaches. He has led the sub-regional node of Asia-Pacific Adaptation Network of UNEP and is devoted to climate change adaptation and disaster risk reduction in Japan and northeast Asian countries. Recently he is leading the consortium of M-NEX and studying on co-creative design for community-based sustainability.

Rob Roggema (PhD) is Professor of Sustainable Spatial Transformations at the Knowledge Centre Noorderruimte, Hanze University Groningen. He is a landscape architect and an internationally renowned design-expert on sustainable urbanism, climate adaptation, energy landscapes and urban agriculture. He has previously held positions at universities in the Netherlands and Australia, State and Municipal governments and design consultancies. Rob developed the Swarm Planning concept, a dynamic way of planning the city for future adaptation to the impacts of climate change.

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Article

Mapping the Flow of Forest Migration through the City under Climate Change

Qiyao Han * and Greg Keeffe

School of Natural and Built Environment, Queen's University Belfast, Belfast, BT7 1NN, UK; E-Mails: qhan01@qub.ac.uk (Q.H.), g.keeffe@qub.ac.uk (G.K.)

* Corresponding author

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Abstract
Rapid climate change will create extreme problems for the biota of the planet. Much of it will have to migrate towards the poles at a rate far beyond normal speeds. In this context, the concept of assisted migration has been proposed to facilitate the migration of trees. Yet current practices of assisted migration focus on "where tree species should be in the future" and thus have many uncertainties. We suggest that more attention should be paid on the flow of forest migration. Therefore, this study develops a three-step methodology for mapping the flow of forest migration under climate change. Since the migration of trees depends on the activities of their seed dispersal agents, the accessibility of landscapes for dispersal agents is mainly considered in this study. The developed method combines a least-cost path model, a graph-based approach, and a circuit theory-based model. The least-cost path model is applied to map the movement of dispersal agents, based on which graph-based indices are used to evaluate the accessibility of landscapes for dispersal agents, which in turn is used as the basis for circuit theory-based modelling to map the flow of forest migration. The proposed method is demonstrated by a case study in the Greater Manchester area, UK. The resulting maps identify areas with high probability of climate-driven migration of trees.

Keywords
climate change; forest migration; urban landscape; seed dispersal

Issue
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1. Introduction

Transformation of tree species is the most important threat related with climate change (Dyderski, Paź, Frelich, & Jagodziński, 2018). According to projections by the Intergovernmental Panel on Climate Change (IPCC, 2013), the global mean surface temperature is likely to increase 1.1–4.8°C relative to 1986–2005 by the end of this century. One major consequence is that about 84% of all species have moved towards the poles to track suitable climate conditions (Thomas, 2010). Nevertheless, such movements do not guarantee their survival if they are not able to move fast enough to keep pace with the moving climate, especially for those relatively immobile plant species (Jump & Peñuelas, 2005).

Normal rates of plant movement in unfragmented habitats range from 1.7m to 1500m every year, whereas the rates of future climatic warming could be 3000m to 5000m each year (Petit, Hu, & Dick, 2008). This implies that most plant species will lag behind future climate change (Cunze, Heydel, & Tackenberg, 2013). Since trees are essential elements of forest ecosystems, the failure of them to track climate change will not only lead to the loss of wood resource and ecological functions but also slow the movements of animals that depend on them for habitat or food.

Within this context, the concept of assisted migration (also called managed translocation or assisted colonisation) is gaining increased acceptance as an important strategy to facilitate natural migration. Assisted migration refers to the translocation of species or genotypes from their natural ranges to areas where future climate might be favourable (Petit et al., 2008). In the face of ongoing climate change, assisted migration has already been incorporated into forest management in many regions and countries. In England, the Forestry Commission recommends that "at least one source of seed from slightly warmer climates sources from two to five degrees of latitude further south than the site is used". In Canada, several provinces have modified their seed-transfer guidelines in anticipation of moderate climate warming. Despite the widespread implementation of assisted migration, there is a considerable uncertainty in the projections of future species ranges due to the large uncertainty and variability among the projections of climate change (Lindner et al., 2014), which results in a risk of moving tree species too far or not far enough (Ferrarini et al., 2016).

To address this problem, we suggest that more efforts should be made on understanding the process (flow) of forest migration rather than predicting "where species should be in the future". Since migration of trees is a continuing process that does not rely on their future ranges, a "process-oriented" solution avoids the projections of future climate, and thus might be more robust to climate change than current "goal-oriented" practices. Moreover, understanding the process of forest migration enables us to identify critical locations along the process for accommodating relocated tree species, so that from those areas the species could expand further to colonise other suitable habitats (Pereira, Saura, & Jordán, 2017). Also, it may be easier for managers to focus on the process of forest migration, rather than to maintain a relocated species at a given site, especially in urban areas where human activity is intense and implementing large continuous reserves is not possible.

There are several methods available to map ecological processes and flows in heterogeneous landscapes (Adriaensen et al., 2003; Cushman et al., 2013; Lechner, Doerr, Harris, Doerr, & Lefroy, 2015; Rayfield, Fortin, & Fall, 2011; Saura, Vogt, Velázquez, Hernando, & Tejera, 2011). Of all these methods, circuit theory (McRae & Beier, 2007) has been widely applied in recent years because of its ability to model random dispersal patterns and to predict all possible movement pathways across a landscape simultaneously. Circuit theory treats the landscape as a conductive surface within an electrical circuit, characterising resistance/conductance to movement for every raster grid cell, considering current flow as analogous to movement patterns across the landscape. Recently, many methods have been developed to model climate-driven migration of species based on circuit theory (e.g., Lawler, Ruesch, Olden, & McRae, 2013; Littlefield, McRae, Michalak, Lawler, & Carroll, 2017). However, most of them focus on the movement of active dispersers (animals), characterising resistance/conductance based on specific landscape features related to habitat quality or the intensity of human modification (e.g., land cover type, road density, and housing density), and thus may be less suitable for the migration of tree species that depends on passive seed dispersal.

Successful forest migration depends on effective seed dispersal between forest fragments, which is affected by the ways in which seed dispersal agents move and interact with the landscape (Carlo, Aukema, & Morales, 2007). Hence, the movement of dispersal agents should be taken into account for the analysis of forest migration. It should be noted that, for the aim of this study, we only focus on animal-dispersed tree species, since water- or wind-dispersed species can be carried for long distances and thus may have a better chance of survival. From this perspective, the spatial pattern of a landscape is actually of great importance because it directly influences the accessibility of the landscape for dispersal agents, whereas landscape features related to habitat quality or human modification may be of limited value. Therefore, a new method is needed for mapping the flow of forest migration from the perspective of seed dispersal.

To this end, this study develops a three-step methodology combining a least-cost path (LCP) model and a graph-based approach with the circuit theory. The LCP model is applied to map the movement of dispersal agents in the landscape, based on which graph-based indices are used to evaluate landscape accessibility for dispersal agents, which in turn is used as the basis for circuit theory-based modelling to map the flow of forest migration under climate change. Since the focus of this study is on seed dispersal, the behaviour of dispersal agents is mainly considered; other biotic or abiotic factors such as soil type, plant diversity, or interspecific competition are excluded. In particular, the habitat and home-range scale of dispersal agents are simultaneously considered in this method to account for their multi-scale behaviours. The proposed method is demonstrated by a case study in the Greater Manchester area, UK.

2. Study Area and Data

Greater Manchester is a metropolitan region of approximately 127,600 hectares in North West England, UK (Figure 1a). The region comprises ten districts: Bolton, Bury, Manchester, Oldham, Rochdale, Stockport, Tameside, Trafford, Wigan, and Salford. The total forest area in Greater Manchester is about 4695 hectares, representing 3.7% of the land area (Figure 1b). Broadleaved forests are the dominant woodland type representing 74.6% of all woodlands, followed by mixed forests 8.0% and conifer forests 7.8%.

The Ordnance Survey Master Map of Greater Manchester (provided by Digimap at digimap.edina.ac.uk) is used as the land-cover data source for the study. To avoid

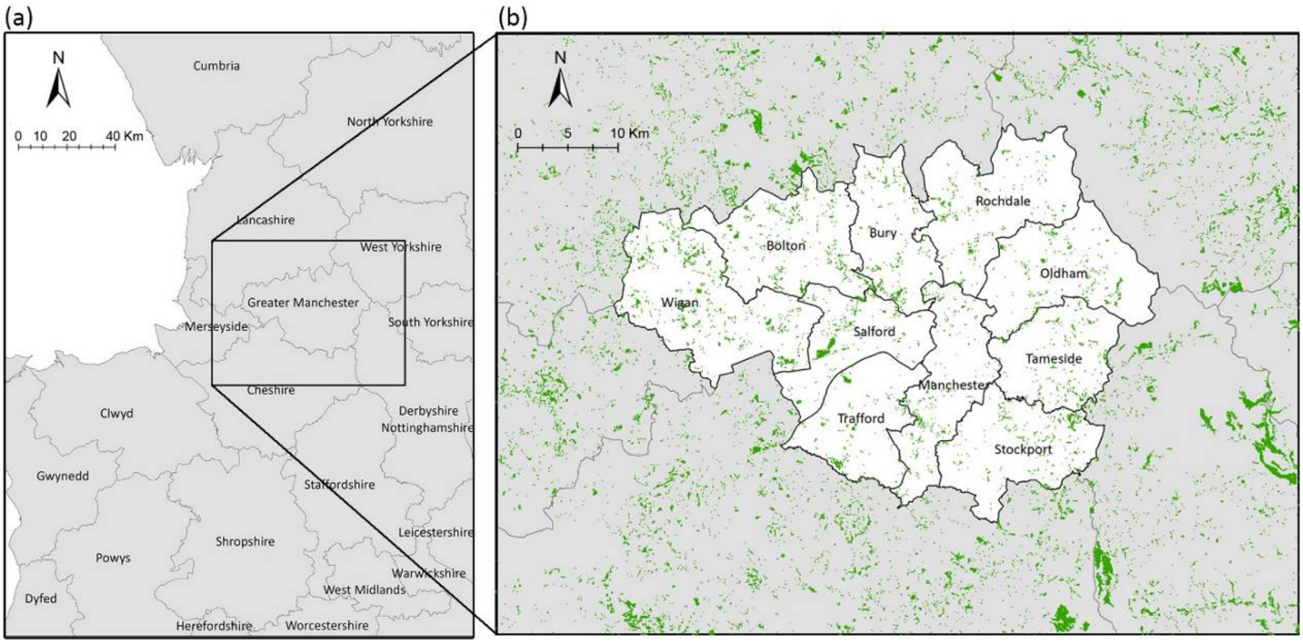

Figure 1. The study area: (a) the location of the study area; (b) woodlands in the study area.

the bias that would result from selecting a study area with merely administrative delimitations, the land-cover data are extended into the peripheral regions surrounding Greater Manchester. The 2010 topography layer (vector map) in the Ordnance Survey Master Map gives a comprehensive view of 13 broad land-cover types in the study area. In addition, to compare the resulting map from the proposed method with that from other circuit theory-based methods which focus on habitat quality or human modification, the Greenspace Layer (with detailed land use categories which captures the major aspects of human modification) in the Ordnance Survey Master Map is used to classify urban landscapes as: (1) natural, with a low intensity of human modification (e.g., natural woodland); (2) semi-natural, with an intermediate intensity of human modification (e.g., camping park, cemetery, golf course, public park or garden); and (3) manmade, with a high intensity of human modification (e.g., transport, bowling green, sports facility).

Although tree species can be dispersed by various dispersal agents, this study mainly considers frugivorous birds as effective dispersal agents, given their contribution to long-distance seed dispersal, which is highly important for climate-driven range shifts of trees (de Casas, Willis, & Donohue, 2012; Nathan, 2006). Compared with other frugivores, birds have relatively large habitats and home ranges and are much more effective for seed dispersal: rodents—such as mice and squirrels—have restricted dispersal distances and act mainly as seed predators (Hougner, Colding, & Söderqvist, 2006; Wenny, 2000); and even for some "wind dispersed" seeds, their large-scale dispersion is due to birds (Wilkinson, 1997). For the study of Greater Manchester, Eurasian jay (*Garrulus glandarius*) is selected as the main dispersal agent. Eurasian jay is a prevalent and probably the most active seed dispersal agent for many tree species that need to migrate through Greater Manchester in this century (Gómez, 2003; Pons & Pausas, 2007), such as lodgepole pine (*Pinus contorta*), sweet chestnut (*Castanea sativa*), sessile oak (*Quercus petraea*), beech (*Fagus*), and Scots pine (*Pinus sylvestris*; see the Forestry Commission at forestry.gov.uk/fr/infd-837f9j). The large habitat and home-range size, as well as flight distance of the bird contribute to the high migration rates of many tree species (Cunze et al., 2013). Table 1 shows the key parameters of Eurasian jays in relation to their seed dispersal ability. The spatial records of Eurasian jays are obtained from the UK's NBN Atlas (nbnatlas.org).

For the propose of this study, climate change is considered as the main factor shaping tree species distributions in the future. We use the average mean temperature from 1970 to 2000 with a spatial resolution of 10 minutes (approximately 340km^2) to obtain the regional temperature gradients in the study area. The cli-

Table 1. Key parameters about the dispersal ability of Eurasian jays, obtained from Conway and Fuller (2010), Dyer (1995), Gómez (2003) and Rolando (1998).

Spatial scale	Area	Dispersal distance
Habitat	≥ 4ha	≤ 1km
Home range	≥ 10.7ha	1km–5km

mate data are downloaded from the WorldClim Version2 (Fick & Hijmans, 2017).

3. Methods

The developed method is a three-step mapping process: (1) identifying landscape networks for dispersal agents (Eurasian jays) based on least-cost modelling; (2) assessing landscape accessibility for dispersal agents based on graph analyses; and (3) mapping the flow of forest migration based on circuit theory. The following will go through each of these steps in detail. Figure 2 is an illustration of the mapping process.

3.1. Step 1: Identifying Landscape Networks

This study uses a hierarchical approach to map the movement of dispersal agents, given that animals experience their landscape as a mosaic of patches at multiple scales nested within each other (Holling, 1992). Since the case study is a metropolitan region, only the habitat and home-range scale of Eurasian jays are considered; other scales are either too small in time or too big in space for the study.

3.1.1. Habitat Network

The landscape network at habitat scale (hereafter simply referred to as habitat network) provides animals access to food resources on a daily basis (Holling, 1992). It comprises habitat patches that serve as resources and paths which support the movements of animals among resources.

To identify habitat patches, the vector map of land cover is converted to a raster-format map, in which land-cover types are reclassified as either habitat or non-habitat area for dispersal agents. For the aim of this study, all the woodlands, including broadleaved, coniferous and mixed forests, are selected as suitable for habitat. After that, we change the resolution of the habitat map based on the minimum size (4ha) of habitat utilised by jays, aggregating small, scattered habitat fragments into large, contiguous habitat patches (Figure 2a). This is because animals utilise their habitats with species-specific grain size and may occupy habitat patches which contain non-habitat fragments (Holling, 1992). Cells are assigned to the habitat class when at least 30% area inside the cell is woodland (Andrén, 1994; Freemark & Collins, 1992). Specifically, hexagonal grids are used to represent habitat maps for the birds, rather than frequently-used rectangular grids, considering their advantages in modelling movement paths (Birch, Oom, & Beecham, 2007). ArcGIS 10.4 software is used for the identification of patches.

Since the dispersal probability between habitats is inversely related to the least-cost distance between them (Peña-Domene, Minor, & Howe, 2016), the LCP model is applied to map the paths between habitats (Figure 2b). The LCP model uses a raster-based optimi-

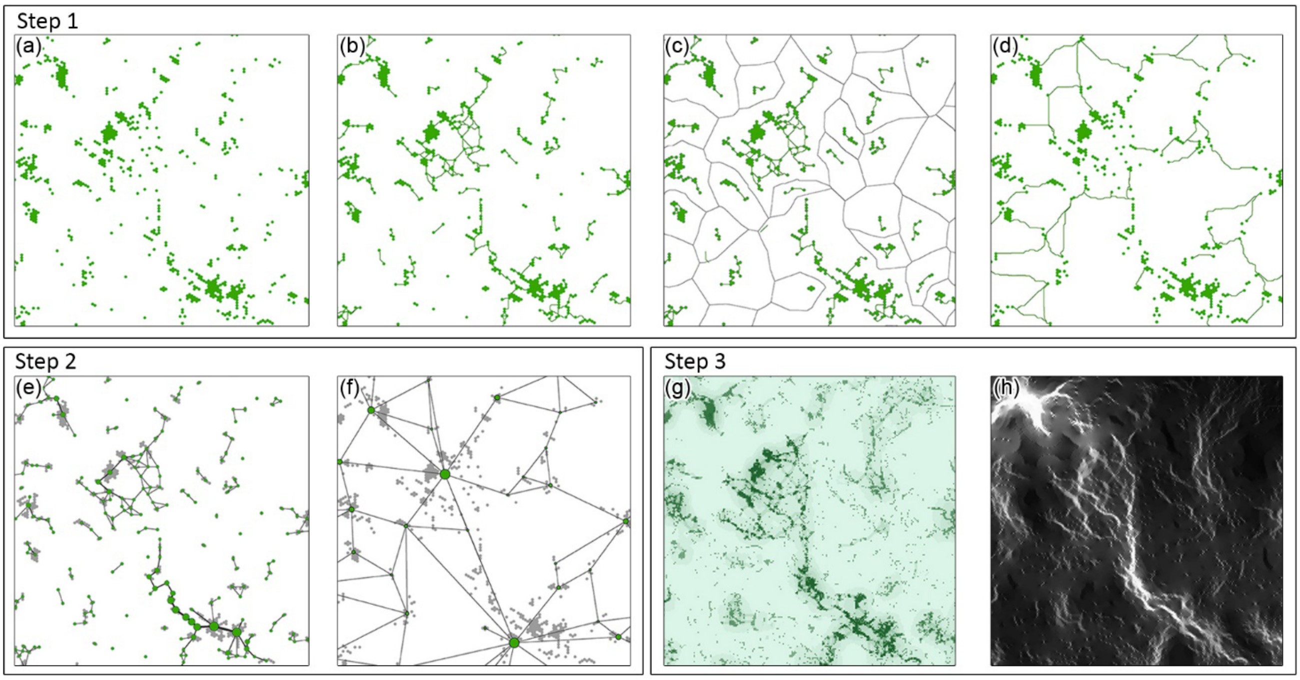

Figure 2. An illustration of the mapping process. Step 1: (a) identify habitat patches; (b) map LCPs between habitats; (c) identify home ranges by grouping connected habitat patches; (d) map LCPs between home ranges. Step 2: (e) assess habitat accessibility based on graph analyses; (f) assess home range accessibility based on graph analyses. Step 3: (g) create a conductance surface for circuit modelling based on landscape accessibility (dark green areas are high conductance to movements, while light green areas are low conductance); (h) map the flow of forest migration (white areas) by circuit theory-based modelling.

sation algorithm to identify the single most optimal path between patches, in terms of cumulative land-cover resistance (e.g., energetic cost, difficulty, or perceived risk; Watts et al., 2010), based on an assumption that animals have accurate cognitive maps of their home ranges and thus tend to follow the optimal paths (Hovestadt, Bonte, Dytham, & Poethke, 2012). In the study of Greater Manchester, the resistance values of the 13 land-cover types for Eurasian jays are obtained by habitat suitability modelling.

Habitat suitability modelling provides a more objective approach for evaluating resistance values than commonly-used expert-based approaches (Milanesi et al., 2017; Stevenson-Holt, Watts, Bellamy, Nevin, & Ramsey, 2014). It calculates the habitat suitability index (HSI) scores of non-habitat areas to infer land-cover resistance values, given that the spatial records of a species in non-habitat areas are related to its preference in movements (Stevenson-Holt et al., 2014). We use the MaxEnt software to conduct habitat suitability modelling (Phillips, Dudík, & Schapire, 2017). The spatial records of Eurasian jays from 2005 to 2015 and the 2010 land-cover raster map (with a resolution of 100m to match the spatial accuracy of the jay records) are used as input data. All habitat areas (woodlands) are removed from the land-cover map to prevent their incorporation in the model. At the same time, all areas over 500m from roads are also removed to account for sampling bias towards accessible areas (Warton, Renner, & Ramp, 2013). This leaves a total of 148 records of Eurasian jays that are within the remaining areas for habitat suitability modelling. The output HSI scores (in a logistic format) from MaxEnt indicate the probability of a species' occurrence within each land-cover type, ranging from 0 to 1. To obtain land-cover resistance values, the HSI scores are reversed to a range of 0–100 by using (1-HSI) * 100. Woodlands are given a value of 1 to account for their suitability for habitat.

Based on the resistance values, the LCP tool in Graphab software (Foltête, Clauzel, & Vuidel, 2012) is applied to create edge-to-edge dispersal paths between habitats, as well as the corridors associated to the paths. The distance threshold of the dispersal paths is determined by the maximum daily dispersal distances of jays (1km).

3.1.2. Home-Range Network

While the inter-patch movements at habitat scale contribute to daily seed dispersal, the long-distance dispersal (> 1km) of seeds, which facilitates the migration of trees over wider spatial extents, depends on the movements of dispersal agents at their annual home-range scale (Hougner et al., 2006; McCarthy-Neumann & Ibáñez, 2012; Rayfield et al., 2016).

The identification of home ranges (foraging areas) is based on the above mapping of habitat networks. In highly fragmented landscapes, animals that cannot find habitat patches large enough to support their survival may be able to overcome short distances through non-habitat areas and include neighbouring patches within their range of movement to supply their resource needs (Galpern, Manseau, & Fall, 2011; Kang, Lee, & Park, 2012). Therefore, the home range of Eurasian jays is composed of a cluster of functionally connected habitat patches (an isolated patch makes up a home range itself), which could support their minimum resource requirement (minimum home-range size, 10.7ha; Figure 2c). The long-distance dispersal paths between home ranges are mapped by LCP modelling (Figure 2d), using the land-cover resistance values previously obtained. The distance threshold of the paths is determined by the maximum distance (5km) that jays could move in their search for new home ranges.

3.2. Step 2: Assessing Landscape Accessibility

Since animals experience their landscapes at multiple scales and make different decisions at each scale, the presence of dispersal agents (the probability of seed dispersal) at a given location is based on resource accessibility at multiple scales, especially in fragmented landscapes (Boscolo & Metzger, 2009). Landscape accessibility is determined by patch area and inter-patch connections (Boscolo & Metzger, 2011). In this respect, graph-based indices are especially suitable for assessing accessibility because they can integrate both patch area and inter-patch connections in one measure. Graph analysis has been shown to be an effective way of representing complex landscape structures (e.g., Kong, Yin, Nakagoshi, & Zong, 2010), performing connectivity evaluations (e.g., Urban & Keitt, 2001), and modelling species occurrence (e.g., Awade, Boscolo, & Metzger, 2011). It transforms the landscape into a planar graph, in which patches are represented as nodes and the paths between them are expressed as links. In general, the area of each patch is taken as the attribute of its corresponding node, and the distance of each path is assigned to the link's attribute as well.

In this study, two graph-based connectivity indices, the probability of connectivity (PC; Saura & Pascual-Hortal, 2007) and the integral index of connectivity (IIC; Pascual-Hortal & Saura, 2006), are used to assess landscape accessibility for Eurasian jays at habitat and home-range scale, respectively (Figures 2e and 2f). The main difference between PC and IIC is that the former is a probabilistic index, where the length of each dispersal path is taken into account to calculate inter-patch connection probabilities, while the latter is a binary index, which focuses on the topological distances (in terms of the number of paths) between patches, with the degree of connectivity decreasing as the topological distance gets larger.

The PC index relates significantly to the actual movement and occurrence patterns of species at habitat scale (Awade et al., 2011; Pereira et al., 2017), especially for seed dispersal, because the probability of effective seed dispersal is a decreasing function of inter-patch distance (Peña-Domene et al., 2016). The accessibility of each habitat or path for jays can be inferred from a quantification of its contribution to the overall connectivity (PC value) of the home range that the patch or path belongs to. To do this, we first calculate the PC index for the home range, and then remove each patch or path and recalculate the PC index. The percentage of connectivity loss indicates the individual contribution of each patch or path. Patches with a high contribution are believed to be key hubs for seed dispersal and have a high frequency of visitation by dispersal agents (Carlo et al., 2007; Hock & Mumby, 2015). The calculation of the PC index is conducted with the Graphab software, in which a few parameters are set to obtain a 5% probability of dispersal corresponding to the maximum daily dispersal distance (1km) of jays.

Along with the calculation of the PC index at habitat scale, the IIC index is used to evaluate the accessibility of each home range, within which all habitat patches are conceptualised as a single node. The IIC index provides a rough description of inter-patch connections and has been shown to better relate to the functional connectivity among home ranges than PC (Decout, Manel, Miaud, & Luque, 2012). Similarly, the accessibility of each home range is evaluated by a measurement of its contribution to the overall connectivity (IIC value) of the home-range network, using the Graphab software.

3.3. Step 3: Mapping the Flow of Forest Migration

In the final step, a circuit theory-based method is applied to model the flow of forest migration based on the understanding of landscape accessibility for dispersal agents. A conductance surface which represents the permeability of landscapes to forest migration and sets of sources and targets that determine migration directions are used as inputs for the modelling. Accordingly, the potential migration patterns of trees are predicted as the electrical current flows from sources to targets through the conductance surface.

The conductance surface is the basis for the modelling, which relates the above assessment of landscape accessibility to the migration process of trees. In this study, the conductance value of each land-cover cell is determined by its accessibility at multiple scales, based on an assumption that landscapes with higher accessibility for dispersal agents might have a higher probability of seed dispersal and thus are more permeable to the migration of trees (Figure 2g). Given the interactions between landscapes at different scales (Awade et al., 2011), the conductance surface is created by multiplying the results of accessibility assessment at both habitat and home-range scale. ArcGIS 10.4 software is used to calculate the conductance surface. Since landscape permeability is a relative measure, the conductance values are normalised to a range of 1–100, with higher values indicate greater ease of movement.

To avoid the uncertainty in the projections of future climate change, the directions of forest migration are predicted by the historical climate gradients in the study area, according to an assumption that spatial temperature change is relatively uniform in direction. This assumption is based on evidence that temperature gradients over extensive geographical areas (from several kilometres to several hundred kilometres) are driven largely by topography (Daly, 2006). Since topography is constant over time, it can be expected that the directions of these climate gradients will not change substantially. This same assumption has been used in many studies for identifying corridors for climate-driven movements (e.g., Cushman et al., 2013; McGuire, Lawler, McRae, Nuñez, & Theobald, 2016; Nuñez et al., 2013). As a result, we use the temperature gradients in the study area to identify pairs of source and target forests (woodlands bigger than 100ha), that, if connected, would allow trees to move from warmer to cooler areas. The advanced mode in Circuitscape software is applied to model the flow of forest migration between each pair of forests (Figure 2h).

4. Results

4.1. Landscape Networks

At habitat scale, the aggregation of habitat areas yields 1886 habitat patches for Eurasian jays, covering 5.3% of the total study area (Figure 3a). These patches are connected by 1808 dispersal paths in the LCP model. The land-cover resistance values for the LCP model are derived from the habitat suitability modelling in MaxEnt. Table 2 shows the HSI score for each land-cover type and the corresponding resistance value. After that, all habitat patches are divided into 551 separate components of interconnected patches. According to the minimum home-range size of Eurasian jays, 285 components are identified as annual home ranges, accounting for 94% of all habitat patches. These home ranges are connected by 554 long-distance dispersal paths in the LCP model (Figure 3b).

4.2. Landscape Accessibility

The result of graph analyses is an understanding of which patches in the landscape are expected to be accessible for dispersal agents. Figure 4 illustrates the relative accessibility of individual habitats and home ranges. Patches with high values are critical for maintaining landscape connectivity and therefore can be regarded as key hubs for seed dispersal. As shown in Figure 4b, at home-range scale, only a handful of habitats are responsible for a disproportionate contribution to the overall connectivity (IIC value) of the landscape, and therefore should be given more attention for protection.

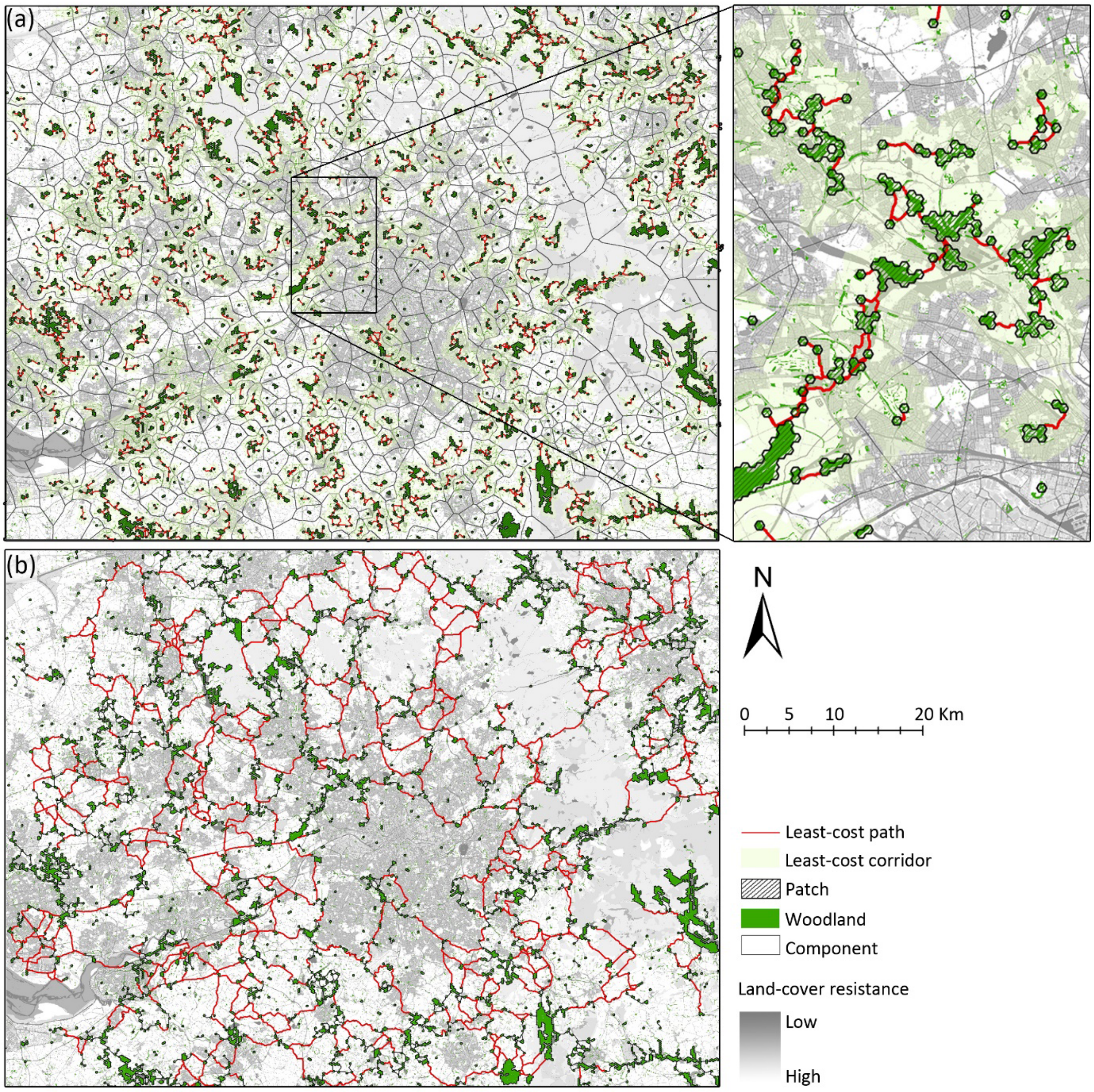

Figure 3. Landscape networks for Eurasian jays: (a) habitat network; (b) home-range network.

Table 2. HSI scores obtained from MaxEnt and the corresponding resistance values.

Land-cover type	HSI score	Resistance value
Buildings	0.46	54
Health	0.43	57
Marsh	0.43	57
Residential land	0.47	53
Agricultural land	0.4	60
Orchard	0.43	57
Roads	0.69	31
Rock	0.5	50
Rough Grassland	0.41	59
Scrub	0.67	33
Urban	0.43	57
Water	0.85	15
Woodland	N/A	1

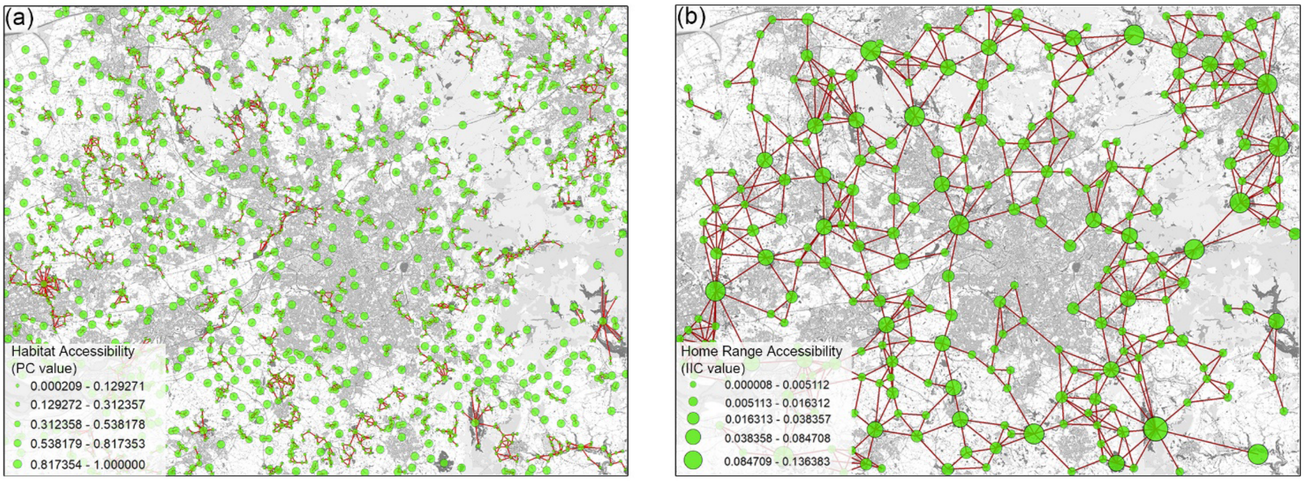

Figure 4. Landscape accessibility for Eurasian jays: (a) habitat accessibility (PC value); (b) home-range accessibility (IIC value).

4.3. Forest Migration Flows

In the final step, flows of forest migration are modelled as the electrical current flows from source to target forests. The resulting current maps (Figure 5) capture the broad-scale migration pattern of trees, with high current values (amps) indicating a relatively high probability of movement. All the current maps are then integrated to generate a cumulative current map (Figure 6) for identifying critical areas for forest migration where conservation efforts should be concentrated. Sites with higher values are suggested to be a high priority for protection or improvement, as they have a great impact on the process of forest migration. In these areas, a habitat loss would impede migration speed or modify migration pattern, whereas maintaining or enhancing habitat quality would guarantee or facilitate this ecological process. However, areas with lower values could be considered to be low in priority for protection as they have little contributions to forest migration, when only the seed dispersal activities of Eurasian jays are considered. As shown in Figure 6, locations that are critical for forest migration is likely to be concentrated in a few areas. For example, in Bolton, most areas are considered important for the flow of forest migration, while greenspaces in Rochdale and Oldham contribute little to this ecological process. This allows implementing a more efficient measure for forest management to cope with the warming climate.

With an aim to illustrate the difference between passive and active migration, we compare the resulting map generated with our seed dispersal-based method with a map of ecological flows based on the intensity of human modification of the landscape (Figure 6 versus Figure 7). Considering seed dispersal in circuit theory-based modelling substantially shifts and constrains the priority areas for movements to a smaller proportion of the landscape than when human modification is considered. Many areas that emerge as important for passive tree migration in our resulting map are less important for active species' movements that based on the intensity of human modification. Our results illustrate that migration flows that depend on passive dispersal may differ from those that rely on active dispersal.

5. Discussion and Conclusion

This study develops a sophisticated method to map the flow of forest migration under climate change. The resulting map of Greater Manchester not only identifies the functional connections between urban landscapes that may be able to conduct flows of forest migration, but also highlights important areas in the study area that could support the migration of trees. This allows designers to re-visualise the landscape as a series of interconnected flow channels, which in turn allows for a more piecemeal form of landscape design to optimise urban landscapes for climate adaptation. In this respect, this method would be especially important for the areas where human activity is intense and implementing large continuous reserves is not possible.

This study avoids a tree species-specific perspective but focuses on the movement of seed dispersal agents. This is because a tree species-specific approach requires an explicit assessment of many biotic and abiotic factors, such as species density, life-history traits, interspecific competition, elevation, land use, soil type and moisture. Such an approach is useful, especially for species of particular ecological importance at a local scale. However, the complexity of these factors makes it is difficult, if not impossible, over extensive geographical areas, especially under a changing climate. Moreover, our purpose here is not to provide a detailed assessment for a single tree species but to capture broad-scale potential movements and, specifically, to provide more general guidance for planning or designing urban landscapes for forest migration. In this respect, the method based on seed dispersal is more efficient and general because it could capture the migration pattern of a set of tree species dispersed by a

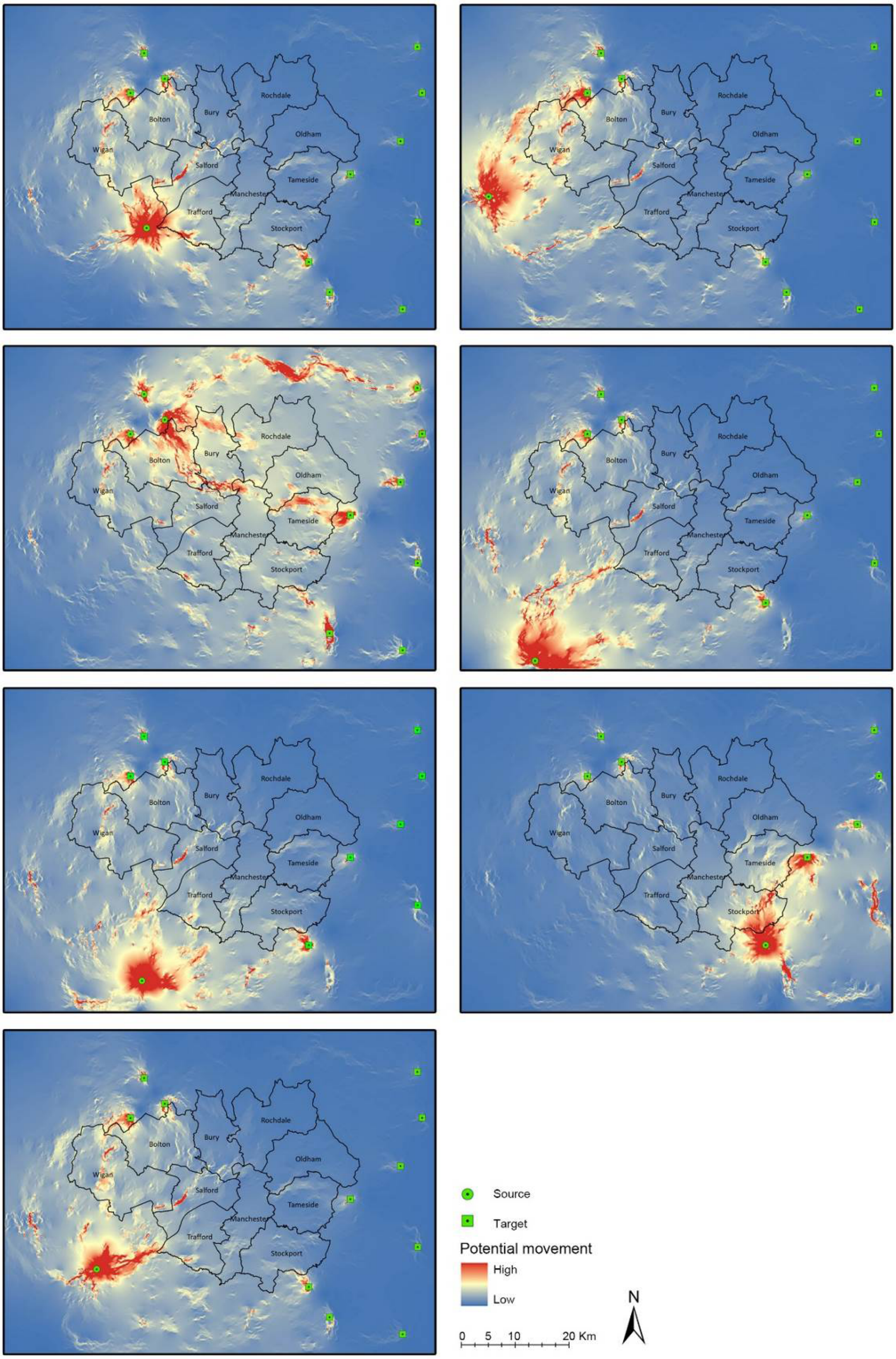

Figure 5. The flows of forest migration between different pairs of forests.

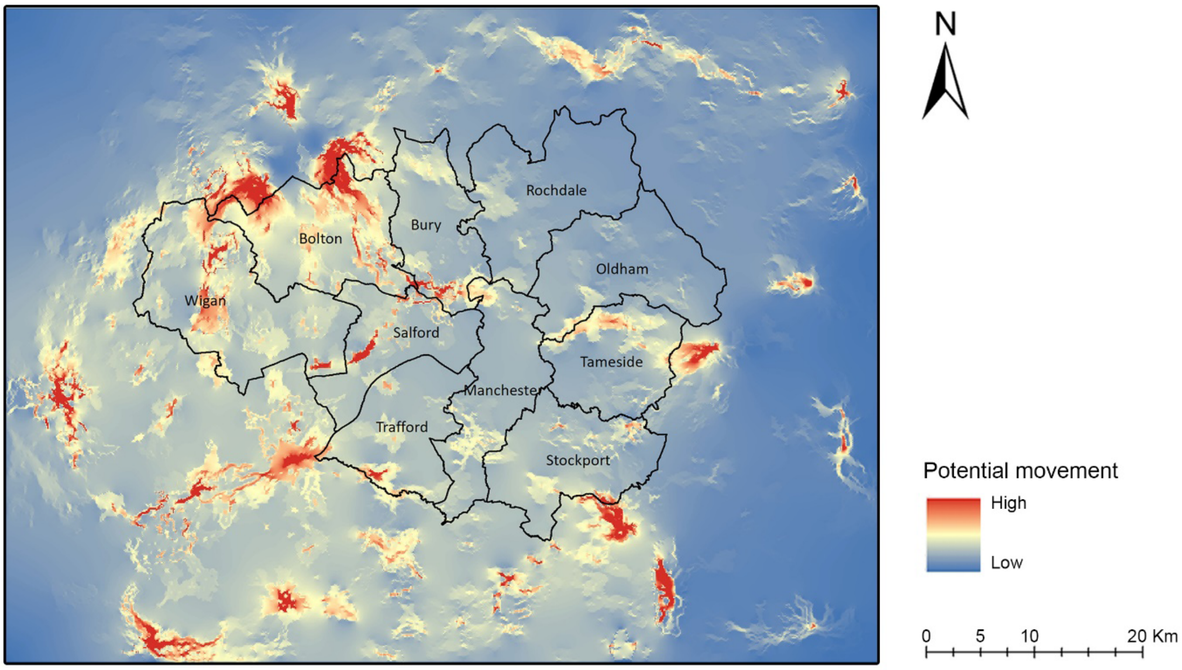

Figure 6. The integrated flows of forest migration in the study area.

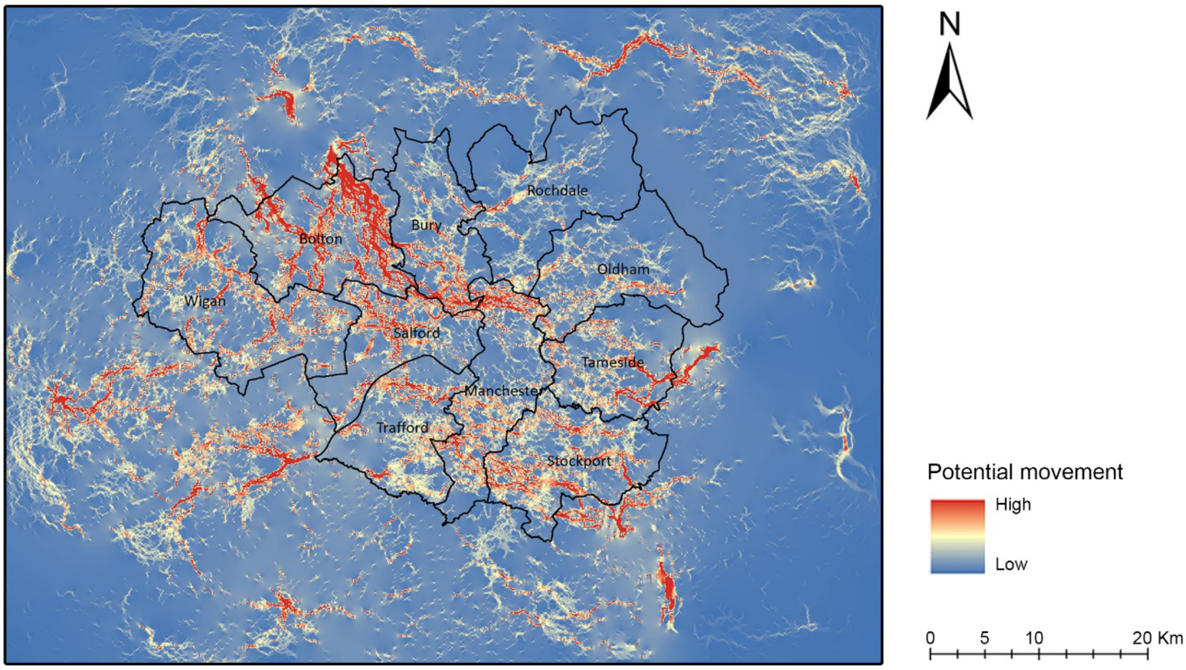

Figure 7. The flows of active migration based on the intensity of human modification.

specific dispersal agent. Nevertheless, this method could be complemented with species-specific models for tree species with specialised habitat requirements.

This method evaluates landscape accessibility for dispersal agents based on graph analyses. A more sophisticated approach would be a field-based analysis of dispersal agents. However, the data required for the analysis is not commonly available, particularly for bird species over a large spatial extent, and observing bird activities is beyond the scope of this research. Moreover, a distinction is difficult to made between the presence of a bird in a landscape that can be explained by a habitat function and the presence due to a dispersal function. In other words, capture of a bird in a particular location does not necessarily indicate that it is foraging in that area, rather it may simply be moving through the area to a different location (Aborn & Moore, 1997). Therefore, a graph-based approach might be more suitable and practical for analysing the activities of dispersal agents. Particularly, this method offers an additional advantage: it allows a precise evaluation of the potential benefits and efficiency of adding new patches (through forestation or restoration programs) in the landscape matrix to favour the movements of dispersal agents and thereby to facilitate the migration of trees.

Furthermore, this method avoids the uncertainties associated with the projections of climate change. Rather than connecting current habitat areas to areas predicted to have suitable climate conditions in the future, our method connects forests based on general climate patterns, assuming that temperature gradients are conserved in a changing climate. In this way, this method could be more robust to future climate change.

Although this mapping method provides certain advantages, it is based on several simplifying assumptions, and therefore has two limitations. On one hand, since this method uses temperature gradients at a large scale, it might miss some of the more localised climate patterns (e.g., urban heat island effect) and thus cannot be applied to a small spatial extent or locations with unique climatic gradients. On the other hand, Eurasian jays are assumed to be the main dispersal agents in the study, although there are a number of seed dispersal agents available in Greater Manchester, for example, Eurasian siskins, coal tits and grey squirrels. As different dispersal agents (with different dispersal abilities) may respond very differently to the landscape (Saunders, Hobbs, & Margules, 1991), results presented in this study do not cover all the important greenspaces that could facilitate forest migration. For future studies of Greater Manchester, it would be desirable to take other seed dispersal agents into account.

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Conflict of Interests

The authors declare no conflict of interests.

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About the Authors

Qiyao Han is a PhD (Architecture) candidate at the School of Natural and Built Environment, Queen's University Belfast. She has a Bachelor's and Master's degree in Landscape Architecture. Her research fields are resilient landscape design and planning and landscape ecology. Currently, her PhD research focuses on mapping and designing urban landscapes for climate-driven migration of trees.

Greg Keeffe is Professor of Architecture and Urbanism and Head of School of Natural and Built Environment. His work focusses on urban sustainability and resilience, particularly focussing on large-scale interventions to the city that add productive capacity, particularly through green infrastructures.

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Article

Incorporating Metabolic Thinking into Regional Planning: The Case of the Sierra Calderona Strategic Plan

Juanjo Galan [1,*] and Daniela Perrotti [2]

[1] Department of Architecture, Aalto University, 02150 Espoo, Finland; E-Mail: Juanjo.galan@aalto.fi
[2] Université Catholique de Louvain, 1348 Louvain-la-Neuve, Belgium; E-Mail: daniela.perrotti@uclouvain.be

* Corresponding author

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Abstract
A metabolic study of the South-Eastern part of the Calderona Mountain Range (Sierra Calderona) was developed in 2014 as a part of the Sierra Calderona Strategic Plan (SCSP). The goal of the study was to define strategies to optimise materials and energy flows in the region and, thereby, enhance the sustainability of the entire regional system. Due to its location on the outskirts of the Metropolitan Area of Valencia, Sierra Calderona presents most of the metabolic challenges and potentials that characterise peri-urban areas, giving the SCSP case a wider and transferable interest. After introducing the scope, rationale, and research questions, the article first summarises the main theoretical and methodological frameworks underpinning the integration of metabolic studies in regional and urban planning. Following our literature review, the article focuses on the way in which the metabolic analyses were inputted and informed the different phases and outcomes of the SCSP: analysis and diagnosis, regional objectives and strategies, landscape and land-use plan, sectoral plans and pilot projects. This approach was based on the combination of complementary analytical methods such as material and energy flow accounting and Ecological Footprint Analysis. Additionally, the article reflects on how new conceptual tools such as the Functional Metabolic Areas were used in the SCSP in order to operate in a complex spatial system and to generate a regional metabolic model. Subsequently, the main contributions and shortcomings of the use of metabolic inputs in the SCSP are discussed by comparing the metabolic assessment approach adopted in the SCSP with available models and methods. Finally, our conclusions suggest potential improvements and future lines of research on a two-way implication between urban metabolism research and regional and urban planning practice.

Keywords
ecological footprint; material and energy flow analysis; regional metabolism; spatial metabolic studies; sustainable metabolism; sustainable planning; urban metabolism

Issue
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1. Introduction

1.1. The Scope of the Article

This article positions itself within the growing body of literature advocating the need for better integration of urban metabolism (UM) thinking and, more specifically, UM assessment methods, in spatial planning (e.g., Ibañez & Katsikis, 2014; Li & Kwan, 2018; Perrotti & Stremke, 2018). In line with one of the most cited definition of UM in industrial ecology (Kennedy, Cuddihy, & Engel-Yan, 2007), in this article we refer to UM as the multiple socio-technical processes by which cities or—in the case of our study—regions gather, transform, and use biotic and abiotic resources, and expel waste, to ensure their functioning.

An increasing number of UM review articles nowadays discusses the extent to which a metabolic perspective is essential for spatial planners to understand the natural and anthropogenic processes underpinning the spatial and temporal transformations of human environments (e.g., Cui, 2018; Dijst et al., 2018; Zhang, Yang, & Yu, 2015). The success recently enjoyed by the UM research field results from a growing consensus in the wide "urban sustainability" scientific community that deeper knowledge of the material and energy inputs and outputs of urban systems can contribute to their sustainable and resilient maintenance and growth (Beloin-Saint-Pierre et al., 2017). The transition from a "linear" UM (i.e., based on the assumption of a limitless supply of resources from the hinterland and high amounts of expelled waste) towards a more "circular" metabolism has been identified as a condition to achieve a more sustainable development of urban systems since the early stages of industrial ecology (Girardet, 1992). More recently, this hypothesis has been further explored and developed throughout a wide range of case studies across the globe, based on evidence that cities lie at the beginning and at the end of many production-consumption chains and material waste paths.

The question of how UM assessment methods can be used and incorporated into spatial planning is a recurring topic in UM scientific literature nowadays. The considerable progress made in the UM research field in the early 2000s (Cui, 2018) has not always resulted in a large exploration of the UM applicability in planning. Until very recently, only a limited number of published studies specifically addressed this aspect of UM research. One of the first and most cited journal articles discussing applications of UM studies (282 citations in Scopus at the time this article was written) was published in 2011 (Kennedy, Pincetl, & Bunje, 2011). The article reports only three applications in urban planning, of which one book (Oswald & Baccini, 2003), one master's thesis (Quinn, 2007, later expanded in a PhD thesis; see Quinn, 2012), and one set of three journal articles that refer to the same case study (Codoban & Kennedy, 2008; Engel-Yan, Kennedy, Saiz, & Pressnail, 2005; Kennedy et al., 2007).

This trend has rapidly changed over the last five to seven years. Since 2011, UM research initiatives and published works specifically exploring applications of metabolic studies in spatial planning have gained momentum. According to Scopus data, 103 journal articles containing "urban metabolism" and "planning" in the abstract, title, or keywords have been published in English between the beginning of 2011 and September 2018 (date at which the search was conducted), whereas only 26 journal articles were published between 1994 and 2010. Moreover, at least two interdisciplinary research projects within the European Community's Seventh Framework Programme (EU-FP7) have been concluded and published to date on the link between UM and urban planning (Chrysoulakis, de Castro, & Moors, 2015; Davoudi & Sturzaker, 2017).

1.2. Goals, Research Questions, Research Method, and Article Structure

This article makes a twofold contribution to the growing body of research on UM applications in spatial planning. First, within the broad spectrum of spatial planning disciplines, it focuses specifically on regional planning and aims at clarifying the benefit of incorporating UM thinking and UM assessment methods in the development of planning orientations and documents at the regional level. In this article, regional planning is understood as being concerned primarily with the sustainable distribution of land uses and activities in a geographical scope including different land/use and landscape patterns. This definition is in line with the one proposed by Glasson and Marshall (2007), who argue that the primary objective of regional planning is to inform the distribution of new activities and developments, leaving a flexible interpretation of both the limits of the region and the timescale. To achieve this goal, we will discuss a recent case study, the Sierra Calderona Strategic Plan (SCSP; Galan, 2014b). SCSP is an integrated plan for the sustainable development of the Sierra Calderona informed by two complementary UM assessment methods: material and energy flow accounting and the calculation of the ecological footprints (EFs) associated with users' and inhabitants' lifestyles. The combination of these two UM methods in the same plan arguably reinforces the validity of the Sierra Calderona case to illustrate a possible way through which regional planning can be informed by UM studies. Although planning might have always been about integration (Glasson & Marshall, 2007), for the purpose of this article, the concept of "integrated planning" places special emphasis on the interaction between different activities, land uses, and agencies in contrast to classic zoning or to sectoral planning, traditionally concerned with one particular activity or land use.

Secondly, through the discussion of the UM approaches and main outputs of the SCSP, the article addresses a series of challenges that can emerge from the application of UM methods in real-world regional planning practice (e.g., quantitative versus qualitative research approaches, availability of datasets). This allows discussing the main limitations of the two UM assessment methods used in the SCSP in terms of the translation of UM knowledge into planning strategies. Although based only on the Sierra Calderona example, our conclusions can provide insights and recommendations for UM researchers to better respond to practitioners' needs and policy requirements.

In synthesis, the article addresses the following research questions through a critical analysis of the UM approach adopted in the SCSP and its outputs:

1. How can the results of UM studies be incorporated into integrated regional planning?
2. Which UM assessment methods can facilitate this incorporation and what are the main limitations

of current UM methods to better inform regional planning?

From a methodological perspective, we develop a single case study research (Yin, 2014), in which critical analysis of the SCSP is used as a means to explore our two research questions and to draw conclusions that could be generalised to similar case studies. In fact, as discussed throughout the article, the Sierra Calderona represents a prototypical example of many natural areas located at the limits of urban agglomerations, which, by being often exposed to the same pressures and challenges, are susceptible to share similar strategic solutions. Moreover, the critical analysis is conducted with a double embedded perspective (research and practice), as the corresponding author was also involved in the development of the SCSP, in collaboration with the local authorities (Municipalities of Náquera, Serra, Olocau, Marines, and Gátova).

The article is structured as follows. In Section 2 we firstly elaborate on the specific contributions and potential of UM methods to inform regional planning, beyond the traditional focus of UM research on urban planning and the study of strictly-speaking “urban” systems (i.e., based on cities’ administrative boundaries). Secondly, we present a brief review of the two main UM methods used in the SCSP, considering their potential and limitations in regional planning.

In Section 3, the UM methods, planning challenges, and solutions proposed in the SCSP are discussed, as well as the challenges emerging from the use of UM methods in regional planning. The SCSP builds on some broadly accepted assumptions found in UM literature (e.g., benefits resulting from increasing circular cycling in urban/regional systems, and from reducing consumption levels and resource-intensity without affecting people’s well-being). In addition, the SCSP assumes as a fact the beneficial effect of dense and multifunctional urban fabrics in the levels of consumption of water and energy in different types of urban fabrics in the Valencian Region (Lloret, 2013). In addition, section 3 illustrates the way in which UM concepts and assessment methods were integrated into the SCSP, the studied metabolic flows (water, waste, and energy) and the use of EFs as a tool to assess the metabolic performance of individuals and communities. Finally, section 3 explains how the metabolic inputs informed the development of strategies, sectoral plans, and one pilot project, by making use of operational units named Functional Metabolic Areas (FMAs). Through the article, FMA is proposed as a key concept that can facilitate the incorporation of UM methods into regional planning practice.

Section 4 elaborates on the answers to the proposed research questions by discussing the main contributions and shortcomings of the use of metabolic inputs in the SCSP, and by suggesting potential improvements. This discussion is based on a critical comparison between the available theoretical and methodological frameworks and the work developed in the SCSP. Additionally, questions for future research on a two-way implication between UM theory and models and planning disciplines are presented.

Given its scope and goals, the article may be of interest to three main readership profiles. Regional and urban planners will find an example of how UM methods can inform planning and design processes. UM researchers will be introduced to a recent example of how regional planners have engaged with resource accounting methods and related shortcomings when it comes to their use in daily practice. Finally, local and regional authorities will be provided with an overview of the potential and limitations of combining spatial planning and UM tools into decision-making processes.

2. Background

2.1. Regional versus Urban Scopes in Metabolic Studies and Planning

The unclear limits of the urban phenomena, as well as the high connection between urban areas with their surrounding and the metabolic processes taking place in regional mosaics, suggest the relevance of adding regional scopes to the integration of metabolic studies in planning (Baccini & Brunner, 2012).

In this article, we argue that the introduction of the regional scale can open new directions of inquiry for metabolic studies by exploring the interactions between urban and non-urban systems and by incorporating a wider palette of land uses. Thus, a regional perspective can further enhance the UM research agenda by working across (at least) three levels. Firstly, the differences between areas ascribed within the same land-use can provide the opportunity to identify how morphological and functional variations affect metabolic behaviours. This idea is supported by several authors (e.g., Alberti, 2005; Ferrão & Fernandez, 2013) who advocate the need for further research into the effect of diverse land uses and the urban physical form on the resource intensity of urban settlements; the same may apply to other land-use categories (e.g., agricultural or infrastructural areas). Secondly, a regional perspective can allow for the identification of areas with similar or distinctive metabolic patterns. This can lead to a more systematic metabolic characterisation and modelling of a region or complex spatial system. Thirdly, the comparison between the resource demand and provision from areas with distinct metabolic patterns can offer a deeper understanding of the current and potential metabolic interactions between different areas within the same region, and therefore inform more resource-efficient spatial, land use, and sectoral planning and policies.

Following this reasoning, a regional metabolic model for the Sierra Calderona was proposed, based on the interactions between different spatial subsystems. This approach advances previous studies’ suggestions of classifying “spatial types” according to their metabolic performance (see city types in Ferrão & Fernandez, 2013) and offers an alternative to the definition of regional metabolic models based on metabolic activities (see the use of "nourish", "clean", "reside & work", and "transport & communicate" activities in the METALAND model by Baccini & Brunner, 2012).

2.2. UM Assessment Methods

Within the broad range of UM disciplinary strands, related modelling, and conceptual frameworks (Castán Broto, Allen, & Rapoport, 2012; Wachsmuth, 2012), in this article we focus only on the two assessment methods which were used in the SCSP: material and energy flow accounting and the calculation of the EFs associated with the material/energy consumption of different types or user/inhabitant profiles. Both methods originated within industrial ecology, which, in quantitative terms, represents the most influential research path in UM studies (Newell & Cousins, 2014). Although different in scope and utilised metrics, both flow accounting and EF calculation are relevant to the regional focus that is adopted in this article.

The mass-balance method Material Flow Analysis (MFA) is the most used input-output method for material and energy flow accounting in urban systems (Cui, 2018). Similarly to other industrial ecology's UM methods, MFA is based on an understanding of the city as an individual open system embedded into the wider earth system and whose metabolism is the result of the interactions between different sub-systems. MFA was firstly introduced in the late 1960s by Ayres and Kneese (1969), further implemented in the 1990s (Baccini & Brunner, 2012; Bringezu, 1997), and then formalised by the Statistical Office of the European Community in the early 2000s (Eurostat, 2001). The Eurostat's MFA was initially designed as a flow accounting method at the scale of national economies. Hammer, Giljum, Bargigli and Hinterberger (2003) adapted the Eurostat's method to the scale of urban regions, and the validity of the regional MFA was demonstrated through a study of the metropolitan region of Hamburg. Since then, the regional MFA has been used as a basis in the study of several urban systems since the late 2000s and in the 2010s (e.g., Bahers, Barles, & Durand, 2018; Barles, 2009; Niza, Rosado, & Ferrão, 2009; Voskamp et al., 2017). The application to the regional scale by Hammer et al. (2003) as well as the increasing popularity of MFA in UM urban and regional case studies worldwide (Cui, 2018; Newell & Cousins, 2014) suggest that the use of MFA can favour the incorporation of UM methods in regional planning.

Among the several methods used to calculate the EFs of urban populations, Ecological Footprint Analysis (EFA; Wackernagel, Kitzes, Moran, Goldfinger, & Thomas, 2006) represents to date the most widely used methodology in published scientific literature. EFA was initially designed as a tool to measure if and to what extent the outputs of human economic activities can be supported by the regenerative capacity of the biosphere (Rees, 1992). Footprints can be assessed on different spatial scales, from economic activities performed by the entire population of the planet, down to those within urban systems or even individual dwellings. The standardised unit used to measure EFs is global hectares, namely hectares adjusted to represent the average yield of all bioproductive areas on Earth (Monfreda, Wackernagel, & Deumling, 2004). One global hectare is understood as one hectare of biologically productive space, which is calculated based on the average productivity across the planet in a given year. The fundamental hypothesis behind the use of EFA in UM assessment frameworks is that most of the flows that sustain the metabolism of an urban/regional/national system can be associated with the biologically productive area that is required for their generation or maintenance (Wackernagel et al., 2006). Despite its high level of aggregation and subsequent limitations when aiming at assessing the magnitude of metabolic flows, EFA can be considered as a valuable and intuitive tool to link metabolic thinking with planning, decision-making processes, and policy-making (Ferrão & Fernandez, 2013)

In this article, we argue that both MFA and EFA provide useful results that can improve spatial planners' understanding of the metabolic functioning of a region and, if incorporated in the spatial planning process, can facilitate the elaboration of planning strategies aiming at achieving an optimised metabolism of regions.

3. Case Study: The SCSP

3.1. Contents and Structure of the SCSP

The SCSP (Galan, 2014b) was developed during the years 2013–2014 in five municipalities (Serra, Náquera, Olocau, Marines y Gátova) located in the outskirts of the Metropolitan Area of Valencia (Figure 1), in the south-eastern part of the Sierra Calderona. The SCSP covers a surface of 200km^2 with a permanent population of 13,000 people that reaches 40,000 people in the high season. A significant part of this area is included in the Sierra Calderona Natural Park (49%) and an additional 30% in its buffer area.

In general, the whole SCSP aimed to integrate environmental, cultural, social, economic, and urban planning, as well as to guide decision-making processes and the development or updating of local plans (Planes Generales de Ordenacion Urbana). In the Spanish and Valencian jurisdiction, local plans are the statutory instruments that define the spatial evolution of municipalities. The drafting of the SCSP was informed and driven by the analysis of social, cultural, sustainability, and economic factors, and was supported by a participatory process.

As displayed in Figure 2, the plan included three main chapters. The first chapter consisted of a multi-layered analysis and diagnosis. The second chapter defined a set of regional objectives and strategies based on the same layers used in the first chapter. Finally, the third chapter

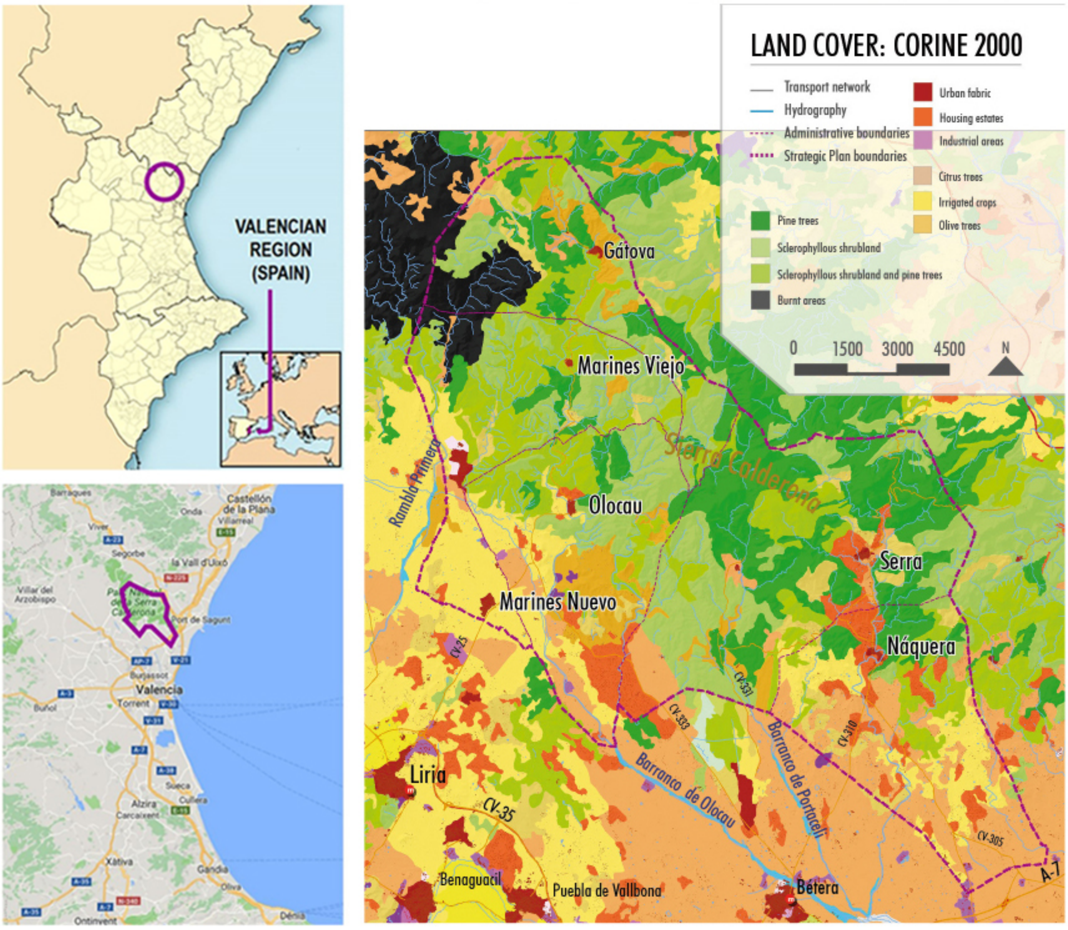

Figure 1. Location and land covers in the SCSP (municipalities of Serra, Náquera, Marines, Olocau and Gátova, SPAIN). Source: CITMA (Galan, 2014b, 2018).

included one landscape and land-use plan, nine sectoral plans, and eighteen pilot studies and projects. Throughout the three chapters, analysis of landscape, sustainability, socioeconomic processes, and their associated metabolic flows were used to support planning.

3.2. Metabolic Approaches and Concepts in the SCSP

As discussed in the previous section, one of the key challenges in UM studies is to incorporate UM results into planning processes, using UM knowledge to better express the drivers behind the socio-economic functioning of the planned system or territory. Moreover, the study of the mutual interactions between metabolic flows and the spatial distribution of land use and cover types has recently emerged as a rich line of research in metabolic studies (Zhang, 2013). In the SCSP, an instrumental approach to UM knowledge was used, meaning that the focus was mainly on the contribution of UM studies regarding sustainable regional planning.

In the SCPS, the study of metabolic flows was organised according to a set of spatial units or subsystems that in this article are formalised and presented as FMAs. These FMAs are proposed as a tool to facilitate the study of complex metabolic systems, such as regions or metropolitan areas, in which the different components of the land-use mosaic have distinctive metabolic behaviours or performances.

FMAs might be associated with land uses as well as to specific characteristics influencing the metabolic functioning of those land uses, such as “density” in urban areas or “cultivation techniques” in agricultural land. In particular, the following types of FMAs were defined in the SCSP: (1) urban areas, with two internal subtypes: compact dense towns, and low-density housing estates; (2) agricultural areas with two internal subtypes: irrigated fields for intensive agriculture and rain-fed fields; (3) industrial areas; and (4) natural areas.

As displayed in Figure 2, the SCSP was developed over a set of land-use layers, territorial systems, and sustainability dimensions. A sequential Public Participation Plan informed the development of the Strategic Plan during its three phases: analysis and diagnosis, strategies and objectives, and land-use/landscape and sectoral plans.

In particular, the metabolic studies developed during the analysis and diagnosis phase included the assessment of some of the main metabolic flows within the system (water, energy, and waste), and the calculation of the EFs of a set of representative user profiles (permanent and temporary residents).

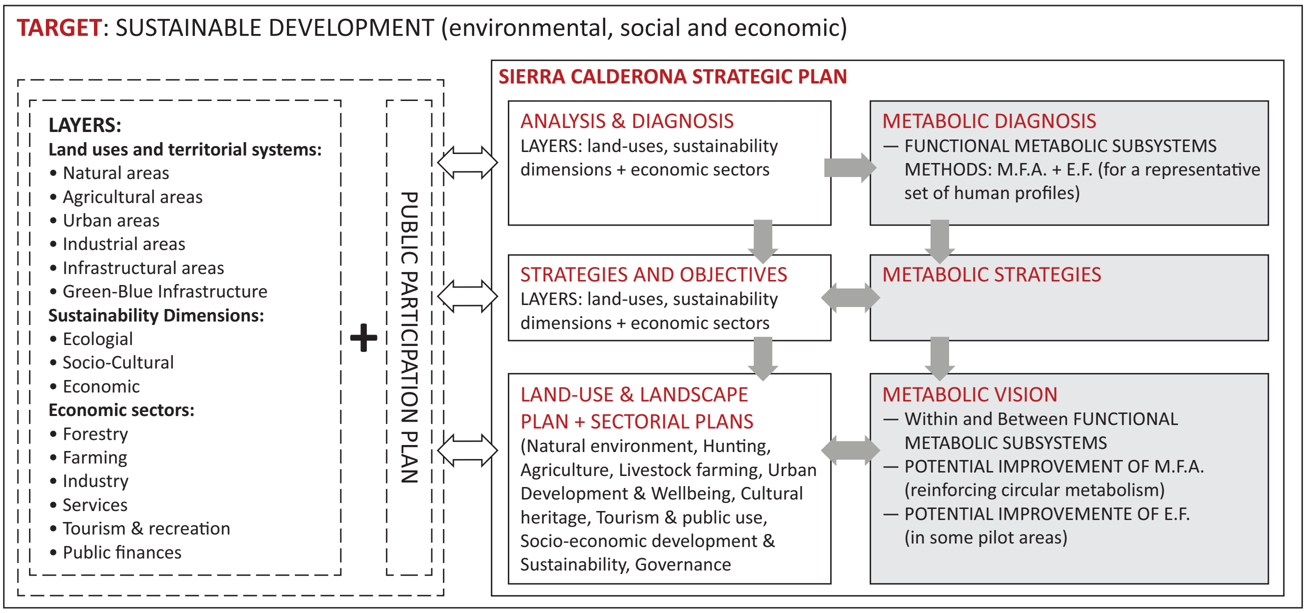

Figure 2. Contents of the SCSP and use of metabolic studies.

During the second phase, the strategies and objectives of the SCSP were formulated based on the outcomes of the first phase and the metabolic assessment of the Sierra Calderona.

Finally, the third phase included a land-use/landscape plan and a set of sectoral plans that responded both to the strategies and objectives and to the metabolic adjustments proposed in a regional metabolic model, which was developed as a part of the "Socioeconomic Development and Sustainability" sectoral plan.

Therefore, in the SCSP, sustainability and regional metabolism were used as transversal themes, guiding spatial, functional, and economic planning. This approach is aligned with previous works' recommendations to expand UM methods into a more comprehensive framework encompassing the "human, social, policy, economic, and related systems that both structure and govern specific urban metabolic processes" (Pincetl, Bunje, & Holmes, 2012, p. 200).

Thus, building on the model proposed by Baccini and Brunner (2012) for "resources correlations within a regional urban system", the SCSP resulted from the analysis of the interaction between a social metasystem and a physical metasystem. The social metasystem integrates the socio-cultural, economic, political, and governance drivers that operate in the anthroposphere as the "strings that are moved by the values of a society and its individuals" (Baccini & Brunner, 2012, p. 285). The physical metasystem consists of the nature system (geosphere and biosphere), and the anthropogenic environment, including the built environment and the colonised ecosystems (e.g., agricultural and semi-natural areas as well the human-managed natural areas). As displayed in Figure 3, the interactions between these metasystems and systems can be described in terms of metabolic flows, economic processes, and socio-political frameworks that regulate human-environment relations. Moreover, the analyses, strategies, and sectoral plans included in the SCSP cover each of these dimensions although, due to their transversal character, the landscape and land use plan, the socio-economic and sustainability plan, and the metabolic studies can be perceived as overarching umbrellas affecting and affected by all the systems.

3.3. Metabolic Assessment of the Sierra Calderona

3.3.1. Methods and Data Sources

Based on the availability of datasets at the regional or national level, the metabolic study developed in the analytical phase of the SCSP concentrated on the following material flows: water (clean water and sewage) and waste (urban and industrial solid waste and green waste from agriculture, gardening, and forestry). On the other hand, flows of energy (in the form of electricity) were considered essential, due to their contribution to nearly all human activities and material processes. Finally, the use of EF methods complemented the information provided by material and energy flow accounting.

Table 1 summarises the methods used for the calculation of each metabolic flow or EF as well as the data sources and data accuracy. Most calculations were performed at the level of the spatial subsystems or FMAs defined for the Sierra Calderona. Due to the limited availability of high-resolution datasets, the metabolic analyses were based on approximations and extrapolations of regional/national data, and average per-capita ratios were used to estimate overall consumptions in the different Sierra Calderona subsystems (e.g., data or ratios extracted from: Ayuntamiento de Sevilla, 2008; City of Valencia, 2010).

Table 1. Metabolic methods, application scopes, data sources and data processing used in the SCSP.

METHOD	SCOPE IN SCSP	DATA SOURCES ANDA DATA PROCESSING IN SCSP	ACCURACY IN SCSP
Material Flow Accounting **WATER**	Assessed in different FMAs (associated with different land uses and urban or agricultural types)	**CLEAN WATER**: — **Domestic uses**: total consumption and generic ratios for compact and low-density housing (90 liters/inhabitant/day and 200 liters /inhabitant/day respectively) (Lloret, 2013; Indicadores de Sostenibilidad Ambiental de la Actividad Urbanística de Sevilla, 2008; Observatorio de la ciudad: Sistema de ratios e indicadores_Valencia (2010)) — **Agricultural uses**: average water supply for irrigated crops (areas devoted to each crop were extracted from the municipal report prepared by Caja España 2012 and average consumption of water in irrigated crops from the Boletín Informativo de cifras-lNE 2008) — **Industrial use**: % of total water demand (estimated as 4% of the overall consumption of water, following the chapter “Pressions antròpiques. Aigua Urbano industrial (Anthropic presures: urban and industrial water)” in the report La situació del País Valencià 2007. — **Services use**: not accounted **SEWAGE** — **Treated sewage**: Data provided by sewage treatment plants. — **Untreated sewage**: A significant portion of sewage goes to cesspits in low density housing estates, especially in those constructed some decades ago — **Sewage directly poured in water courses**: not calculated **LIQUID MANURE**: produced by livestock farming	MEDIUM ACCURACY ROUGH MATERIAL (water) BALANCING
Material Flow Accounting **WASTE**	Assessed in different FMAs (associated with different land uses, activities and urban typologies)	**MUNICIPAL SOLID WASTE**: Calculated using the average production of domestic solid waste in the Valencian Region (1.28 kg/inhabit/day) **CONSTRUCTION, INDUSTRIAL AND ATMOSPHERIC WASTE**: Calculated using the following ratios (from “Flujos de energía, agua, materiales e información en la Comunidad de Madrid (*Flows of energy, water matter and information in the Madrid region*)”): — **Atmospheric waste**: 10.5 kg CO_2 per inhabitant/day — **Construction debris**: 7.2 kilos per inhabitant/day — **Industrial waste**: 1.28 kg per inhabitant/day (80% non-toxic and 20% toxic). This ratio could be decreased due to the low industrial activity in the studied region — **Agricultural waste (plastic and similar)**: 0.05 Ton/ha/year of intensive agricultural land (10% in the Calderona area) **GREEN RESIDUES**: — **From forestry**: An average production of 0.25 Ton/ha/year of forest residues is estimated (based on Forestry chapter in SCSP; see Galan, 2014, 2018). — **Agricultural residues**: 1 Ton/ha/year of agricultural residues (ratio from the study Biomass in Andalusia, September 2011 by the Andalusian Energy Agency, and assuming that 60% of agricultural land in the Sierra Calderona area produces this kind of residues) — **Gardening**: It assumed that the production of garden residues/ha is similar to the one from forest areas) **LIQUID MANURE**: produced by livestock farming based on the census of livestock heads in the five municipalities included in the SCSP (source: National Institute of Statistics [INE]) and the average production of liquid manure per type of livestock unit: bovine, ovine, caprine, porcine, equine	LOW ACCURACY NO MATERIAL BALANCING

Table 1. (Cont.) Metabolic methods, application scopes, data sources and data processing used in the SCSP.

METHOD	SCOPE IN SCSP	DATA SOURCES ANDA DATA PROCESSING IN SCSP	ACCURACY IN SCSP
ENERGY Flow Accounting	Assessed in different FMAs (associated with different land uses, economic sectors and urban typologies)	**POWER CONSUMPTION**: Calculated with the data provided by the power supply companies and extrapolations. The disaggregation of the consumption between different Metabolic Functional Areas and Economic sectors was developed using standard ratios that were adjusted following the importance of each sector in each municipality. **ENERGY CONSUMPTION IN TRANSPORTATION**: not assessed **RENEWABLE ENERGY PRODUCTION**: In Náquera and Olocau there are solar farms and Náquera also has a Hydrothermal Carbonization Plant of biomass. Gátova rabbit farm is self-sufficient in electricity supply. There is no evidence that public facilities make use of renewable energy	LOW ACCURACY NO ENERGY BALANCING
ECOLOGICAL FOOTPRINT ANALYSIS	For different user/inhabitant profiles (before and after metabolic adjustments)	Profile simulation (different user/inhabitant profiles were selected and their ecological footprints were calculated after analysing their ways of living and patterns of production/consumption). The selection of profiles was based on a socio-demographic study of the Sierra Calderona and due to the need of including profiles of individuals living in different types of urban fabrics (compact towns and low-density housing estates). The ecological footprints were calculated with the application http://myfootprint.org.es through a simulation process in which the team working in the preparation of the SCSP assumed the roles of the selected profiles.	LOW due to the simulation method used to calculate the Ecological Footprints

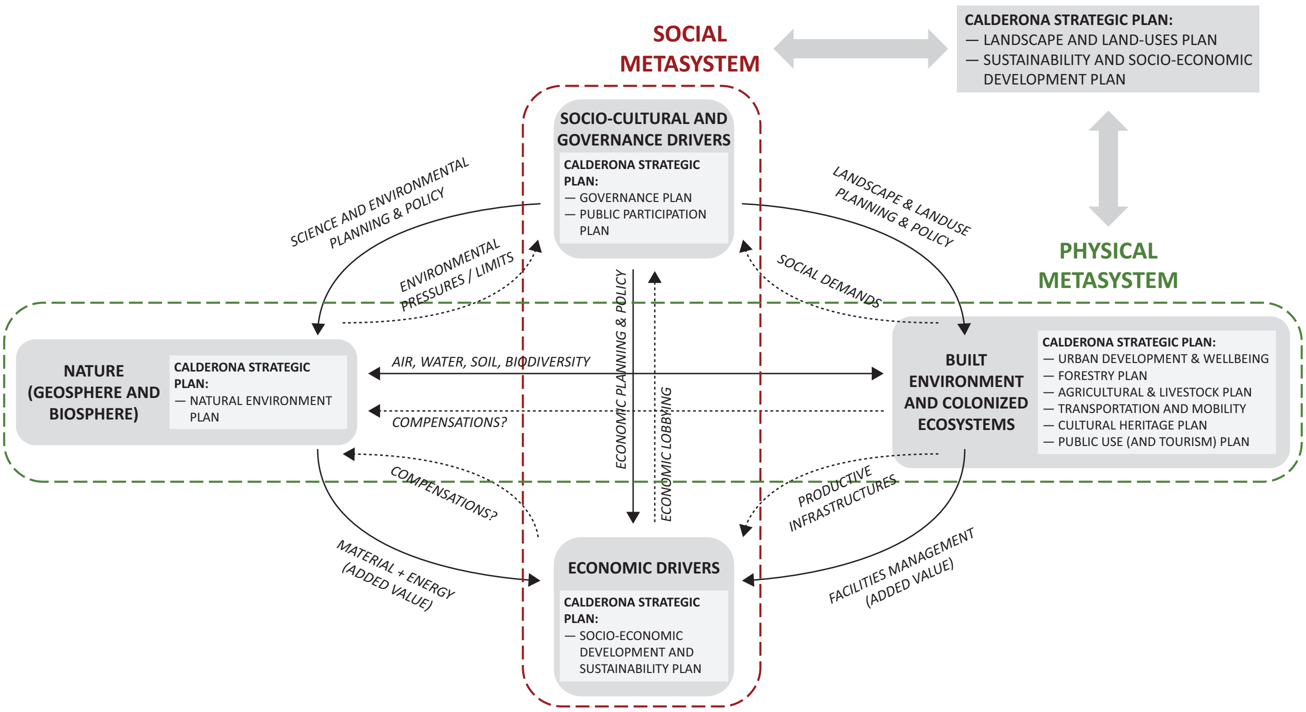

Figure 3. Integration of the social and physical metasystems in the SCSP and links with the proposed sectoral plans, landscape and land use plan, and overarching metabolic studies. Source: based on the model for resources correlations within a regional urban system in Baccini and Brunner (2012).

3.3.2. Water

Figure 4 summarises the flows of water that were analysed in the SCSP. Their magnitudes are in line with the general pattern observed in other semirural areas of the Valencian Region and Eastern Spain. The higher rate of water consumption in low-density housing estates explains the big share of domestic water used in this urban type (or FMA) even in low tourist seasons. It should be noticed that the water used in the service sector was not accounted in the water flow analysis.

The residential and industrial water treated in the local sewage plants (2,530m^3/day in low tourist season and 3,816m^3/day in high season) accounts for approximately 60% of the water entering the domestic and industrial water systems. Almost all the sewage produced in compact urban areas and industrial sites is treated. By contrast, in some housing estates, especially old ones, the use of cesspits is still common, with potential risks for vulnerable aquifers.

3.3.3. Waste

In the SCSP, waste was considered as a family of materials at the end of the metabolic loop of the system. Accordingly, a better knowledge of waste types and volumes was key to understand how the system works/metabolises/recycles and how it deals with the most problematic end-waste products. However, the waste study did not include a mass balancing revealing hidden or unused wastes.

Waste was divided into three categories. "Conventional waste" (MSW) includes domestic waste from compact neighbourhoods and low-density housing estates, industrial waste (either non-toxic or toxic), and non-organic agricultural waste and manure from livestock farming (accounted partially as sewage, conventional waste, and green residues). The "Green residues" category includes natural residues from forestry, agriculture, and gardening. "Debris waste" includes the inert waste produced in the construction sector, both in residential and industrial areas.

Since domestic waste was calculated using the same ratio for compact towns and low-density housing estates (Table 1), the amount of this type of waste varies according to the population of these two urban subsystems (or FMAs) rather than to their specific ways of functioning. However, since waste collection in low-density settlements is less efficient, it has both an extra energy and economic cost.

As displayed in Figure 5, the "Green residues" type includes residues from gardening, agriculture, and forestry and totalled up to 3,823ton/year. However, this amount varies considerably depending on the management regime of the natural and agricultural areas, which cover 65% and 27% of the studied region respectively. This calculation allowed capturing the substantial production of residual biomass that can be reused for different purposes (e.g., waste-to-energy conversion).

3.3.4. Energy (Electricity)

Power consumption in each municipality was calculated using the method and databases presented in Table 1. This consumption was then disaggregated between different FMAs and Functional Economic sectors using standard ratios that were adjusted according to the size of each sector or land use in each municipality (see Figure 6).

Since the sourced energy data referred only to electricity, other essential energy flows (e.g., natural gas, fossil fuels) were not accounted, resulting in a substan-

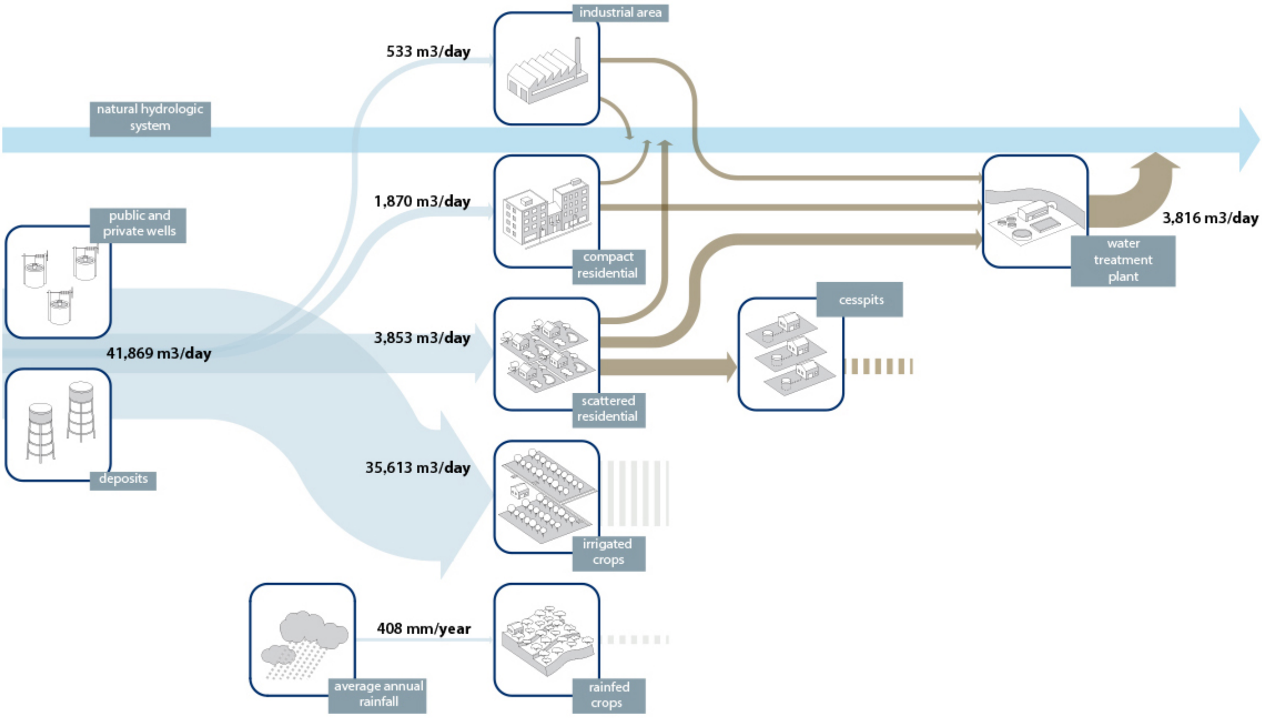

Figure 4. Main water flows in the SCSP. Source: Galan (2014b).

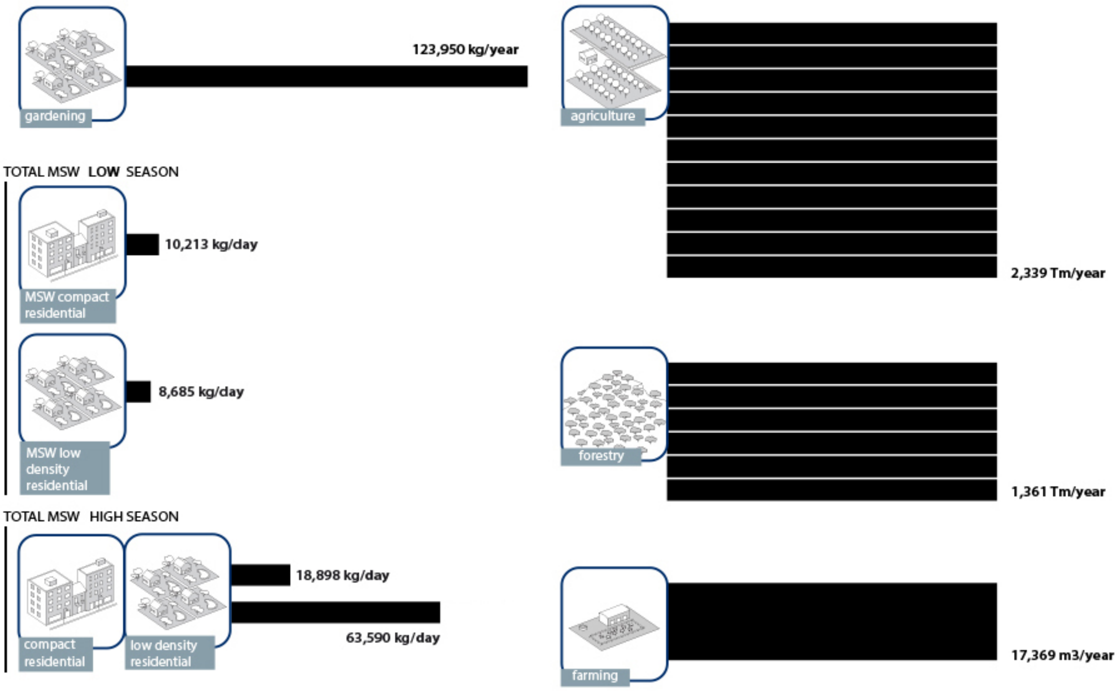

Figure 5. Main waste or residues flows in the SCSP. Source: Galan (2014b).

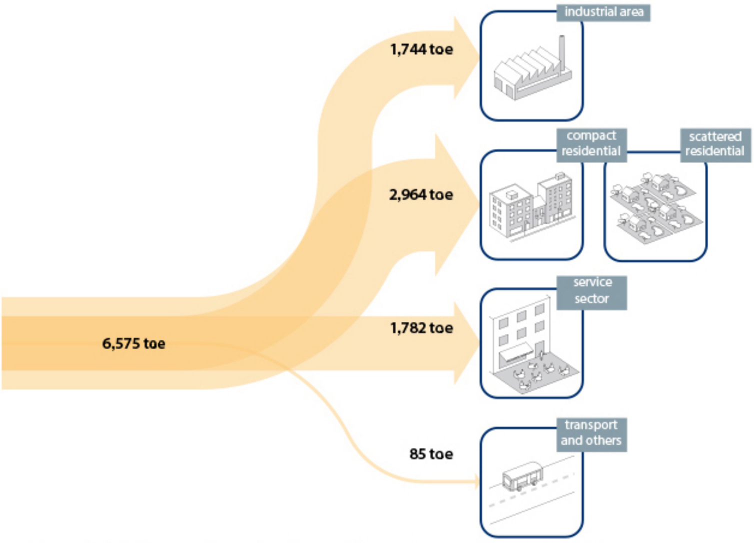

Figure 6. Main electricity flows in the SCSP. Source: Galan (2014b).

tial lack of information regarding some crucial activities like transportation.

Nevertheless, the calculation of EFs for different user's profiles (see Section 3.3.5) allowed identifying and including levels of overall energy consumption in different types of urban fabrics (compact towns or more monofunctional low-density housing estates), as well as estimating the energy-intensity of different ways of living. In addition, EFs allowed accounting other energy usages than electricity consumptions, such as fossil fuels for transportation.

Concerning the production of renewable energy, this is still quite limited in the Sierra Calderona given the administrative constraints for installing wind turbines in the elevated areas of the Natural Park. The main sources of renewable energy are biomass (converted in a CHP plant) and solar energy (photovoltaic systems).

3.3.5. EFs

The calculation of EFs was used in the SCSP to complement the study of material and energy flows. In particular, the use of EFs allowed integrating different material flows in the same analytical framework and including energy flows that were not accounted in the analysis of electricity consumptions.

The selection of a representative set of profiles for the EFs calculation was based on the sociodemographic study of the Sierra Calderona (Galan, 2014a), and resulted from the need of including profiles of inhabitants of different urban fabric types and people with different professional situations (see the first column of Table 2). As explained in Table 1, the EFs calculation was developed using a standard online quiz that divides the footprint of one individual into four consumption categories: carbon (home energy use and transportation), food, housing, and goods and service.[1] However, the use of EF-apps more adjusted to ways of living in the Sierra Calderona would have provided more reliable data.

As displayed in Table 2, significant differences between user/inhabitant profiles were observed, especially between people living in compact towns or villages and those living in low-density housing estates. Such profiles revealed two radically different mobility patterns (with longer and more frequent trips in private cars for people living in low-density housing estates), with highly contrasted mobility-related carbon footprints. As explained in section 3.4, these results were essential to inform the drafting of strategies, sectoral plans, and pilot projects aimed at reducing the transportation share of the studied EFs.

3.4. Metabolism of the Sierra Calderona: Strategies, Plans and Pilot Projects

3.4.1. Sustainable and Metabolic Strategies

The SCSP included 52 strategies/objectives for the natural environment, agriculture and livestock farming, urban environment and wellbeing, transport infrastructure and mobility, cultural heritage, tourism and use of public spaces, landscape, sustainability, socio-demography, economic development, and governance. Although the sustainability goal was embedded in all the strategies, the following five "mainstream" strategies were proposed as a means to improve the sustainability performance of the region and to optimise its metabolism. Firstly, to promote a multifunctional and efficient land use management of the region and its economy, favouring locally sourced flows of energy and materials (see Figure 7). Secondly, to monitor levels of sustainability through active engagement of the local population (e.g., use of more effective EF accounting methodologies). Thirdly, to optimise water consumption and wastewater management. Fourthly, to decrease waste production and to promote recycling and reuse of materials; and fifthly, to reduce energy consumption, increase en-

Table 2. Current EFs (global hectares) for different user/inhabitant profiles in the Sierra Calderona. Source: Galan (2014b).

	Carbon Footprint	Food Footprint	Lodging Footprint	Services Footprint	Total Footprint	Number of Earths
Average Area in Strategic Plan	11.68	17.19	4.79	9.75	43.4	2.76
Person living in a compact town and working in a nearby industrial estate	4.9	16.5	3.6	7.5	32.62	2.08
Housewife living in a compact town	5.7	14.9	3.6	7.5	31.75	2.02
Person living in housing estate and working in the city of Valencia	17.1	19.5	4.5	10.6	51.73	3.29
Part-time farmer living in a compact town and working in the local service sector	5.7	16.5	6.1	12.7	40.92	2.6
Retired person living in a compact town	4.9	12.4	3.2	6.6	27.03	1.72
Retired person living in a low-density housing estate	15.2	17	6.5	9.1	47.73	3.04
Child living in a compact town	5.7	16.5	2.4	11.6	36.22	2.31
Child living in a low-density housing estate	17.4	19.5	7.4	12	56.24	3.58
Young person studying at a university in the city of Valencia and living in a compact town or low density housing estate	9	16.5	3.6	7.5	36.59	2.33
Seasonal resident (summer)	22.8	19.5	6.5	12	60.82	3.87
Person working in the military camp	20.1	20.3	5.3	10.1	55.78	3.55
National Average	12.9	14.9	4.8	9.4	42	2.5

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[1] myfootprint.org

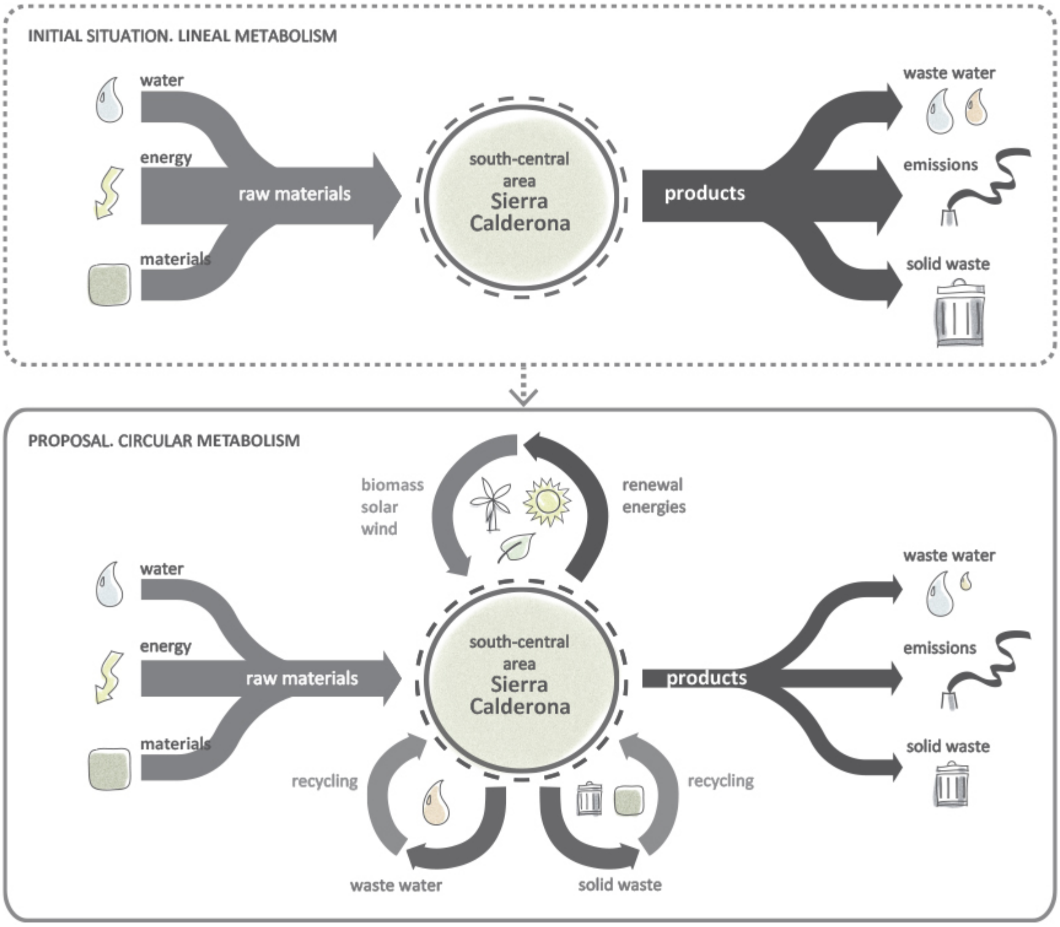

Figure 7. Overview of first-level regional "mainstream" strategies to favour transition towards a circular metabolism in the Sierra Calderona. Source: Galan (2014b) adapted from Rogers (1997).

ergy efficiency and promote the use of renewable energy (Galan, 2014b).

In the SCSP case, the use of material and energy flow accounting and EFs analysis was perceived as a tool to streamline the proposed "mainstream" sustainability strategies and adjust them to the specific conditions of each site.

3.4.2. FMAs and Metabolic Profiles

The difference between the main types of FMAs in the Sierra Calderona is illustrated in Figure 8, where "resource production" and "resource demand" are presented in a qualitative manner for different types of FMAs. Inspired by the diagrammatic representation of the "relation between urban density and productive capacity of land within a polyurban region" (Ferrão & Fernandez, 2013), the figure displays the difference between using per capita ratios or spatial ratios (m^2).

In particular, the conceptual diagram was elaborated based on the FMA's resource demand as well as on the internal production needed to maintain existing activities in each FMA. The following underlying assumptions were made:

1. Resource production: the existing level of production within each FMA needed to maintain the current functioning of the FMA. This can apply to a specific resource (water, oxygen, energy, waste recycling, etc.) or their combination;
2. Resource demand: the demand for a resource or a group of resources within each FMA needed to maintain the current functioning of the FMA;
3. The difference between resource production and demand can be described as the Resource Surplus (when positive) or Deficit (when negative).

Additionally, it was understood that the modification of flows exchanged between FMAs, according to FMAs' respective deficits and surpluses, could lead to internal adjustment of the overall Sierra Calderona metabolism.

The conceptual diagram suggests the value of applying metabolic approaches and accounting methods not only within urban areas but also across these and different types of agricultural or natural areas.

3.4.3. Regional Metabolic Model for the Sierra Calderona

This subsection presents the regional metabolic model defined for the Sierra Calderona. The model conceives

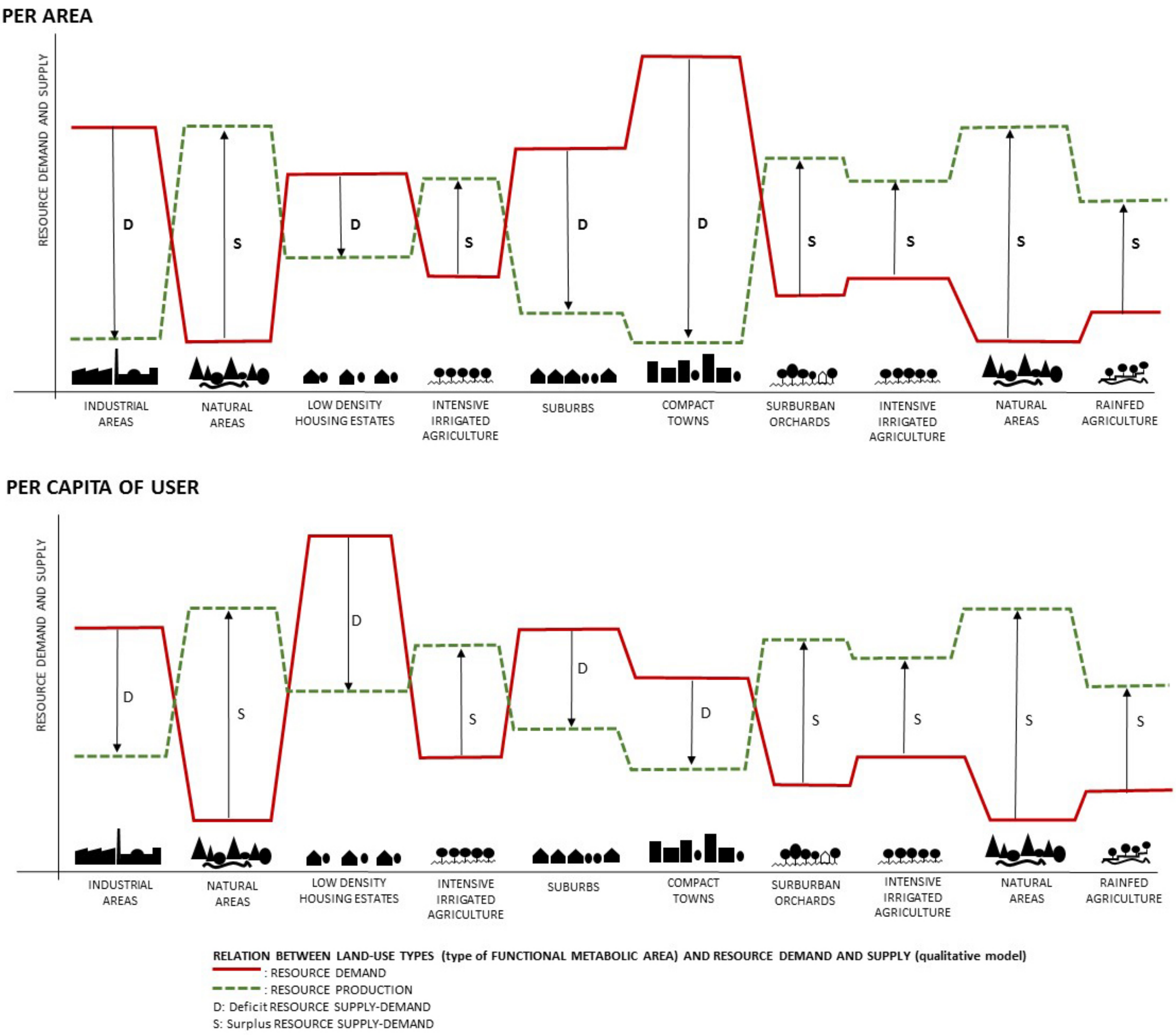

Figure 8. Conceptual diagram expressing resource production and resource demand for different types of FMAs in urban and non-urban areas of the Sierra Calderona per area (on top) or per capita (bottom).

the Sierra Calderona as a collage of different types of FMAs and considers the flows between those types of FMAs based on the metabolic assessment presented in Section 3.3 and the resource surpluses and deficits presented in Figure 8.

The proposed evolution of the regional metabolic model is based on the Sustainable and Metabolic Strategies explained previously and is aimed at exemplifying the transition from linear to circular metabolism represented in Figure 7, both at the system (Sierra Calderona) and subsystem level (FMAs). The improvement at the system level would be based on the modification of flows between FMAs. The proposed adjustments are informed by the results of the metabolic assessment presented in Section 3.2 (water, waste, energy-electricity), and the EF analysis (Section 3.3.5).

In particular, the model is structured around the five main types of FMAs and Economic Sectors identified in the region: compact urban, low-density suburban, agricultural areas, natural areas, and industrial areas. Due to their relevance to the regional economy and impact on the overall regional metabolism, the service sector and the "visitors/tourists" user's profile were also included.

Building on the results of the metabolic assessment/EF analysis, and on the suggestions provided by the sectoral plans, the following flows were considered:

1. Energy: renewable energy;
2. Waste: forest residues, agricultural and gardening residues, urban residues/waste;
3. Materials and services: forest resources, agricultural products, processed products and services, spaces for public use, public transport;
4. Workforce: use of local workforce.

As displayed in Figure 9, these flows were scored on a qualitative basis (low, medium, high) for both the current situation and future projections. In addition to flows analysed in the metabolic assessment (urban waste, forest residues, and agricultural residues, see Section 3.2), other flows were derived from the analysis of activities and land use types in the SCSP (Galan, 2014a; e.g., renewable energies, forestry resources, agricultural products, use of local workforce, use of public spaces, and public transport).

As detailed in Section 3.4.4, the model for the metabolic transition presented in Figure 9 guided the drafting of the Landscape & Land Use plan and sectoral plans in the SCSP.

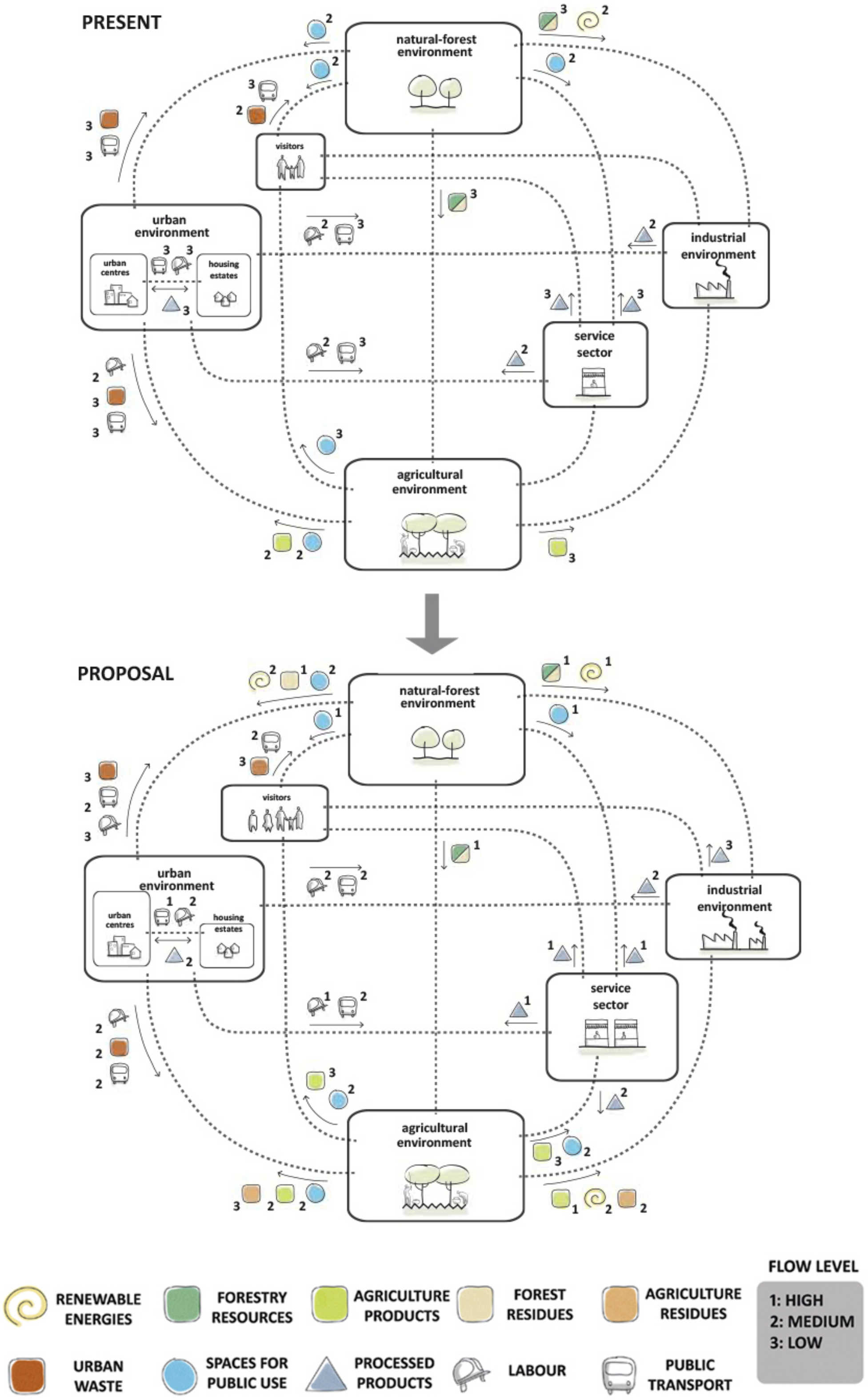

Figure 9. Regional model: Potential improvements of metabolic cycles in the Sierra Calderona region. Source: Galan (2014b).

3.4.4. Landscape and Land Use Plan and Sectoral Plans

The SCSP landscape and land use plan and the sectoral plans were informed by the metabolic assessment of the Sierra Calderona and were used to support the implementation of the strategies and model for the planned metabolic transition (Figures 7 and 9). In the national and Valencian planning system, sectoral plans (dealing with specific activities or land uses) are generally not compulsory at the municipal level. However, due to the supra-municipal character of the SCSP and the interest in exploring the interaction between activities and land uses, the SCSP included a set of sectoral plans (e.g., agriculture, management of the natural environment, urban planning and well-being, cultural heritage, tourism and use of public spaces, etc.), together with an overarching landscape and land/use plan (see Figure 2).

From a metabolic point of view, the Natural Environment Plan proposed the basic conditions for the sustainable use of the natural areas of Sierra Calderona. The Plan quantified sustainable levels for the extraction of natural resources in order to adjust resource flows exchanged between the natural environment and other FMAs (see variation of flows of forestry resources and residues, workforce, renewable energy, and people in Figure 9).

In line with this approach, the Agriculture Plan and Livestock Farming Plan defined the key lines for the sustainable transition of agriculture and farming in the Sierra Calderona. As displayed at the bottom of Figure 9, this evolution involved, in some cases, a significant change in the type and magnitude of metabolic flows towards/from other FMAs (agricultural produces and residues, organic urban waste, and renewable energy), as well as change in metabolic flows within the agricultural FMAs.

As shown in Figure 9, in the Urban and Well-Being Plan, the urban and industrial areas were at the core of the proposed metabolic transition for the Sierra Calderona. In particular, it was proposed to intensify the magnitude of some of the metabolic flows exchanged between natural/agricultural areas and urban/industrial areas (e.g., use of natural resources and agricultural products in local markets, waste processing in agricultural areas, use of local workforce in local industries or functional connections between housing estates and compact towns).

In addition, the Socioeconomic Development and Sustainability Plan, together with the Governance and Implementation Plan, defined a set of programmes and management tools to support the metabolic transition of the Sierra Calderona.

3.4.5. Pilot Project for the Metabolic Transition of the Pedralbilla-Torre de Portaceli Housing Estate

The SCSP sectoral plans included a set of pilot projects, in which the most innovative or critical aspects of the plans were applied and developed on a more detailed level. The biggest housing estate in the Sierra Calderona was selected as one of the pilot projects' areas due to the strong impact of low-density housing typologies on the metabolic performance of the Sierra Calderona and in light of the significant morphological and metabolic differences between this type of FMA/urban tissue and compact towns (see Tables 1 and 2).

The pilot project was developed on the Pedralbilla-Torre Portaceli housing estate (232 hectares) and was part of the SCSP Urban and Well-being Plan. As shown in Figure 10, the main objective of the pilot project was to facilitate the transition from a mono-functional residential area to a multifunctional and sustainable neighbourhood. It was assumed that this transition could be facilitated by: (1) promoting a strategic and controlled densification; (2) adding new functions (e.g., working

Figure 10. Conceptual proposal for the sustainable transformation of the Pedralbilla-Torre de Portaceli housing estate. Source: Galan (2014b).

places and service hubs); (3) improving the quality of the public spaces and green infrastructure at all scales; and (4) strengthening social and community cohesion.

In particular, in the pilot, it was proposed to modify the metabolic performance of the urban fabric by minimising per-capita water and energy consumption (see Tables 1 and 2), optimising waste collection/recycling, and decreasing the EFs of some of the inhabitants' profiles (see Table 3).

The proposal focused on increasing the number of dwellings by 33% (up to 2,060 units) and the permanent population by 70% (4,950 new inhabitants) while decreasing the fluctuating population by 50% (1,240 people). The expected result was a 37% increase in the urban density (up to 26.6 inhabitants/ha), as well as the creation of new public and private services and public transport hubs. The currently underused Portaceli brook was proposed as the spine of a reinforced green infrastructure, contributing to the regulation of water cycles and the provision of other ecosystem services.

Table 3 illustrates the expected change in the EFs of different inhabitants' profiles following the implementation of the Pedralbilla-Torre de Portaceli proposal. The EFs were calculated following the same method as for the user/inhabitant profiles in the whole Sierra Calderona region (Table 2). Moreover, ways of living in compact towns were taken as a baseline for the transformed housing estate (it is worth noting the convergence between EFs in compact towns in table 2 and EFs in the housing estate after the implementation of the proposal in Table 3).

4. Discussion and Conclusion

4.1. Challenges of Incorporating UM Thinking into Regional Planning

There were three main challenges in the development of the Sierra Calderona metabolic study. Firstly, its location at the edge of a metropolitan area made it particularly difficult to differentiate the metabolic flows exchanged between the system (the five municipalities included in the SCSP) and their hinterland. Secondly, the amount and diversity of urban areas in the Sierra Calderona, together with their heterogeneous levels of interaction with the natural and semi-natural environment, resulted in a complex spatial distribution of flows and a wide range of user's profiles, from self-sufficient farmers to semirural/urban inhabitants. Thirdly, the demographic seasonality due to the local touristic activities generated large fluctuations in the metabolic flows.

In response to these challenges, the SCSP concentrated on the optimisation of the internal metabolic flows within the areas/FMAs, assuming that this would result in a positive effect on the inputs and outputs of the whole system.

Secondly, the complex spatial and functional system of the Sierra Calderona was simplified through the definition of metabolic area types that were associated with FMAs or spatial metabolic subsystems. The material and energy flows of these subsystems were studied using data from national and regional sources. However, this spatial approach was complemented with the calculation of EFs for a set of representative users' profiles. This combination of methods (MFA and EF) can potentially inform sustainable urban and regional planning (Galan, 2013, 2014a).

Thirdly, the seasonality challenge was addressed by examining the temporal variation of the metabolic flows that were more likely to be affected by demographic fluctuations (e.g., water, energy, waste).

Another aspect that limited a deeper incorporation of the UM approach into the SCSP was that the regional model (Figure 9) considered only the main types of FMAs. This was due to pragmatic reasons and to the need for simplifying a complex system and reducing the quantity of data processed to a reasonable amount. A broader

Table 3. Current and expected EF (global hectares) for different inhabitants profiles in the Pedralbilla-Torre de Portaceli housing estate. Source: Galan (2014b).

	Carbon Footprint	Food Footprint	Lodging Footprint	Services Footprint	Total Footprint	Number of Earths
Permanent Resident Working in the Area (Current)	17.1	19.5	4.5	10.6	51.7	3.29
Permanent Resident Working in the Area (After Proposal)	4.9	16.5	4	7.5	32.9	2.09
Retired Resident (Current)	15.2	17	3.2	6.6	42	2.67
Retired Resident (After Proposal)	4.9	12.4	4.5	9.1	30.9	1.97
Child Resident (Current)	17.4	19.5	7.4	12	56.3	3.58
Child Resident (After Proposal)	5.7	16.5	3.4	11.6	27.2	2.37
Seasonal Resident (Current)	22.8	19.5	6.5	12	60.8	3.87
Seasonal Resident (After Proposal)	7.5	16.5	3.2	11.6	38.8	2.47

diversification of the number of FMAs and the development of a specific metabolic model for each FMA would have resulted in the elaboration of a more sensitive regional model. Given the internal diversity of both geographic and metabolic features of the region, this would have also allowed for a more accurate translation of UM knowledge into local planning. Moreover, although one of the objectives of the model was to illustrate the impact of the FMAs spatial configuration on the users' and inhabitants' lifestyles, the model fell short in capturing the cause-consequence nexus within each FMA. However, it is worth noting that the simplicity of the model facilitated the incorporation of UM inputs into the SCSP, and the study of flows between FMAs opened a pathway for future investigations.

4.2. Incorporation of the UM Results into the SCSP: Limitations of Used Methodologies

First considerations when evaluating the UM assessment approach adopted in the SCSP relate to the interplay between quantitative and qualitative methods. Although in an initial stage the SCSP included a quantitative assessment of metabolic flows, the final accounting method was influenced by the availability of datasets as well as the need to present results in a comprehensible manner for decision-makers. Thus, the material and energy flow accounting (Table 1) was not performed following the Eurostat's MFA methodology. For example, not all flows were quantified using mass metrics (e.g., tons) and the total mass balance was not calculated. It should also be noted that, due to the informative nature of the SCSP, the effectiveness of the proposed planning strategies in the real world was neither estimated nor monitored (and consequently excluded from the scope of this article).

The calculation of the EF based on alternative user/inhabitant profiles in both the overall plan (Table 2) and the pilot project (Table 3) was performed using the online tool Myfootprint (see Section 3.3.5), instead of applying more rigorous scientific methods as the one described in Wackernagel et al. (2006). It is also worth noting that the majority of tools available online to calculate EFs are based on North American lifestyles, which may significantly differ from lifestyles in other regions of the world. Finally, although the comparison between the EFs analysis before and after the high-density housing proposal in the pilot project suggests a positive impact on the UM (see Section 3.4.5), a more accurate estimation of the EFs (exiting and forecasted) would have helped to move the implementation of the project to the next stage. Overall, rather than as a scientific analytical tool, the EF concept was used as a means to communicate the effects of the urbanisation process and related externalities in a language that could be easily understood by decision-makers and planners.

In conclusion, more user-friendly and intuitive methodologies, such as the material and energy flow accounting and the online-tool based EF calculation used in the SCSP, can provide results that are more intuitive and easier to comprehend by decision-makers. Moreover, one very distinctive characteristic of the SCSP was that the author endeavoured to combine two different UM assessment methods, which allowed broadening the analysis through the specific scope and strengths of each method. For example, it could be argued that the use of the EF calculation can facilitate the integration of resource flows that are normally accounted separately in traditional UM assessment frameworks (e.g., energy, food, etc.). As such, EF analysis can represent a valuable intermediate step between more rigorous UM assessment models and planning practice. In addition, EF analysis can provide a level of information on the metabolic functioning of a system that is more informed by the "micro-scale" of the user's lifestyles (bottom-up) than by the "macro-scale" of the aggregated assessment of the whole system (top-down). In this sense, EFs can help translate UM scientific knowledge into operational tools that may be closer to those used by planning practitioners.

However, the use of qualitative UM assessment tools and their combination into user-friendly analytical frameworks should not preclude the integration of rigorous UM knowledge into planning practice. For example, scientific models (e.g., the Eurostat's MFA) can be used to validate the results of the analysis internally, before their incorporation into planning documents. This would involve more diversified working teams, in which researchers and practitioners would be able to test emerging methodologies through a multiple feedback loop. Similar experiences have been conducted within the two EU-FP7 interdisciplinary projects mentioned in the Introduction (Chrysoulakis et al., 2015; Davoudi & Sturzaker, 2017).

4.3. Questions for Future Research

Following our evaluation of the way in which metabolic data were used in the SCSP, the following question for future research emerges: Can regional and urban planning act as a catalyst for adjustments and advances in metabolic analytical frameworks? As a suggestion for future investigations, it could be argued that a two-way interrelation exists between planning disciplines and UM studies. On the one hand, UM assessments are of utmost importance when modelling different kinds of resource flows across urban scales and for compiling comprehensive sets of urban sustainability indicators. On the other hand, planning practice can provide a "proving ground" for testing the operational potential of UM assessment methods and tools in real-world settings, thereby advancing UM research in a systemic way. As seen in the Sierra Calderona case, this involves addressing weaknesses and methodological shortcomings emerging from the testing of new conceptual frameworks and modelling approaches (availability of high-resolution datasets, combination of qualitative and quantitative methodologies, as well as methods using different kinds of datasets such as material and energy flow analysis and EF calculation). In addition, planning practice can advance current black-box models, for example by facilitating a better understanding of the spatial dynamics associated with the distribution of resource flows, through concepts such as FMAs.

Explorative planning research based on the integration of qualitative/quantitative methods and spatially resolved analyses of cities and regions (as in the case of the SCSP), can help formulate new research questions for the UM scientific community and, thus, stimulate future science-practice collaborative research. Moreover, a "designerly way of knowing" (Cross, 2007) can represent a valuable complement to purely analytical or theoretical approaches in UM research. It is our conviction that collaborations between planning practitioners and UM scientists have a great potential to drive societies towards a shared understanding and achievement of more sustainable metabolisms of cities and regions.

Conflict of Interests

The authors declare no conflict of interests.

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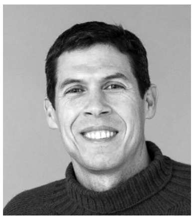
About the Authors



Juanjo Galan is Associate Professor at the Department of Architecture, Aalto University, Finland. Galan's research focuses on landscape planning, regional and urban planning, landscape design and, in a general level, the intersections between ecological and social systems. His Doctoral Dissertation explored the methodological and planning dimensions of the European Landscape Convention. The use of metabolic inputs in sustainable regional and urban planning has been a key element in his academic and research activity since 2011.

Daniela Perrotti is Professor of Landscape Architecture at Catholic University of Louvain, Belgium. Her research interests cover applications of urban metabolism models in urban planning and design, with a focus on green infrastructure strategies to mitigate energy demand and the resource-intensity of cities. Daniela serves/has served as Principal Investigator and co-Investigator for several research projects on integrated urban metabolism modelling approaches, in collaboration with local authorities and academic/industry partners in Europe, China, and South America. Daniela has published over 30 peer-reviewed papers in international journals and books.

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Article

Planning for a Prosumer Future: The Case of Central Park, Sydney

Lisa McLean [1,*] and Rob Roggema [2,3]

[1] Open Cities Alliance, Sydney, 2000 NSW, Australia; E-Mail: lisa@opencities.net.au
[2] Office for Adaptive Planning and Design, Cittaideale, 6706 LC Wageningen, The Netherlands; E-Mail: rob@cittaideale.eu
[3] Knowledge Centre NoorderRuimte, Hanze University Groningen, 9747 AS Groningen, The Netherlands

* Corresponding author

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Abstract
Rapid convergence of utility and mobility solutions enabled by data and the Internet of Things is future-proofing economies around the world, delivering liveability, sustainability and resilience, and importantly decreasing pressure on utility bills and infrastructure costs. Australians cannot miss out on the many benefits brought to families and businesses by the digitisation of infrastructure and services, not just reduced household bills but also the ability to generate income as prosumers, not consumers. Localised sustainable Next-Gen infrastructure and services are growing from within communities, creating a new class of consumer—the prosumer: where customers are more than consumers but also producers. Prosumers have the ability to generate free energy from the sun at home or office and sell the excess, recycle water and waste reaping the financial benefit, avoid the second largest household expense of a car by sharing mobility, and access shared data networks to plug in and play at little cost. Planning frameworks play a critical role in enabling a new utility prosumer future in Australia and reform of planning gateway processes is essential. This article highlights Sydney's Central Park as a best practice urban infill development showcasing how the flows of water and energy are organised to provide enhanced sustainability, liveability and resilience for the local and neighbouring communities. Central Park proves the benefits of taking a precinct approach to utility and mobility services. It shows how these benefits can grow and be exported to neighbouring buildings and existing communities, in this case University of Technology driving inclusion and affordability. Central Park also demonstrates the opportunities to drive deeper socio/environmental benefits by enabling prosumer services through low-cost access to utility services and circular resource flows. Importantly, this article demonstrates that Central Park's phenomenal sustainability benefits can be replicated at scale in land release communities, but planning reform is required.

Keywords
Next-Gen infrastructure; prosumers; sustainability; Sydney; urban infill; utility convergence; water-energy nexus

Issue
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1. Introduction

The way water and energy are supplied to households has traditionally determined the level of sustainability. Under current traditional infrastructure, higher sustainability is delivered when as little resources are used as possible. That is because they are linked to non-renewable and inefficient centralised networks such as rainfall dependent water systems and coal-fired energy networks. Using Next-Gen Integrated Water Management (IWM) and precinct-scale energy utility approaches it is possible to use resources in a highly efficiently way that meets rapid urbanisation and climate change. It means it is possible to create flows in and through the city—an urban metabolism—that is sustainable. This approach means flows can stay within a precinct enhancing the liveability, vibrancy and ecology of that community, but can also be exported to neighbouring communities sharing the benefits and in fact creating abundance not scarcity. Taking this modern approach to utilities means there is a greater resource in wastewater, in organic waste, in solar and the use of water to heat and cool. A circular, not linear, approach can ensure waste streams leaving the city can be kept to a minimum reused again and again.

This (extended) metabolism model (Newman, 1999) is capable of describing the flows that run through the city and which parameters need to be used to increase sustainability. This model is used in urban planning and design to create the strategy of the two networks (Tjallingii, 2015), in which the flows of the transport network form the framework of higher dynamic functions and the flows of the water system are related to land use of lower dynamics. This way these flows have been separated and connect to each other in the residential area. Generally, the flow of energy is linked with the higher dynamic network. However, the recent technological developments, availability in next generation data (Cavallo & Cooper, 2015) and the development of the Internet of Things (IoT) places this approach under scrutiny. Smarter, more unexpected gains, more efficient use and exchange of production and consumption becomes possible when behaviour and demand of individuals can be collected, analysed and through algorithms be turned into precision supply, smart reuse and efficient waste management.

The circular economy decouples population growth from resource use (Webster, 2017) ensuring materials and resources are not exploitable but have continuous flows of reuse and reconnection within a city precinct: reshaping and transforming matter in a new context so that everything becomes a resource and creates reusable flows that are continuously available and in abundance. Scarcity becomes redundant, and citizens have the opportunity to harvest those circular resources, use them and trade them. This contrasts with current linear urban metabolism models that prelude circularity and struggle to embrace technological developments, such as IWM, local energy generation and IoT.

For residents in Next-Gen utility precincts, this means seamless change. While there is no physical difference to customers buying local energy and water—i.e., water and energy look the same at point of use, people are participating in circular systems that put downward pressure on utility bills. Recycled water is 10 to 30% cheaper than drinking water (Flow Systems, 2018a) and has a positive property investment impact, increasing property value due to self-sufficiency and resilience (Marsden Jacobs, 2013). In addition, sustainable utilities provide a platform for greater customer awareness and participation: making them more aware of the resources they use, providing them with more information, and greater control. Being informed about your usage and having an option to use sustainable water for non-drinking uses—since, according to the Australian guidelines for water recycling (National Health and Medical Research Council [NHMRC], n.d.), Australia does not drink recycled water—provides customers with the ability to make financial benefits compared to centralised utilities providing only drinking water. It can therefore be argued the decentralised utility has a bigger stake in connecting with their customers.

The use of water and energy can be measured and organised at different scales. Though it is often thought that larger scales make the flows more efficient in operation, precinct-scale utilities are proving that not to be the case. At urban precinct-scale generation, supply and consumption of water and energy could be well balanced and, because the resources are not transported over longer distances, this scale seems to be a good level to balance supply and demand. Keeping water local for greening, preserves drinking water supplies and removes upstream and downstream augmentation requirements, driving significant financial and broader sustainability benefits for the entire network.

In this article we firstly discuss the change IoT and Next-Gen data bring to the way energy and water is delivered to households. After this context is described we identify the problem and use the example of Central Park, Sydney, how a modern way of supplying, using and recycling water and energy can be operationalised, and, how residents benefit from sustainable, data driven utilities in their precinct and building. We present the development process of the precinct, the involvement of citizens/end users, and the technical aspects related to the flows of water and energy. We end with some recommendations and conclusions.

2. From Consumer to Prosumer

Big Data, algorithms and the IoT, and the translation of these data-technologies in propositions for smart cities is changing the way we look and plan our cities. It is also changing our utility and mobility models to be precinct scale and more sustainable. The siloed approach to utility infrastructure solutions and services is moving aside for converged solutions where waste and water are energy, they can heat and cool, and power mobility all within a single neighbourhood. Technological advancements enabled by IoT are also allowing people to own their infrastructure to be producers and consumers of energy, water, mobility and data. The rise of the prosumer: the consumer and producer will deliver big changes to our current utility markets. It is particularly important the vulnerable and disadvantaged who are most impacted by rising utility costs benefit directly from prosumer opportunities. This article looks at the consequences and opportunities these new technologies bring to the creation of more sustainable and user-beneficial flow-systems of water and energy. This is delivered by a new utility model that is precinct-scale not centralised and converging—bringing together water, energy, waste and transport, and has at its heart the prosumer (Figure 1).

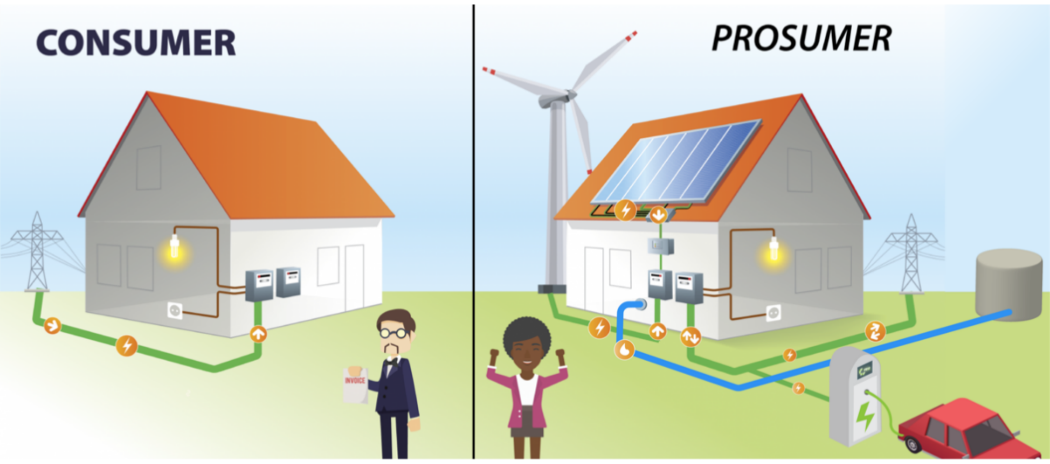

Figure 1. Consumer and prosumer (Open Cities). Source: adapted from US Department of Energy).

In water, there is now a growing movement—including industry, councils, research organisations, utilities and peak associations[1]—delivering critical transformation to decentralised precinct-scale sustainable water management (Watson, 2017). These decentralised water schemes embrace the principles of IWM (UNDESA, n.d.) and represents a new era for water in Australia.

In energy, the emergence of microgrids, Virtual Power Plants (VPPs) and local energy generation from tri-generation, solar with battery storage and organic waste to energy are driving a parallel shift to decentralisation. Unsurprisingly there are deep and significant benefits to people in being self-sufficient and not relying on costly, unsustainable coal-dependent energy. Retirees are Australia's fastest growing category of prosumers—as they rush to cover their homes in solar. Rooftop solar installations are at record highs. Almost $700 million could be saved annually by enabling decentralised stand-alone connections instead of the mandated conventional "grid connected" services (ENA & CSIRO, 2018).

Like the transition to decentralised water, decentralised energy is also challenging centralised thinking. Significant reform of policy, new regulatory arrangements are required. An unlevel playfield exists where all policy, legislation, regulation and tariff structures face and support last century centralised solutions. New regulatory arrangements are required as a matter of urgency to ensure communities, businesses, households and farms are able to be self-sufficient. Customers are exiting rapidly from the grid challenging the aging business models of centralised energy utilities which assume incorrectly all future growth belongs to them. If customers leave coal-fire powered networks in pursuit of their own free renewable rooftop solar, energy costs are immediately increased for the remaining customers to cover the deficit. This is clearly the wrong response and will only drive more people off the grid. More innovative and affordable network services that reward and incentivise prosumers to sell their own energy back to the grid and enable microgrids is a sensible outcome promoted by industry (ENA & CSIRO, 2018). The opportunity for the most vulnerable in the community to get free energy from the sun, to recycle their water and save on utility costs—is an important component of a transition.

There is no doubt new developments provide significant opportunities to implement Next-Gen infrastructure and services with the potential to embrace innovation and leap frog to new technologies. Urban infill and land release developments are driving different combinations of Next-Gen infrastructure and leveraging different financial drivers. For land release, deploying local renewable energy and recycled water is saving developers millions in upstream and downstream augmentation costs including upgrades to centralised drinking water and wastewater infrastructure or new substations. Here, these solutions can be deployed within the footprint of the development saving capital costs and land holding costs because they are faster to roll out and avoid the need for construction across multiple land holdings—as is required for centralised water or energy infrastructure. Importantly this demonstrates to planners how cost-effective Next-Gen sustainable water and energy is for new homes and developments—and why action now is required so another generation are not locked into high utility costs with no infrastructure or services to break away from rising costs.

In urban infill communities like Central Park where augmentation savings are limited there are growing examples of cost efficiencies from combining water and energy. For example, recycled water can extend the life of air coolers because the minerals and salts have been removed from the water as a result of Reverse Osmosis (RO; Saleh, Elhassan, & Abdalla, 2015). This practice occurs at Central Park Sydney—where the recycled water facility provides a mineral-free RO water quality specifically for air cooling. Local recycled water can also be used for heating and cooling, preserving rainfall dependent drinking water and removing the need for air conditioning units. Central Park is also proving the benefits of this approach and is now sharing both recycled wa-

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[1] See, for instance: anz.smartcitiescouncil.com; www.asbec.asn.au; new.gbca.org.au; www.opencities.net.au

ter and chilled water for cooling with its neighbours—the University of Technology Sydney (UTS). See Central Park case study below.

2.1. Energy

IoT technologies deliver real time responses to energy generation and enable detailed mapping of fluctuations allowing for the deployment of more renewable energy for example in wind and solar. IoT technology is being integrated in utilities to effectively harvest solar energy locally (Nonnecke, Bruch, & Crittenden, 2016). It has a critical role to play in connecting infrastructure while cities wait for the deployment of 5G networks which will become widely available over coming years. IoT is enabling efficient management of energy sources that may be remote from each other by connecting and aggregating different energy resources for example microgrids and VPPs (AEMO & Energy Networks Australia, 2018).

Cities are readily making use of local renewable resources and not coal—or gas-powered power plants because "smart grids" are introduced as a distributed system with the help of IoT. When the demand for energy is high the normally used centralized power plants often use less efficient and polluting fossil resources. A distributed local energy system, with machine-to-machine data exchanges "decides" on the use of which local renewable resources, can provide the energy needed during periods of high demand or during a power outage and save energy because they are more efficient than a traditional grid. The data provided by such smart grids is more detailed than automatic meter reading, better known as AMR-systems hence can account for sudden consumption changes by residents and allows utility companies to manage their systems more accurately. A so-called smart meter in the house makes it possible to collect user data real time instead of reading out monthly totals and opens up the options to remotely disconnect a client and control the availability of the service in an area or even for a specific house (Oracle, 2009). Due to the granularity of the collected data through Internet, a utility company can raise its energy efficiency and savings. Home-owners can get access to their actual energy-use through an in-home display, better known as IHD, which shows precisely when and how much energy the people living in the house use. This could have a small but significant impact on the amount of energy people use. The Environmental Change Institute at Oxford found that direct feedback through a smart meter reduces the use of electricity by 5 to 15% (Darby, 2006). The utility company HydroOne in Ontario conducted a real-time feedback study amongst its customers and found a reduction of 6.5% of their aggregate use of energy (HydroOne, 2006). Another study focusing on people's behaviour found that the in-house display, providing real-time use and costs of energy, reduces the use by 11 to 14% (Jessoe & Rapson, 2014). It is therefore necessary that researchers, vendors and the utility companies collaborate to invent the most effective smart meters upon which consumers will base their actions.

These tools, to be used by individual consumers, carry the potential to reach a high level of energy savings hence deliver substantial improvements for the sustainability of urban neighbourhoods and their energy systems. The monitoring of heating and cooling, lighting and energy use in general facilitated by IoT technology is optimising energy efficiency and providing building managers with data on strange extreme usage patterns or local disconnects in the system making it easier and faster to act when there are system failures. Homeowners have the opportunity to track their current and possible reduction of energy used through "retroficiency"—making the benefits accessible to new and existing communities. Software programs can identify where and how energy is wasted through instant analytics of the data collected. The recognition of usage patterns when a building is heated or cooled can be automated using machine learning and make it possible to remotely adjust and customize the thermostats of customers. The use of intelligently placed sensors provides information on the times a building and its individual rooms are in use, the demand of lighting and the desired temperature in specific areas of a building and can automatically turn of lights and HVAC, reducing the costs on energy not spend in empty or unused spaces in a building. Consumers and companies can make use of hardware indicating the potential choice for different renewable energy providers, allowing them to switch to renewables more easily. IoT can also calculate the most optimal timing when appliances such as washing machines can be best used given the availability of renewables offered on the grid. For instance, the charging of electric vehicles (EVs) can be programmed to times when renewables are available.

2.2. Water

The 52,000 water utility companies in the US together lose about 2.1 trillion gallons of treated water because their infrastructure is leaking (Adler, 2015; Forer & Staub, 2013). Up to 15% of Houston's water was lost in 2013 as result of leaking pipes (Adler, 2015). Remote sensors, placed in water infrastructure can monitor waterflows and identify leaks, making the water pipes "smart". The IoT can reduce the water pressure in the system to the minimal required levels, resulting in less water being used. When the entire water distribution system connects these sensors with the central pumping station the water can be accurately regulated, minimizing the amount of water in the system, reducing the water lost through leaks and reducing the pumping electricity. Pipe bursts and other sudden fatalities in the system can be quickly identified and repaired as the sensors are distributed throughout the network (Adler, 2015). This way, the IoT can prevent loss of water and the amount of waste water and does so much cheaper than the reconstruction of a whole nations water network would cost (Tilley, 2015).

Similar to the smart meters in the energy system, the water consumption of individual customers can be recorded and offer both the home owner as well as the water utility company the opportunity to drive improved water management outcomes (Australian Government Initiative, n.d.). Water system managers in centralized water utility companies could easily identify leaks in homes or offices. Individual home owners gain access to the information of their water usage and can detect a leak when the smart meter never indicates zero use. Leaks in the water system in businesses can be found by applying algorithms provided by software vendors. Smart meters provide high granularity and real-time information about the use of water by which the water utility company can detect resource-wasting, illegal behaviour or non-essential use of water in sensitive climatic conditions (Finley, 2015). The higher granular data smart meters provide allow customers to understand their different water uses, give them the opportunity to adjust their consumption patterns, and reduce their costs of water use.

IoT has importantly enabled a new water management approach. Local, precinct-scale IWM systems, such as Central Park, can be run remotely from a laptop anywhere in the world. Complex water treatment approaches such as Membrane Bioreactor (MBR), Ultraviolet (UV) and RO are easily built and operated—for example in the basement of a residential building (Figure 2) or among a land release community. Technological advances are delivering smaller more effective kit that can be deployed in many more locations and integrated into the community. These systems are safer and more reliable because they are IoT-enabled and can communicate through SCADA systems from machine to machine, and to the utility operations manager. Wastewater management and drinking water management can all be brought together in a highly efficient and localized way thanks to IoT.

Centralised water utilities are struggling to meet the demands of rapid urbanisation in a cost-effective way. Next gen IWM utilities licensed under the Water Industry Competition (WIC) Act and councils are highlighting the limitations of ageing centralised water utility approaches (New South Wales [NSW] Consolidation Acts, 2017).

Building these systems in new developments can in fact speed up land release and ensure resilience and self-sufficiency—this has been demonstrated in schemes that implement pressure sewer systems instead of gravity sewer systems (Flow Systems, 2016) Pressure sewer systems utilise smaller more agile pipes that can be deployed in the footprint of the approved development at more shallow depths. Avoiding lengthy infrastructure and planning negotiations required to build centralised infrastructure and speeding up land release. "Local water innovation is providing cost-effective alternatives to BAU while driving more affordable housing in growth areas. The use of recycled water can reduce water bills by around 10 percent. IWM and recycled water are speeding up land release in NSW by 5 to 7 years. The Gables Estate in North Box Hill has commenced home completions this year when BAU delivery would have been post 2025" (IPART, 2018).

The costs of servicing centralised water infrastructure are impossible to quantify as Sydney Water, for example absorbs its costs across its postage stamp pricing and subsidies servicing for new growth. Industry has called for more transparent data from public utilities on both costings and locational servicing strategies. Meanwhile developers and utilities implementing Next-Gen solutions keep cost savings confidential. However, water augmentation for new land release can be as much as $AUS100M depending on the location—centralised drinking water and wastewater augmentation with upgrades to pumping stations and centralised infrastructure are costly and gold-plated. These costs are inflating

Figure 2. Central Park Plus: The world's biggest recycled water centre at the basement of a residential building. Source: www.centralparkplus.com.au

customer bills and putting unnecessary upward pressure on utility bills. Water and wastewater bills are set to rise to $2500 by 2040 simply due to the rising capital and operating expenses of centralised water utilities (Infrastructure Australia, 2017).

In the case of North Box Hill, the centralised water utility Sydney Water would not have been able to service the development for five to seven years—estimating land holding costs to developers over this time would sit in the millions. On the other hand, a recycled water centre could be constructed for $15–25 million in a land release development. The infrastructure on the ground can be installed within the precinct very quickly (12–18 months) and the local infrastructure required by the household to connect to a local recycled water centre is cheaper than a rainwater tank but delivers more resilient and reliable water supply (Flow Systems, 2018b). For urban infill IWM there are limited augmentation savings. Here regulatory requirements to connect to recycled water drives more innovative outcomes such a Central Park but also Parramatta City which has amended its Local Environmental Plan (LEP) to require high water savings (Parramatta City Council, 2016).

Reclaiming storm water is a necessity specifically for areas with increased or peak rainfall. The IoT is capable of combining information regarding the actual weather, short-term weather predictions and capacity analysis of available storage spaces to allocate the rain water surpluses real-time to different locations. In contrast, areas with a dry climate and less rainfall would need to store stormwater as much as possible. The IoT can provide the information to finetune sluice positions to increase the amount of water stored, based on accurate weather predictions and the current water levels in canals and creeks (Adler, 2015). The cleaning of wastewater and its reuse as well as sewage treatment, essential in areas with a limited freshwater resource can be upgraded using the IoT. Online data and information systems are able to identify and provide data instantly to operators in case of hazardous chemicals or the appearance of pathogens in the water. Because wastewater has both inorganic as well as organic components and pathogens mixed in its complex system, a quick response is needed to identify, adapt and respond to a progressing and constant changing of the water quality in the waterflow. Sensors and devices use machine learning algorithms to immediate adjust the treatment of wastewater whenever required hence increase its effectivity.

The IoT and the collection of Next Gen data is also delivering new utility models capable of bringing together previously siloed utility systems. The water energy nexus (US Department of Energy, 2014) is opening up exciting leaps in utility innovation that benefit customers. As a result, utilities are getting closer to households and households are liked to precinct networks. An intensive communication exchange occurs, at the household level and at a larger-scale where monitoring and real-time adaptation brings together previously siloed systems, and of course interpersonal contacts between utilities and customers. Prosumers are increasingly playing a more important role, which in turn is driving utilities to develop inclusive plans for participation which enables them to change their behaviour. This trust and reliability can be further enhanced as Next Gen data and IoT contribute to realising sustainability (Nonnecke et al., 2016).

3. Problem Statement

Despite the rapid developments in data-science and the IoT, many Australians miss out on the many benefits brought by the digitisation of infrastructure and services to people, families and businesses—not just significantly reduced household bills (City of Sydney, 2018) but the ability to generate income by being prosumers not consumers (European Commission, 2017). Localised sustainable infrastructure solutions and services are growing from within communities, creating a new class of consumer—the prosumer: where customers are not only consumers but also producing resources. For instance, they have the ability to generate free energy from the sun at their home or office and sell the excess, recycle water and waste reaping the financial benefit, avoiding the second largest household expense of a car by sharing their mobility instead, and accessing free shared data networks to plug in and play at no cost. Large siloed command and control centralised infrastructure approaches are more than 75 years old and not suited to the changing data-led economy. It is too expensive, it is inefficient and cannot deliver sustainability. Centralised linear approaches to water and energy remove resources from communities—stripping them of water needed locally to green and address heat island effect. For example, Sydney produces enough wastewater to fill Sydney Harbour every year while Western Sydney is dry and requires water for greening, for features and to mitigate heat island effect. Centralised utilities business is unable to make recycled water cost effective due to regulatory constraints such as ring-fencing which prevents revenues from drinking water or waste water to be used for recycled water infrastructure. Additionally, there is no incentive for centralised providers to reduce drinking water sales (Watson, 2017). Transitioning to 21st century energy, mobility, waste and water businesses and services is urgent and essential, moreover beneficial. Significant rethinking and modernising of government policy, legislation, regulation and market settings needs to occur. A vision for this future infrastructure state needs to be created and targets set to make the transition rapidly. It is essential that innovation and decarbonisation are placed at the core of this transition. Localised utility and mobility providers require a seat at State planning tables and competitive markets need to be established for new business models and solutions that better meet peoples' needs.

As the market seeks to embrace and implement new utility approaches, it has become apparent that a number of NSW potential development sites are being constrained due to the current Gateway and land release processes which only allow "public authorities" to participate in the planning proposal. Incumbent "public authorities" traditionally consider centralised non-sustainable utility solutions—big pipe in, big pipe out. Alternative decentralised and self-sufficient sustainable solutions by non-government utilities are currently not appreciated, understood or considered.

Increased participation by licensed Next-Gen utility providers in the planning and implementation of land use change across NSW is critical if the State is to reap the benefits of sustainable precinct servicing. Old thinking and servicing solutions for land release are locking out communities from achieving more innovative solutions that future proof homes and buildings and drive down costs.

By planning and developing in partnership with licensed utility providers, land and housing supply can be increased to the benefit of stakeholders and without burdening State finances. Innovation and change can be implemented in NSW through the development of strategy and regulatory changes (Flow Systems, 2018c). Amendments to the Environmental Planning and Assessment Act are necessary to provide "public authority" status to water and energy utilities providing decentralised solutions. At the moment, only centralised utility providers are given public authority status to provide services to new growth, so when more innovative outcomes are sought by developers or councils only Business As Usual (BAU) default servicing is enabled under planning gateway processes. Instead, Next-Gen licensed water and energy utilities should also be given public authority status. This change will open the market to urgent reform, enable greater competition and innovation and deliver significant prosumer benefits to families and businesses.

4. Central Park, Sydney

Central Park (Figure 3) has taken its many stakeholders with it in the creation of this world-leading sustainable precinct. This journey has always challenged stakeholders whether they be investors, developers, contractors, utilities, government or the community, to be more sus-

Figure 3. Central Park, Sydney. Source: www.frasersproperty.com.au

tainable and do things differently. In the end this approach has paid off: It has influenced the market, challenged linear, centralised utility approaches while delivering circular water and energy flows to the community that are now so efficient, they are expanding to neighbouring buildings and communities. Central Park in Sydney is showcasing how the local involvement of future residents and stakeholders can influence design, and how the flows of energy and water can be successfully organised at a circular precinct-scale, not the linear centralised approach of the past which fails to value our resources.

4.1. The Planning and Design Process

In 2004 Australand, the original developers of the former Carlton United Brewery site, were not granted development approval by City of Sydney Council following some negative community responses to the Master Plan. The site was then sold to Frasers Property who went on to deliver on the aspirations of the community and Council. The site was called in by the State Government under State Significant legislation and granted approval in 2009 with more open space, larger floor area, trigeneration and the objective of five green stars (De Manincor, 2014). Once development consent was achieved, the developers began partnerships to secure the higher sustainability aspirations including what is now the world's largest recycled water system in the basement of a residential building (Flow Systems, 2018d) and one of Australia's largest mixed-use tri-generation facilities (Figure 4)—now exporting energy to the neighbouring UTS (Clarke, 2016) to deliver Australia's first district energy sharing project. What was not known at the time was how this new approach to utility infrastructure would both set a precedent for best practice but also challenge centralised water management practices and regulations and market settings including the wholesale water prices.

4.2. Involvement of Citizens and End-Users

The City of Sydney's 2030 Vision provided Mayor Clover Moore with a sustainability mandate to push for higher community and environmental outcomes. Nine months of community engagement resulted in the City's flagship 2030 strategy (City of Sydney, 2017a) to create a more sustainable city and the conclusion of one of the most comprehensive community consultations in the City's history. Thousands of residents, businesses, community organizations have an overwhelming vote for a "greener more international and a better-connected city" (City of Sydney, 2013). This consensus-building approach won the City community buy-in to create a bold vision and set transparent targets to meet that vision.

The appointment of Flow Systems as the Central Park utility provider brought with it a more personalised approach to customer engagement. Flow's Central Park Plus customers became the first in the State to receive monthly water e-bills. Believe it or not, most States including NSW were still on quarterly paper water bills when Flow switched-on its services. The Central Park community benefitted from not only monthly bills to reduce bill shock but also paperless ones. They also learnt that a new circular flow of water meant they needed to be careful about what goes down the sewer, kitchen or bathroom sinks. This respect has fostered a new under-

Figure 4. Cooling towers of the Trigen-plant. Credit to Shane Lo.

standing of sustainability and resource use. Citizens have also seen enormous global interest in their precinct—it is winner of more than 30 awards and runner up or shortlisted for another 60—the precinct proves that money does grow on trees: the magnificent green walls are powered by recycled water and drive up property value (Central Park Sydney, n.d.)

4.3. Technical Features

To achieve the Green Star sustainability targets, Frasers sought a decentralised local energy solution in trigeneration, local recycled water solutions and green walls. It partnered with Australian leaders in sustainable utility solutions and green infrastructure, including Flow Systems, Enwave and Junglefy. In doing so, Central Park became Australia's first water and energy multi-utility supplying sustainable services to 5,000 residents, 15,000 workers and 65,000 square metres of retail and commercial space in the 14 buildings at Central Park, through the thermal energy, and embedded electric and recycled water networks. It has also since developed the ability to export the benefits to the neighbouring UTS buildings, with pipes constructed under the busy Broadway Road to a new UTS building, carrying chilled water for cooling and recycled water for air coolers. Central Park is not alone, as at the other end of Sydney city centre, developer Lend Lease has delivered the Barangaroo sustainable precinct and, working with Flow Systems, the City of Sydney has the same vision for its Green Square development (City of Sydney, n.d.) just ten minutes to the Sydney Kingsford Smith airport. Precinct-scale management of water and energy keeps resources locally for greening to reduce heat island effect, improve air quality and raise property prices, and for self-sufficiency: the ability to reduce utility costs with more efficient energy infrastructure.

4.3.1. Water

The Next-Gen approach to water management within Central Park was outsourced to Flow Systems who set about establishing a globally-leading innovative solution that was resilient, sustainable and would put downward pressure on the cost of water. It resulted in the construction of a 1ml/day sustainable water recycling facility and local water network spanning the site. This is an IWM approach collecting multiple water sources of varying qualities, whilst creating several water supplies to meet the needs of the community. Australian laws prohibit the drinking of recycled water in nearly all jurisdictions, although some indirect potable reuse schemes exist. Recycled water can be used for toilet flushing, clothes washing, irrigation, fire-fighting, use on vegetable gardens and water features (Environment Protection and Heritage Council, NHMRC, & Natural Resource Management Ministerial Council, 2008). This still represents an opportunity to reduce water consumption in a drought-stricken country like Australia by up to 70% (Flow Systems, 2017). A recycled water facility of that size had never been built before in Australia, or the world. It changes how Australia had managed and serviced its water for the past 100 years, it challenged industry's centralised thinking and along with it the 75-year-old business model of Sydney Water and the market settings, supporting those approaches.

The Central Park sustainable water centre required its own planning and design processes. Innovative State legislation, the WIC Act, licenses private companies and councils to be water utilities generating the highest quality water services including drinking water and wastewater. Introduced following the Millennium Drought (Bureau of Meteorology, 2015) as a drought-proofing measure in 2006, the WIC Act was set up to catalyse greater water innovation and to increase recycled water schemes in the State. The Central Park project was the first full-service WIC Act licence (IPART, n.d.) in NSW and many learnings were required to construct the water recycling facility tanks and filtration equipment in the basement of the Central Park One residential building and the precinct network.

The WIC Act regulations were passed by the NSW Parliament in 2008 and have resulted in the development of a number of world-leading recycled water schemes, including Central Park, Barangaroo (Barangaroo Delivery Authority, n.d.), Discovery Point (Discovery Point Water, 2018) and Pitt Town (Pitt Town Water, 2018). Flow Systems set up a local community utility Central Park Water which was granted a WIC Act licence allowing it to retail water and authorising it to operate a network. WIC Act companies are subject to the same licensing requirements as Sydney Water. IPART and the Minister for Natural Resources, Lands and Water oversees the administration and operation of private water licences. Flow Systems designs, builds, manages and operates its sustainable water centres, directly billing customers for all waste water services—drinking, recycled water and wastewater. It is a wholesale customer taking drinking water at the gate of the precinct. Precinct approaches take large water-using communities and reduce the water consumption dramatically. At the gate of Central Park, a 50% reduction of drinking water is realised.

At Central Park there are seven water sources, including (Figure 5):

1. Rainwater from roofs;
2. Storm water from planter box drainage and impermeable surfaces;
3. Groundwater from basement drainage systems;
4. Irrigation water from all green walls;
5. Drinking water from the public water main;
6. Wastewater from all buildings within the Central Park community (from sewage, bathroom, laundry & kitchen);
7. Sewage from an adjacent public sewer (sewer mining protocols were established with Sydney Water regulator).

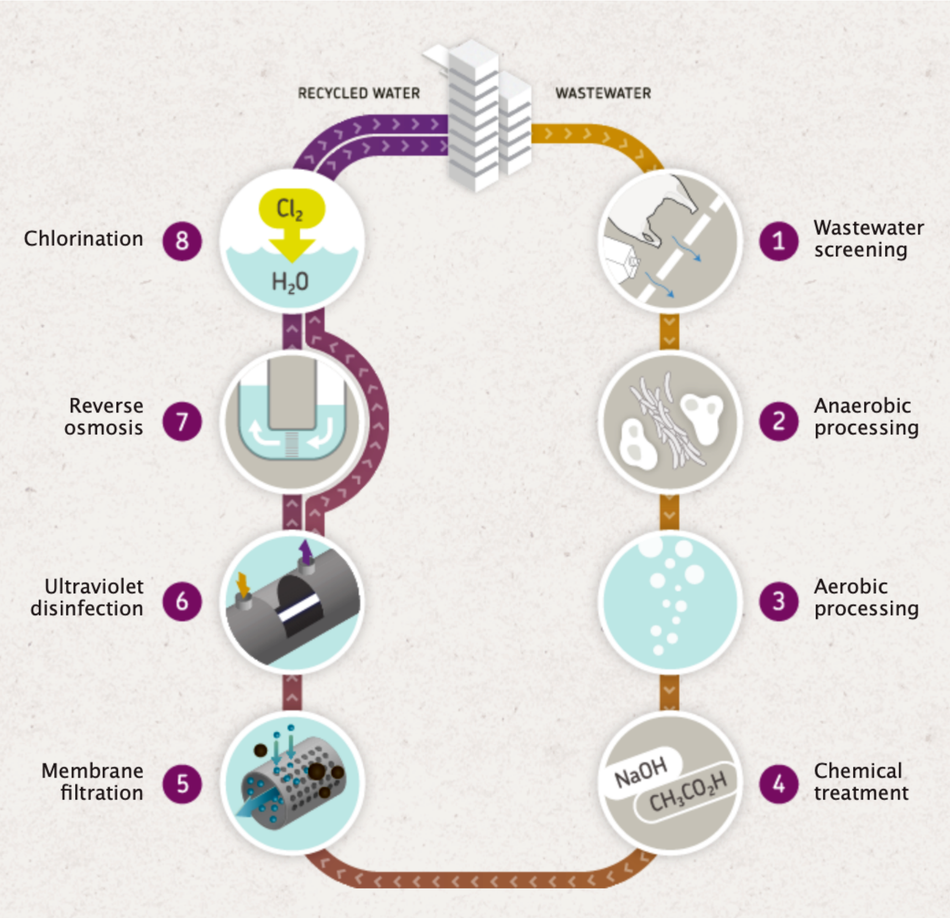

Figure 5. Central Park Plus 8-Step purification process. Source: www.centralparkplus.com.au

Wastewater is purified to the highest Australian standards undergoing eight purification processes including MBR, RO and UV treatment. Multiple sustainable water infrastructures within the precinct deliver three water qualities: recycled water and drinking water to households, shops and commercial space, and recycled water for air chillers. Given that Australia does not drink recycled water, dual reticulation is required to separately transport the drinking and recycled water. Households use up to 20% of water for drinking and cooking, another 30% for showering and bathing, and for the remaining 50%—toilet flushing, washing machine use, irrigation, green-wall watering and air cooling—it is possible to use recycled water. The sustainable water centre is built over four basement levels (Figure 6). Its technology can be completely controlled remotely from a laptop anywhere in the world. The facility requires minimal space, does not smell or make any disturbing noise. Every year water recycling technology becomes more efficient, smaller in size and more cost effective—confirming the need to shift to precinct-scale approaches.

4.3.2. Energy

Brookfield took over the Central Energy Plant at Central Park and it became operational in 2013. It is expected to produce 2mw of sustainable energy and reduce greenhouse gas emissions by 190,000 tonnes over the 25-year life of the plant—the equivalent of taking 2,500 cars off the roads each year for those 25 years (Central Park, 2013). Designed to run on natural gas (this technology can also use bio-fuels) it produces low-carbon thermal energy and also heats and cools the homes, offices and shops across the precinct, using water through heat exchanges. The centre also supplies low-carbon electricity to the multi-storey Clare Hotel and the mixed-use Brewery Yard building next to the Central Park precinct. Using water for heating and cooling can be 98 times more efficient than coal-fired power—with reduced emissions (Energy Efficiency Council, 2015). Apartments and shops no longer require air conditioners, as the highly effective network uses water to heat and cool. Since its construction in 2013, the facility has expanded, using thermal pipes to connect the central thermal plant to the neighbouring UTS, helping it reduce greenhouse gas emissions by around three per cent or 1111 tonnes annually (Clarke, 2016). Technologies such as solar are today more cost-effective in many cases in precincts than trigeneration. Coupled with batteries there is now greater accessibility for precincts to participate in a sustainable energy future.

There is also a significant potential role for organic waste to energy at Central Park. Flow Systems has part-

Figure 6. Central Park One. Source: www.frasersproperty.com.au

nered with the City of Sydney and UTS Institute for Sustainable Futures to quantify the benefits of aggregating organic waste from the recycled water process with food waste from restaurants and precinct businesses and apartments. The report has found apartments providing their organic waste to Anaerobic Digestion processes producing biogas could get as much as 20% of their electricity needs met or 50% of their hot water needs met. This trial, in its infancy, is demonstrating significant promise (Turner et al., 2018).

Central Park is also home to a superpod of car share vehicles. GoGet has Australia's largest car share depot with 44 car-sharing vehicles in under and above-ground parking lots (GoGet, 2018). As Australia transitions to fleet electrification the value of solar spill or local renewable sources such as biogas will increase to provide an affordable renewable local energy source for vehicles. These examples are proof of the convergence that is occurring between utility and mobility infrastructure and services.

4.3.3. Precincts

Exporting the benefits of precinct power and energy is a critical discussion for cities as they attempt to manage growth sustainably and ensure there is real downward pressure on utility bills. "If we are going to enable a low carbon future it will be critical that we learn how to transition existing urban systems ageing water and power infrastructure to flexible, resilient and sustainable networks" (Swinbourne, Hilson, & Yeomans, 2016). Existing communities that leverage new precinct developments with Next-Gen infrastructure innovations are expanding the benefits to their communities. Research and global best practices demonstrate that precincts with local water and energy solutions has lowered utility costs and carbon reduction. It's not just the technology, but the new business models that are allowing a transition to the future. The past decade has seen a shift away from single building water and energy innovations to precinct-scale. Here the ability to aggregate multiple revenue streams from water (drinking, waste, trade, sewage) and energy enables more creative business models that stack up in precincts of 1000 or more.

4.3.4. Green Finance

Finance for the trigeneration facility came through an innovative approach using an Environmental Upgrade Agreement (EUA; City of Sydney, 2017b). Frasers and the City of Sydney signed the $26.5 million agreement in 2013. It was the City's first agreement. Also known as Building Upgrade Finance, this approach to securing capital for commercial building improvement projects—and enabled owners and tenants to secure a benefit from operating buildings that are more sustainable and efficient. The City of Sydney offers EUAs to building owners with a lender who advances funds for the upgrade works. The loan is then repaid by the City's existing rate collection process. This is an environmental upgrade charge (City of Sydney, 2017c).

4.4. Role of the IoT and Next Gen Data

The rapid convergence of utility solutions enabled by new emerging business models, next generation digital technologies including the IoT, data analytics, AI and Blockchain, is enabling the transition to next generation multi-utility energy, waste and water businesses and services. It is driving new jobs, efficiencies and productivity, while decarbonising the economy. People will grow their own localised energy and water solutions from within communities using affordable sensors and participating in IoT use cases. They will get greater understanding of their water and energy usage through their own infrastructure—on the roof of their houses, their neighbour's community facilities and smart meters and apps. They will experience and see the benefits of local energy generation, recycling water and waste on their budget but also their environment. They will be able to do all this because of next gen data which can gather critical information about how utility services function, such as their costs and benefits.

5. Conclusions and Recommendations

Governance and market settings around the provision of precinct-scale water and energy need desperate reform. In all Australian States, legislation, regulation policy and tariff structures support and focus on last century centralised energy and water management. With 18,000 new dwellings constructed every month across the country (ABS, 2018), it is urgent governments mandate Next-Gen precinct-scale water and energy infrastructure and services in new growth areas. Centralised utilities unable to adapt their business models to the changing needs of communities have no place in the provision of services in new growth. Centralised water and energy infrastructure are gold-plated and the services lock families and businesses into ever-increasing costs, as their linear approach to resource use is unable to harness the value of reusing water or renewable energy options.

This is not just a question of cost. Home after home is currently built in communities facing higher temperatures (Webb & Hennessy, 2015), some with average 50-degree days, yet they are not equipped for these temperatures. Nearly every rooftop is without solar, and black in colour, absorbing more heat. Neighbourhoods lack established tree canopies, enabled and sustained by local recycled water. A failure to embrace Next-Gen infrastructure available now to the market will only lock families and businesses into an unsustainable and costly future—where quality of life and the value of property is diminished due to last century costly water and energy infrastructure.

Regulators and market operators need to show leadership and not engage in control fraud by supporting centralised energy and water business models at the exclusion of new innovative infrastructure and service solutions. Innovative regulation is urgently needed to position Australia towards a zero-carbon future by ensuring existing water and energy networks are resilient but also open to greater competition from circular economic approaches. This means valuing externalities such as reduced carbon, preservation of drinking water supplies, improved liveability and reduced ocean outfall. It also means considering the impact of new circular business approaches—for example the way EVs will use local energy networks is absolutely critical to the debate but absent from current policy settings, as is organic waste to energy and the potential for biofuels to provide sustainable alternative energy sources.

Innovative policy and regulation are transforming consumers to become prosumers around the world thereby achieving greater financial benefit, greater ownership and control by selling homegrown energy, recycling waste and water (European Commission, 2018). Next-Gen infrastructure approaches, such as those at Central Park, provide proof and inspiration for the prosumer future we must prepare for. Government has an unprecedented opportunity today to set a vision for the future, and targets to get there. Instead of looking at the past and replicating it. They need to look to the future and provide the infrastructure we need to succeed.

Conflict of Interests

The authors declare no conflict of interests.

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About the Authors

Lisa McLean (GAICD, BA) is CEO of Open Cities, a national peak association for Next-Gen infrastructure. Lisa has worked with government and the private sector to catalyse the zero-carbon economy over the past 15 years. She was part of the founding global team for the Clinton Foundation's Clinton Climate Initiative, ran award-winning environmental campaigns in the UK, established the Australian Solar Thermal Association and advised utility and mobility providers. Lisa is a former political adviser to two Premiers, as well as political journalist reporting on Canberra politics.

Rob Roggema is Professor of Sustainable Spatial Transformations and Urban Environments at Hanze University Groningen, the Netherlands. He is a landscape architect and an internationally renowned design-expert on sustainable urbanism, climate adaptation, energy landscapes and urban agriculture. He has previously held positions at universities in the Netherlands and Australia, State and Municipal governments and design consultancies. Rob developed the Swarm Planning concept, a dynamic way of planning the city for future adaptation to climate change impacts.

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Article

Governing the City of Flows: How Urban Metabolism Approaches May Strengthen Accountability in Strategic Planning

Cathrin Zengerling

Urban Footprints Research Group, HafenCity University Hamburg, 20457 Hamburg, Germany;
E-Mail: cathrin.zengerling@hcu-hamburg.de

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Abstract
The article aims to provide an initial insight into if and how urban metabolism perspectives and approaches may strengthen accountability in urban environmental strategic planning. It argues that many of the challenges in governing urban environmental flows successfully result from accountability gaps in strategic planning. The aim of the research is to test the assumption that urban metabolism perspectives and approaches strengthen accountability in urban environmental strategic planning. Applying a four-pillar accountability analysis to the strategic climate and resource plans of New York and Zurich, two cities which put environmental sustainability high on their political agenda, the study traces the role of urban metabolism perspectives and approaches and discusses the benefits these may have for accountable strategic planning with a focus on carbon and material flows. The interim results show on the one hand that implicit urban metabolism approaches are vital for both cities' strategic planning and that they contribute to strengthened accountability in all four pillars of the analysis: responsibility, transparency, assessment and participation. On the other hand, the analysis highlights further potential benefits of urban metabolism perspectives and approaches in urban strategic climate and resource planning.

Keywords
accountability; carbon flows; material flows; strategic planning; sustainable cities; urban governance; urban metabolism

Issue
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1. Introduction

Cities are becoming increasingly engaged and recognized actors in multi-level and polycentric environmental governance. They develop and strive to implement environmental sustainability strategies, join transnational municipal networks (TMNs) and become visible in the institutional architecture of multilateral environmental agreements (MEAs) such as the Paris Agreement and the Convention on Biological Diversity. For example, more and more cities report climate targets in collaboration with TMNs via the transparency platform of the Non-State Actor Zone for Climate Action (NAZCA) established under the Paris regime. Some countries also explicitly include cities' mitigation and adaptation efforts in their Nationally Determined Contributions (NDCs). Due to their 'environmental weight', cities are among the crucial actors in environmental governance. Research by the International Resource Panel has shown that in 2010 cities consumed about 75% of global energy and material flows (IRP, 2013) and that urban material consumption is expected to more than double from 40 billion tons in 2010 to approximately 90 billion tons in 2050 (IRP, 2018). Recognizing this key role, international political mandates, such as the Sustainable Development Goals and the New Urban Agenda, task cities to work towards (environmentally) sustainable urban systems. With this growing political importance of cities in environmental governance, there is also a growing body of research, especially in the field of urban climate governance (Bai et al., 2018; Bansard, Pattberg, & Widerberg, 2017; Bulkeley et al., 2011; Heidrich et al., 2016; Heikkinen, Ylä-Anttila, &

Juhola, 2018; Reckien et al., 2014, 2018; see also Urban Knowledge-Action Network of Future Earth, n.d.).

This article builds on the initial insights of work in progress under an interdisciplinary research project at the intersection between law, urban planning and environmental sciences, focusing on the accountable governance of cities' carbon and material flows. It argues that many of the challenges in governing urban environmental flows successfully are based on accountability gaps in strategic planning and implementation and aims to identify ways to strengthen accountability. The research is based on the hypothesis that an urban metabolism perspective is helpful in strengthening accountability in urban environmental strategic planning. The aim of this article is to provide an insight into if and how urban metabolism perspectives and approaches are—explicitly or implicitly—instrumental in strengthening accountability in urban environmental strategic planning in the cities of New York and Zurich. It thereby intends to contribute to the puzzle of how to link urban metabolism and policy (Bai, 2016, p. 827; Dijst et al., 2018, p. 201). Section 2 below introduces the methodological approach of this interim study. Section 3 defines the basic terms and concepts of the research and introduces the four pillars of the accountability analysis. Section 4 applies the accountability analysis to climate and resource governance in the cities of New York and Zurich and traces the role of urban metabolism perspectives and approaches. Sections 5 and 6 discuss key findings and draw initial conclusions respectively.

2. Methodology

The methodological approach of this study is both conceptual and empirical. Conceptually, the study inserts urban strategic environmental planning and urban metabolism approaches into the wider context of accountable (urban) environmental governance. As an analytical framework the study applies an accountability analysis which has been developed in prior research and is explained in greater detail below (Section 3.2). The aim of the present study is to gain insights into how 'the city of flows' can be accountably governed internally via strategic environmental planning. The aim of the larger research project, which this study is part of, goes beyond this internal perspective. It traces accountability chains and their instrumental design not only within cities but also externally in cities' connections in multi-level and polycentric environmental governance structures (see Section 3.2 and Figure 1). Strategic plans are an important instrumental interface for internal and external relations because they steer and coordinate cities' efforts in the governance of environmental flows.

Empirically, the qualitative study applies the accountability analysis to key strategic environmental plans and related policy documents in the two case studies of New York and Zurich. With regard to New York, the analysis focuses mainly on the sustainability section of the current plan OneNYC; in the case of Zurich it examines the Roadmap 2000-Watt-Society as well as the 2050 Resource Strategy. The study examines in the context of each pillar of the accountability analysis—responsibility, transparency, assessment and participation—if and how urban metabolism perspectives and approaches, as presented in Section 3.3, have been used explicitly or implicitly in strengthening accountability in such plans (Sections 4 and 5). In addition, the study also draws on related scientific and grey literature. It is important to note that this methodology can only produce interim results of work in progress. In the further course of the research it will be extended and deepened conceptually as well as empirically, inter alia via interviews and the collection of local data.

3. Governing the City of Flows: Definitions and Conceptual Approaches

The following subsections introduce the understanding of environmental governance and strategic planning as used in this study, the methodological approach of the accountability analysis and the concept of urban metabolism.

3.1. Urban Environmental Governance, Strategic Planning and Modes of Governance

The term governance is applied in this study as defined by the Commission on Global Governance in its fundamental report Our Global Neighborhood. Accordingly:

> Governance is the sum of the many ways individuals and institutions, public and private, manage their common affairs. It is a continuing process through which conflicting or diverse interests may be accommodated and co-operative action may be taken. It includes formal institutions and regimes empowered to enforce compliance, as well as informal arrangements that people and institutions either have agreed to or perceive to be in their interest. (Carlsson, Ramphal, Alatas, & Dahlgren, 1995)

Environmental governance refers to governance activities concerned with the common matter of the environment. Consequently, urban environmental governance encompasses city-led initiatives such as, for example, municipal climate action planning or waste recycling schemes, as well as neighborhood cooperatives, multi-urban bodies developing an integrated transport plan with user groups or regional initiatives of state agencies, industries and residents, for example, to control deforestation (cf. Carlsson et al., 1995).

This study is written from a global north perspective and focuses on urban environmental strategic planning. The quality of such overarching strategic plans, such as, for example, the OneNYC plan, is one crucial factor in the success or failure of a city's ambitions to reach certain development goals. As those tools may cover many flows in the city, such as energy, water, waste, traffic, green infrastructure, materials, etc., they are an important place to identify and deal with systemic changes, areas and measures which need integrative planning and areas of synergy and conflict. The strategic plans may contain procedural and substantive rules which require or enable future cross-sectoral communication, coordination and integrated decision-making. They may also set up new institutional bodies empowered and staffed to facilitate such tasks. Another important success factor for strategic plans is appropriate budgeting. Tasks may only be completed if the necessary staff and measures can be financed. From a procedural point of view, adaptive management cycles enable a periodic assessment and review of past measures and achievements and eventually adjustment of strategic plans.

A strategic plan usually establishes targets and a management framework to ensure that the targets are reached. However, before specific measures are implemented, the broader rules of the strategic plan need to be fleshed out and translated into formal and informal instruments which actually bring about specific changes in urban land use, infrastructures or activities. At this point, sectoral administrations, plans and instruments come into play and may hinder or facilitate changes as envisaged by the overarching strategic plan (see Jones, 2016). Institutional, procedural and substantive rules which require continuous communication, coordination and joint decision-making may increase the chance of the need for systemic, integrative, synergistic and conflict-sensitive detailed planning and implementation not to get lost in sectoral routines and power structures. The process of developing a strategic plan and the design of specific measures can be crucial for the success of its implementation. If relevant actors, including sectoral administrations, private businesses and citizens, participate in the process and co-shape plans and measures responsive to their needs and capacities, it becomes much more likely that the envisaged changes become reality (with a focus on knowledge building see Sara & Baud, 2014).

When designing strategic plans, urban planners and policy-makers may establish measures in six modes of governance as identified in the extensive research into city-level action on climate change by Bulkeley et al. (2011): self-governance, provision, regulation, enabling, partnership and experimentation (see also Bulkeley & Castán Broto, 2013; Bulkeley & Kern, 2006, p. 2242; Bulkeley et al., 2011, p. 8). This comprehensive approach to clustering municipal scope for action may also be transferred to the broader field of urban environmental strategic planning. Self-governance refers to the power of municipalities to govern their own activities; provision addresses municipalities' influence on the provision of certain services and resources; regulation encompasses local law-making and planning law and thus basic instruments of exerting local authority; enabling captures municipalities' opportunities to support, coordinate and incentivize activities with or of private businesses, NGOs, local communities and citizens; local governments may cooperate with other stakeholders via partnerships (Bulkeley & Kern, 2006, p. 2242; Bulkeley et al., 2011, p. 8); finally, municipalities may use experimental interventions to reconfigure socio-technical systems (Bulkeley & Castán Broto, 2013).

Procedural and substantive legal requirements for strategic planning may vary significantly depending on each country's legal framework. However, in many cases instruments of strategic planning are either 'informal', in the sense that there is no law prescribing the procedure or (limited) content of the planning tool or formalized but not strictly limited in content. Thus, very frequently, a local government may choose to include measures from all six modes of local governance mentioned above in their strategic planning. This opens a wide scope of action for urban environmental strategic planning and enables the local government to steer and coordinate city-wide efforts in the governance of environmental flows towards reaching agreed environmental targets.

3.2. Accountability (Gaps) in Three Perspectives of Environmental Governance

SDG 16 and the New Urban Agenda contain political mandates for accountable (urban) governance. However, they do not define what accountability actually means. In layman's terms, accountability is defined as "the quality or state of being accountable (= answerable, explainable); especially: an obligation or willingness to accept responsibility or to account for one's actions" (Accountability, n.d.). In the theory of representative democracy, accountability plays a crucial role in the context of the exercise of state authority and the so-called principal-agent paradigm. In this traditional view, the principal is the citizens and mechanisms of accountability ensure that the exercise and delegation of power to state-agents takes place according to the principal's will (see Biermann & Gupta, 2011; Shah & Shah, 2006; Zengerling, 2018). A growing body of research, especially in the field of political science, grapples with the concept of accountability. For example, Biermann and Gupta (2011) identified four essential elements of accountability: (1) a normative element defined as a certain standard of behavior, (2) a relational element linking principal and agent, (3) a decision element in the form of a judgment about whether the standard of behavior has been met, and (4) a behavioral element that allows deviant behavior to be sanctioned. Chan and Pattberg (2008) define accountability more broadly as a "more or less coherent set of rules and procedures, delineating who takes part in decision-making, who holds whom responsible for what kind of actions, and by which means".

In a system of polycentric environmental governance—which emphasizes the diversified structure of actors in different forms of networks and focuses on bottom-up rather than top-down initiatives (Dorsch &

Flachsland, 2017; Jordan et al., 2015)—accountability becomes more complex than defined in the traditional view of representative democracy (Widerberg & Pattberg, 2017). There is a wider range of principals and agents (Bäckstrand, Zelli, & Schleifer, 2018, p. 344). For example, cities as actors in polycentric climate governance regulate themselves but are also regulated. They do not only function in a vertical system of state hierarchy but also horizontally, for example as members of TMNs (Bäckstrand et al., 2018, p. 344). Therefore, the accountability analysis of the overall research project aims to trace accountability chains and their instrumental design in three different perspectives: vertically (relationships between cities, states and MEAs), horizontally (relationships between cities, e.g., via TMNs), and internally (focusing on cities' internal strategic environmental planning; see Figure 1).

The present study focusses on the internal perspective of urban environmental strategic planning. Reacting to empirical findings that indicate accountability gaps in cities' climate action planning, it aims to trace internal accountability chains and accountability design. Despite empirical research on urban climate governance in Europe which showed efforts in target setting and strategic climate action (Heidrich et al., 2016; Reckien et al., 2014), there is still little evidence as to whether this actually led to GHG emission reductions (van der Heijden, 2018). Instead, research identified a lack of mechanisms that ensure that targets are met (Bulkeley et al., 2011; Sippel, 2011) and an "accountability vacuum" (Bache, Bartle, Flinders, & Marsden, 2015; see also Bäckstrand et al., 2018). Empirical research focusing on the role of TMNs suggests that membership has not so far fostered reliable implementation and monitoring procedures (Bansard et al., 2017) or transformational change (Heikkinen et al., 2018). The lack of local data (Bai et al., 2018) and standardized accounting in urban GHG inventories also makes it difficult to assess the effectiveness of cities' climate action planning (Dahal & Niemelä, 2017; Yetano Roche et al., 2014; see also Wang, Engels, & Wang, 2017; Zengerling, 2018). With regard to material flows, empirical studies show a trend towards increasing resource use and material inefficiency on a global scale (Chávez et al., 2018, p. 85). However, due to lack of local data it is difficult to assess the part played by cities in this trend (Chávez et al., 2018, p. 85).

Prior research in this project identified four pillars of accountability drawing on political mandates, scientific literature and mechanisms established under the Paris regime: responsibility, transparency, assessment, and participation (Zengerling, 2018, pp. 148–149). The following paragraphs describe each pillar in greater detail and highlight the associated accountability gaps in urban environmental strategic planning. Responsibility covers who is responsible to whom, for what kinds of actions (e.g., emission reductions), by which means (e.g., monitoring and reporting, submitting to compliance control), and in which forms (e.g., voluntary, intended, or mandatory). The internal responsibility of a city government to reach certain environmental goals depends on the formal or informal nature of an environmental strategic plan. In most cases environmental strategic plans are informal plans, which means that they are not legally binding for other actors. This constitutes an important accountability gap which can be mitigated, for example, by ensuring that targets and measures in the strategic plan are implemented via formal sectoral or detailed plans. Another option to alleviate this challenge is to adopt clear and detailed targets connected to a transparent assessment which allows for public scrutiny. Furthermore, implementation of an informal strategic plan in the absence of enforcement powers becomes more likely if it is based on a broad societal consensus and contains economic or social incentives.

Transparency refers to who needs to communicate to whom, what kind of information (e.g., current emissions,

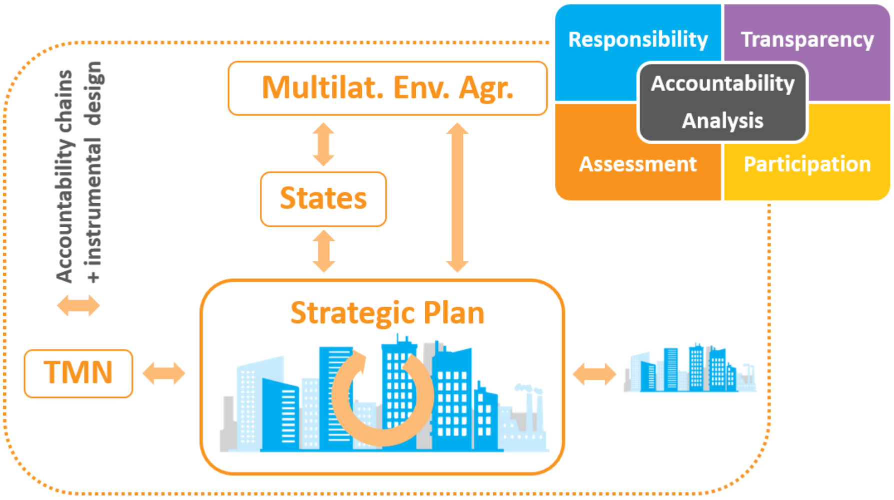


Figure 1. Framework of accountability analysis in multi-level and polycentric governance system Source: Zengerling and Gionatan Vignola (graphic design).

strategies, or costs) and in which form (e.g., publicly available or disclosed only to certain actors). Transparent governance of the city of flows would e.g., encompass transparency portals which make a wide range of information on the city's environmental flows publicly available. Key accountability gaps with regard to transparency in strategic planning are the lack of local data, shortcomings in the quality of data, and limited disclosure of data.

Assessment encompasses collection, measurement, verification, evaluation and modeling of data relating to an agreed goal, choice and application of methodologies and evaluation schemes (Zengerling, 2018, p. 149; see also Jones, 2016). Among the key accountability gaps with a view to assessment in strategic planning are the lack of local data, methodologically sound and comparable inventories, or indicators. As stated above, cities' GHG inventories use a variety of different methodologies and data and are generally not comparable (Dahal & Niemelä, 2017; Yetano Roche et al., 2014). Usually, cities apply some form of production-based accounting. The vast majority of current urban GHG inventories result from the chosen methodologies and use, in the absence of local data, of national data not appropriate for informing local decision-making or assessing progress at local level. A joint initiative of the World Resources Institute, C40 Cities and ICLEI developed the Global Protocol for Community-Scale GHG Emission Inventories (GPC). It is based on the IPCC methodology and offers a framework to account for not only scope 1 but also scope 2 and 3 emissions. Member cities of C40 and ICLEI are encouraged to apply this framework. Kennedy, one of the researchers involved in developing the GPC, applied the methodology to his comparative study on 22 global cities' infrastructure emissions (Kennedy, Ibrahim, & Hoornweg, 2014). Increasingly, scientists are developing methodologies for consumption-based accounting and transboundary footprinting at city level (Pichler et al., 2017; Wheeler, Jones, & Kammen, 2018; see also Creutzig et al., 2018). It is important not to mix methodologies because this would lead to double-counting (Wheeler et al., 2018, p. 37).

Participation refers to involvement of different actors in decision-making processes. Participating parties may be representatives of other sectors of the administration, private businesses, NGOs, groups of or individual citizens. There are different forms and stages of participation, ranging from direct to indirect and from information, consultation, involvement and cooperation up to empowerment. Forms of participation may also differ along the steps of a policy cycle from goal setting, choice of instruments and implementation to evaluation and adjustment. In many procedural rules of formal planning instruments, only parties affected by a certain plan or policy have a legal right to participate. However, planners and other administrative representatives in charge of decision-making are usually free to go beyond such legal minimum requirements. With respect to informal instruments, such as most strategic environmental plans, the decision-maker is free to design participatory processes. Thus, accountability gaps in strategic planning with a view to participation are often the limited scope and quality of participation.

3.3. Urban Metabolism Perspectives and Approaches

Looking at a city as a city of flows is directly linked to the concept of urban metabolism. It has been developed by Wolman (1965) and, according to Kennedy, Pincetl and Bunje (2010), may be defined as "the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste". Urban metabolism studies involve "'big picture' quantification of the inputs, outputs and storage of energy, water, nutrients, materials, wastes for an urban region" (Kennedy et al., 2010). The International Resource Panel frames urban metabolism as "a lens through which cities can be studied in order to understand major resource and energy flows, and identify infrastructural investments that would enable cities to shift from a linear (i.e., wasteful) metabolism to a resource-efficient metabolism" (IRP, 2013, 2018). A wider and more human-centered perspective elaborated by Currie and Musango (2017) understands the urban metabolism as the "collection of complex socio-technical and socio-ecological processes by which flows of materials, energy, people, and information shape the city, service the needs of its populace, and impact the surrounding hinterland". Bai (2016) and Chávez et al. (2018) developed and used similarly wide concepts of urban metabolism. Figure 2 aims to visualize the urban metabolism framework in the context of accountable strategic planning.

Comprehensive studies of urban metabolism exist for a still small but growing number of cities (Kennedy, 2016; Kennedy et al., 2010). For example, Rosado, Niza and Ferrão (2014) developed an urban metabolism analyst (UMAn) model and studied material flows from 2003 to 2009 disaggregated into 28 material types, 55 economic activity categories and their spatial location for the Lisbon metropolitan area in 2014. The study was also related to the cities' strategic planning in waste management and could be used as an accompanying projection and assessment tool for informed local decision-making (Rosado et al., 2014). In an international study Kennedy et al. (2015) quantified energy and material flows for 27 megacities and established correlations for electricity consumption, heating and industrial fuel use, ground transportation energy use, water consumption, waste generation, and steel production in terms of heating-degree-days, urban form, economic activity, and population growth. However, it is important to note that those studies are not only based on local data but also still apply extrapolations of national statistical data.

In their UNEP report *Urban Metabolism for Resource Efficient Cities*, Musango et al. (2017) summarize the key approaches for assessing the urban metabolism: ac-

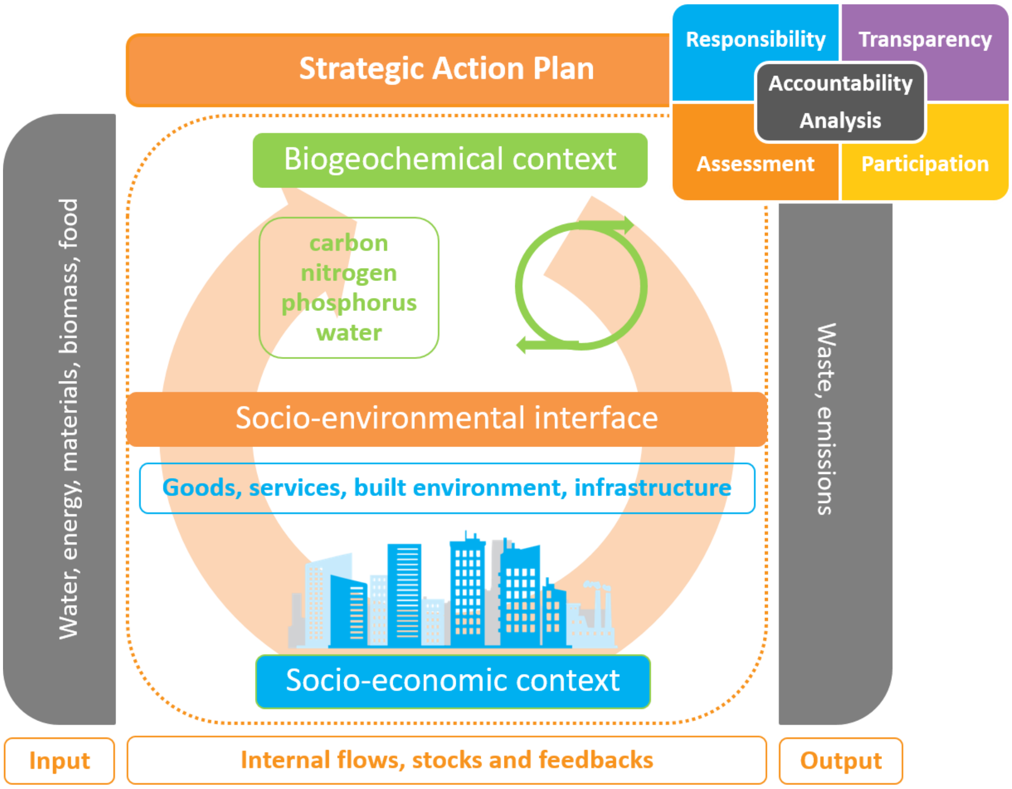


Figure 2. Urban metabolism framework and accountable strategic planning. Source: Zengerling and Gionatan Vignola (graphic design), drawing on Ferrão and Fernández (2013) and Musango, Currie and Robinson (2017).

counting approaches such as material and substance flow analysis, input-output analysis, ecological footprint analysis, life cycle assessment, simulation methods, as well as hybrid methods combining and extending the traditional methods. The report also maps and lists 165 urban metabolism case studies and the approaches used respectively (Musango et al., 2017, pp. 15, 28). In their recent article on urban metabolism and interdisciplinary perspectives Dijst et al. (2018) include a non-exhaustive table on urban metabolism approaches, which encompasses the approaches mentioned by Musango et al. (2017) but goes into greater detail, especially with respect to efficiency, health and socio-economic indicators (Dijst et al., 2018, p. 199). As Kennedy pointed out, there are several fields of application of urban metabolism studies within urban sustainability transitions: urban metabolism research may contribute to developing and following-up on urban sustainability indicators, it may contribute to urban GHG accounting, develop dynamic mathematical models for policy analysis and it may be used as a design tool for urban planning (Kennedy et al., 2010). With such fields of application, urban metabolism studies have great potential to contribute to strengthening accountability in the four fields outlined above. If and how the cities of New York and Zurich use urban metabolism perspectives and approaches in their key strategic plans in the fields of climate and resource governance is explored and discussed in the following two sections.

4. Accountability Analysis of Strategic Planning in New York and Zurich: First Insights

The following case studies explore city-led strategic planning of carbon and material flows in the cities of New York and Zurich through the lens of the four pillars of the accountability analysis.

4.1. New York City

The City of New York has ambitious goals. It strives to be "the most sustainable big city in the world and a global leader in the fight against climate change" (OneNYC, 2015, pp. 6, 160). In 2007, the mayor at the time, Michael Bloomberg, embarked on this journey and enacted the PlaNYC as the key strategic plan in working towards these goals. Building on these prior efforts, in 2015, Mayor Bill de Blasio issued a new strategic plan: the One New York: The Plan for a Strong and Just City (OneNYC, 2015). The 354-page document formulates visions, goals, targets, indicators and initiatives in four fields and respective subthemes: urban growth (covering, inter alia, industry, workforce, housing and transportation); justice and equity (capturing health, social service and criminal justice); sustainability (encompassing GHG emission reduction, clean air and water, zero waste, and green infrastructures) and resilience (dealing with neighborhoods, buildings, infrastructure and coasts). The appendix contains a relatively comprehensive table on initiatives and a total of 47 more or less specific supporting initiatives within each subtheme, the lead agency in charge, as well as status and source of the required funding (OneNYC, 2015, p. 266).

A first review of the sustainability section of OneNYC shows elements of accountability in all four pillars. The City of New York assumes a political (not a legally binding) responsibility towards its citizens for reaching specific reduction goals. The key overarching goals of the sustainability section with regard to carbon and material flows are a reduction of 80% in the cities' GHG emissions by 2050 and a 90% reduction in disposed waste by 2030, both relative to 2005. The GHG reduction goal has been reinforced and turned into an administratively binding goal by Executive Order 26 passed by Mayor de Blasio in June 2017 and planned for in more detail under the strategic 1.5°C: Aligning New York City with the Paris Climate Agreement plan (henceforth called the NYC Climate Action Plan), issued in September 2017. The GHG emission reduction target is fleshed out via four initiatives targeting specific emission reductions in the power, transport, waste and building sectors (OneNYC, 2015, pp. 168–174). Each initiative consists of several specific measures, with a lead agency in charge, funding status and milestones (OneNYC, 2015). Similarly, the OneNYC plan establishes eight initiatives to reach its waste reduction target in the fields of the organics and curbside recycling program, reduction of plastic bags, citizen involvement in reduction and recycling, zero waste schools, reuse and recycling of textiles and electronic waste, a save-as-you-throw program, and reduction of commercial waste (OneNYC, 2015, pp. 178–187).

As far as transparency is concerned, the OneNYC plan is written in accessible language, clearly structured and contains relatively comprehensive tables of goals, initiatives, measures, responsibilities, funding status, milestones and indicators (OneNYC, 2015, pp. 166–187). Concrete budgets are not mentioned in the plan. Strategic plans and progress reports are publicly available (OneNYC, 2018). The City of New York has an open data portal (opendata.cityofnewyork.us) with information on several sectors of environmental quality, including energy consumption, GHG emissions and waste management.

The City of New York publishes annual indicator-based progress reports (OneNYC, 2018). Progress under the GHG emission reduction goal is assessed via two inventories as required under Local Law 22 of 2008 (NYC Climate Action Plan, 2017, Appendix III): a city-wide GHG inventory and a city government GHG inventory. The city-wide GHG inventory applies the methodology of the Global Protocol for Cities (NYC Climate Action Plan, 2017, p. 42). It shows a 15% reduction in the city-wide annual GHG emissions from 2005 to 2016 (NYC Climate Action Plan, 2017, p. 43). Compared to 2015, GHG emissions remained flat. According to the explanatory notes, the reduction was achieved despite significant increases in population and economic activity. Interestingly, the City of New York strives also to account in future for consumption-based emissions in addition to the GPC methodology (NYC Climate Action Plan, 2017, p. 44). This will be an important step towards capturing the contribution of the city's infrastructures and lifestyles to climate change in a more holistic manner (Pichler et al., 2017; Wheeler et al., 2018). Depending on the findings, it will also allow the city to widen the range of reduction activities on the political agenda accordingly. Progress under the waste reduction goal is measured via three indicators. With regard to the volume of DSNY-collected refuse, the 2018 progress report shows a decline in comparison to the 2005 baseline, but a slight increase compared to 2016 (OneNYC, 2018, p. 64). The second indicator is a curbside and containerized diversion rate. It increased slightly from 16.9% in 2016 to 17.4% in 2017 (OneNYC, 2018, p. 64). Regarding the third indicator, citywide diversion rate–covering all waste streams: residential, commercial, construction and demolition, and fill–the report refers to a lack of available data (OneNYC, 2018, p. 64).

Research on participation in the planning process of PlaNYC highlights strengths and weaknesses. On the one hand, Mayor Bloomberg created—alongside the City's Office of Long-Term Planning and Sustainability—a 16-person Sustainability Advisory Committee with representatives from businesses, consultancy, NGOs and community activists (Rosan, 2011, p. 966). Many advocacy groups and individuals commented on the plan and Town Hall meetings were hosted in every borough (Rosan, 2011, p. 967). However, critics argue that participation was not meaningful in the sense of joint development of PlaNYC. They highlight that the plan already existed, and the purpose of participatory activities was rather to sell the idea than to shape it (Angotti, 2008; Rosan, 2011, p. 966). In this context it is interesting to note that neither PlaNYC nor OneNYC went through an approval procedure under Section 197 of the New York Charter (Angotti, 2008, p. 5; Rosan, 2011, p. 966). An evaluation from an environmental justice perspective points to several positive procedural and substantive aspects of PlaNYC but identifies room for improvement (Rosan, 2011, p. 973). A study on the performance management system established under the Bloomberg administration for PlaNYC points to important progress in measuring mitigation activities, but also highlights a lack of community engagement (Jones, 2016, p. 753). Furthermore, it concludes that the managerial approach applied by the Bloomberg administration resulted in most NYC departments not adopting many PlaNYC objectives and significant deficits in support for and implementation of cross-agency initiatives (Jones, 2016, pp. 752–753).

4.2. Zurich

The city of Zurich does not have an overarching urban development vision comparable to the OneNYC plan. In 2015, Zurich city council approved the mid-term strategic document Zurich Strategies 2035 under the slogan

"Zurich—Sustainable today and tomorrow: a summary of challenges and objectives". The 36-page paper is—as the slogan says—more a summary than a strategic plan. It does not contain any specific targets or initiatives but links to more specific plans and policies in various fields. Nevertheless, the City of Zurich can be seen as a role model in governing its carbon and material flows. Via a community vote in 2008, with 74% in favor, the citizens of Zurich signed up to the goal of becoming a "2000-Watt Society" (Art. 2ter from the Municipal Code) and reducing per capita CO_2 emissions to 1 t/y by 2050 (Art. 122 from the Municipal Code). The current overarching policy document guiding this process is the Roadmap 2000-Watt Society plan issued by the city council in November 2016. It encompasses 57 measures mostly at city and partly at Canton and national level in the sectors of consumption, settlement, buildings, energy supply and mobility (Stadt Zürich, 2016a). The Energy Master Plan, the Environment Master Plan and the Urban Traffic 2025 plan are the key sectoral strategic plans for reaching the envisaged goals. With regard to material flows, the city as well as the Zurich Canton are actively engaged in urban mining (AWEL, 2014a, 2014b; Stadt Zürich, 2009). For example, the percentage re-use of construction and demolition waste and use of recycled concrete is continuously being optimized. There are also initial industrial processes in place to recover phosphorus from waste water streams (AWEL, 2018).

Elements of all four pillars of accountability can be found in Zurich's strategic plans. With regard to responsibility, it is interesting to note that—unlike the City of New York—the key targets of the 2000-Watt Society are part of the city's Municipal Code and thus legally binding. The roadmap identifies specific areas of action and specific ongoing, planned and further measures in the sectors of consumption, buildings, energy supply, mobility, and settlement (Stadt Zürich, 2016a). The Energy Master Plan formulates reduction targets for primary energy and GHG emissions for the years 2020, 2035 and 2050 based on 2005 levels with regard to the city as a whole and the city's administration. In line with the overall 2000-Watt goal, targets for primary energy and GHG emission reduction are in addition set on a per capita basis (Stadt Zürich, 2016b, p. 11). In its 2050 Resource Strategy the City of Zurich developed a knowledge base, targets and strategies for efficient use and recycling of mineral building materials (Stadt Zürich, 2009). Targets and strategies in the 2050 Resource Strategy are based on an analysis of the city's material stocks and flows of buildings and physical infrastructure as well as the related energy demand. Based on modeling of urban material stocks and flows, the 2050 resource strategy developed three different scenarios up to the year 2050 and a dynamic modeling of the building stock, as well as best practices for the dismantling, disposal and recycling of construction waste (Stadt Zürich, 2009; see also AWEL, 2009). The strategic plans on the 2000-Watt Society and the 2050 resource strategy are fleshed out further via formal and informal plans and measures (Stadt Zürich, 2016b, p. 13, for energy).

With respect to transparency and assessment, the City of Zurich shows progress in achieving the goals of the 2000-Watt Society via an inventory of its consumption of primary energy and GHG emissions (Stadt Zürich, 2018). 2016 data indicates that the 2020 goal for GHG emission reduction is unlikely to be reached, whereas the 2020 goal for reduction in primary energy consumption is likely to be attained (Stadt Zürich, 2018). Zurich also issues a Statistics Yearbook. The 2017 issue, for instance, provides, inter alia, data on waste (chapter 7), primary energy consumption and GHG emissions (Stadt Zürich, 2017a, chapter 8). Furthermore, the city issues reports as a follow-up to its Master Plans on Energy and Environment (Stadt Zürich, 2017b, 2017c) which transparently show past developments and predictions in the areas of energy and material flows. With regard to consumption-based accounting it is important to note that the inventories at city level do not account for grey energy—the embodied energy required to produce a product or service—in consumption. However, there is an inventory for individual consumers updated every 6 to 10 years which does account for grey energy in individual consumption based on national average data. With regard to material flows follow-up reports show the continuously optimized re-use of construction and demolition waste and use of recycled concrete.

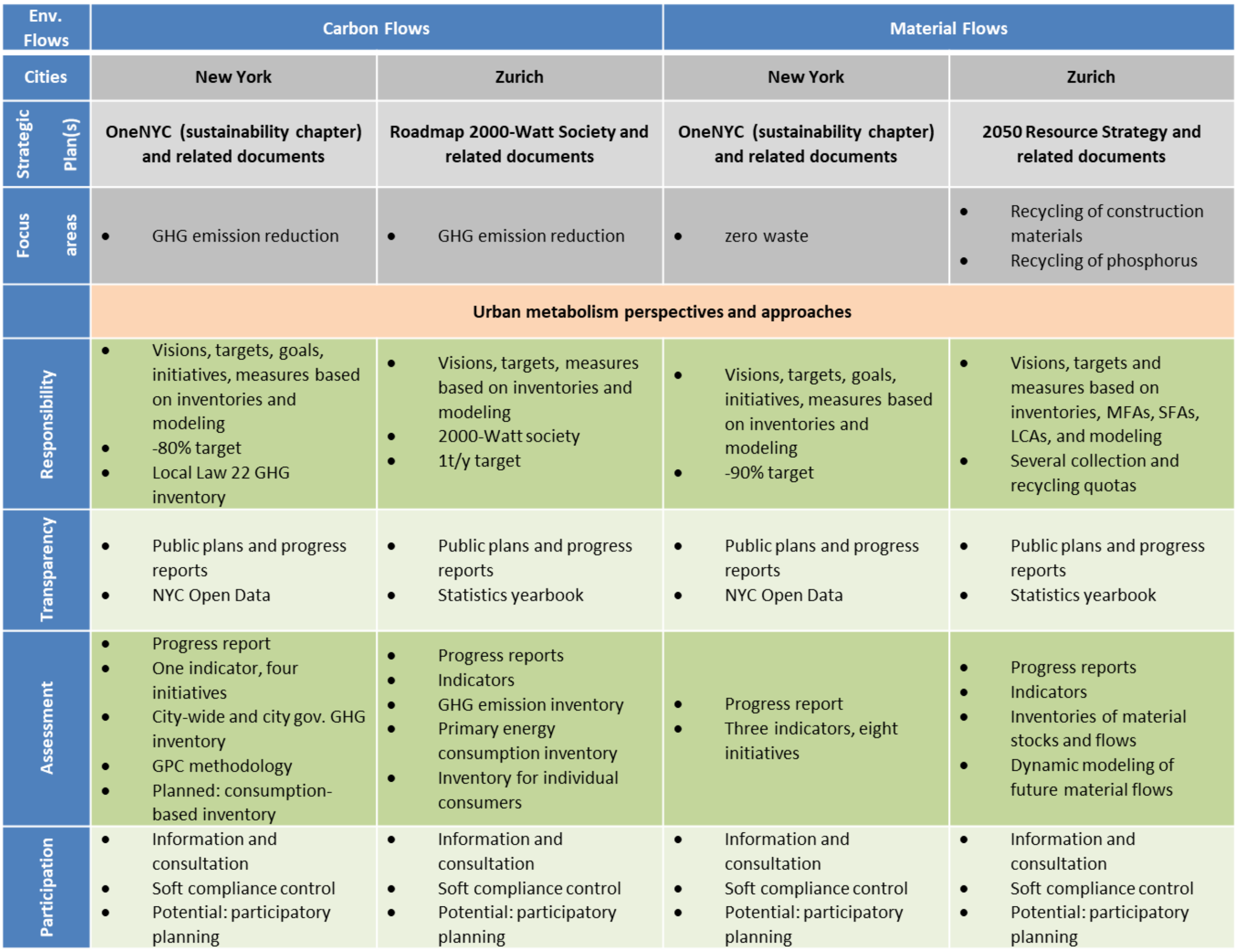
In terms of participation it is noteworthy that the city's decision to transition to a 2000-Watt Society is based on 74% support in a referendum of Zurich citizens. The strategic plan Roadmap 2000-Watt Society has been developed by the city's department for health and environment with broad participation from other departments in Zurich's administration (Stadt Zürich, 2016a, p. 9). The 2050 Resource Strategy has also been developed within the city's administration with the main responsibilities lying with the departments for construction and engineering as well as health and environment (Stadt Zürich, 2009, p. 2).

5. Do Urban Metabolism Perspectives and Approaches Strengthen Accountable Strategic Planning? First Insights

Building on the conceptualizations and definitions of urban metabolism perspectives and approaches outlined in Section 3.3, this section examines whether and how the cities of New York and Zurich use them in their key strategic plans. To gain insights into whether they strengthen accountability in strategic planning, this section traces urban metabolism perspectives and approaches through the lens of the accountability analysis. More specifically, this section examines if and how the concept of urban metabolism as such and its accounting methods, such as material and substance flow analysis, input-output analysis, ecological footprint analysis, life cycle assessment, simulation methods, or a combination of these and the related generation of local data, are explicitly or implicitly used in strategic planning. In addition, the documents are scrutinized with respect to the use of environmental and socio-economic indicators, dynamic mathematical modeling and the use of urban metabolism as a design tool for urban planning. The focus remains on carbon and material flows, specifically GHG emission reduction efforts in both cities and—with regard to material flows—the zero-waste goal of New York and construction material and phosphorus recycling in Zurich. Figure 3 summarizes the use of urban metabolism perspectives and approaches in governing carbon and material flows in the cities of New York and Zurich within the four pillars of the accountability analysis. All areas of the table highlighted in dark and light green build on or directly use urban metabolism approaches as outlined above.

It is important to note that the concept of 'urban metabolism' was not explicitly mentioned in the plans and related documents examined. The clearest use of urban metabolism perspectives and approaches is in Zurich's 2050 Resource Strategy and its efforts in urban mining. Neither of the cities aimed to describe qualitatively, quantitatively or conceptually its urban metabolism either in a holistic manner as outlined above (Section 3.3, Figure 2) or with respect to specific fields, e.g., via relating biogeochemical flows, socio-economic context and the socio-environmental interfaces. Nevertheless, implicit urban metabolism approaches are used in both cities and for the benefit of accountability in strategic planning.

With respect to responsibility both cities use urban metabolism approaches to develop 2050 visions, targets, measures and indicators for governing their carbon and material flows. Both cities used dynamic mathematical models to predict and assess different policy scenarios in their efforts to reduce GHG emissions and work towards zero waste (New York) or improved recycling of construction materials and phosphorus (Zurich). Data on past, current and predicted future scenarios of the cities' carbon and material flows supported informed decision-making in target setting, choice of measures and indicators. It also plays a crucial role in identifying areas of synergy and conflict and the design of integrated solutions (e.g., synergies between energy and waste sectors for New York; see also Hoornweg, Sugar, & Trejos Gómez, 2011).



Env. Flows	**Carbon Flows**		**Material Flows**	
Cities	**New York**	**Zurich**	**New York**	**Zurich**
Strategic Plan(s)	**OneNYC (sustainability chapter) and related documents**	**Roadmap 2000-Watt Society and related documents**	**OneNYC (sustainability chapter) and related documents**	**2050 Resource Strategy and related documents**
Focus areas	• GHG emission reduction	• GHG emission reduction	• zero waste	• Recycling of construction materials • Recycling of phosphorus
	Urban metabolism perspectives and approaches			
Responsibility	• Visions, targets, goals, initiatives, measures based on inventories and modeling • -80% target • Local Law 22 GHG inventory	• Visions, targets, measures based on inventories and modeling • 2000-Watt society • 1t/y target	• Visions, targets, goals, initiatives, measures based on inventories and modeling • -90% target	• Visions, targets and measures based on inventories, MFAs, SFAs, LCAs, and modeling • Several collection and recycling quotas
Transparency	• Public plans and progress reports • NYC Open Data	• Public plans and progress reports • Statistics yearbook	• Public plans and progress reports • NYC Open Data	• Public plans and progress reports • Statistics yearbook
Assessment	• Progress report • One indicator, four initiatives • City-wide and city gov. GHG inventory • GPC methodology • Planned: consumption-based inventory	• Progress reports • Indicators • GHG emission inventory • Primary energy consumption inventory • Inventory for individual consumers	• Progress report • Three indicators, eight initiatives	• Progress reports • Indicators • Inventories of material stocks and flows • Dynamic modeling of future material flows
Participation	• Information and consultation • Soft compliance control • Potential: participatory planning	• Information and consultation • Soft compliance control • Potential: participatory planning	• Information and consultation • Soft compliance control • Potential: participatory planning	• Information and consultation • Soft compliance control • Potential: participatory planning

Figure 3. Use of urban metabolism perspectives and approaches in governing carbon and material flows in the cities of New York and Zurich within the four pillars of the accountability analysis.

Both cities publish strategic plans and follow-up reports. The use of urban metabolism approaches supports detailed display, reasoning and follow-up of visions, targets, measures, indicators and related data and thus overall transparency. Both cities publish past and current data on carbon and material flows in open data portals. There might be potential in future to integrate carbon and material flows also into open mapping portals of the cities (see NYCityMap, 2018).

New York and Zurich strongly draw on urban metabolism approaches with respect to assessment. Inventories of GHG emissions and material flows as well as the collection of data related to the chosen indicators are the basis for the continuing review of success and failures in the implementation of the measures outlined in the strategic plans. In the City of New York, the use of two types of GHG emission inventories is even required under Local Law 22 of 2008 (NYC Climate Action Plan, 2017, Appendix III): a city-wide GHG inventory and a city government GHG inventory. The city-wide GHG inventory applies the methodology of the Global Protocol for Cities (NYC Climate Action Plan, 2017, p. 42). Both cities strive to improve their scope and methodologies of accounting over time. For example, New York aims to track consumption-based GHG emissions in the future. Zurich constantly improves its material inventories.

Finally, urban metabolism approaches contribute to the quality of participation. For example, the transparent and detailed strategic plans of both cities as well as information provided in open data portals and in progress reports enhance the quality of information to citizens and the potential for soft compliance control. At the same time the data gathered in such strategic planning processes may contribute to meaningful consultation, cooperation and co-design of plans and measures on different spatial scales (Attia & Khalil, 2015; Currie & Musango, 2017). However, at this stage of the research it was not clear if urban metabolism perspectives and approaches have been used as a design tool in participatory planning.

To sum up, on the one hand the analysis shows that in both cities the use of urban metabolism approaches in strategic plans and related documents strengthens accountability in all four pillars. On the other hand, the review highlights that neither Zurich nor New York explicitly mention urban metabolism as a concept in their strategic planning. This might be due to the fact that the concept of 'urban metabolism' has so far mainly been developed and applied in academic research. However, this also indicates that more holistic urban metabolism perspectives, that connect biogeochemical and socio-economic contexts via a socio-environmental interface, are not yet used to their full potential in the strategic plans. Perhaps the development of flow charts which connect quantitative environmental flows with specific socio-economic actors and also consider and ideally visualize spatial dimensions could be a first step towards informing strategic planning via a socio-environmental-spatial perspective. To strengthen the socio-environmental interface it might also be important to extend the 'classic' toolbox of urban metabolism approaches as outlined in Section 3.3 by approaches used in the social sciences (see also Dijst et al., 2018).

6. Conclusions

Cities are becoming increasingly important actors in multi-level and polycentric environmental governance. However, empirical research has not so far been able to establish that cities reach their environmental targets. On the contrary, it identified a lack of mechanisms that ensure that targets are met. The article argued that many of the challenges in governing urban environmental flows successfully are the result of accountability gaps in strategic planning. It assumed that urban metabolism perspectives and approaches may strengthen accountability. The objective of the research was to test this assumption and gain initial insights into if and how urban metabolism perspectives and approaches are—explicitly or implicitly—instrumental in strengthening accountability in strategic climate and resource planning in the cities of New York and Zurich.

The analysis showed that implicit urban metabolism approaches are vital for both cities' strategic planning and that they contribute to strengthened accountability in all four pillars of the analysis: responsibility, transparency, assessment and participation. However, it also revealed that neither New York nor Zurich explicitly uses the concept of urban metabolism in their strategic plans. There was also no evidence that cities' strategic planning drew on the holistic urban metabolism perspective encompassing biogeochemical and socio-economic contexts connected via a socio-environmental interface.

Based on these interim results of work in progress, three conclusions may be drawn. Firstly, urban metabolism approaches strengthen accountability in strategic environmental planning. Secondly, there is currently unused potential in holistic urban metabolism perspectives encompassing socio-economic and socio-environmental aspects to further enhance accountable urban environmental strategic planning. Thirdly, urban metabolism researchers might need to extend the toolbox of urban metabolism approaches to better capture the holistic perspective and make it easier for practitioners to draw on it.

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Conflict of Interests

The author declares no conflict of interests.

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About the Author

Cathrin Zengerling is head of the research group "Urban Footprints—Towards Greater Accountability in the Governance of Cities' Carbon and Material Flows" at HafenCity University Hamburg. She holds a PhD in international environmental law and specializes in (international) environmental, planning and energy law. Her current research focuses on urban climate and resource protection at the intersection of law, urban planning and environmental sciences. It is funded by a Volkswagen Foundation Freigeist-Fellowship.

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