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ORIGINAL ARTICLE

The nexus between water, energy and food in cities: towards conceptualizing socio-material interconnections

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Abstract

Sustainable use and supply of natural resources dedicated to feeding urban life are becoming increasingly complex in a time of rapid urbanization and climate change. Sustainable governance of Water–Energy–Food (WEF) requires innovative and cross-sectorial systems of provisioning. However, practitioners have often treated WEF as separate domains, while ignoring their interconnectedness. What is missing is an 'Urban Nexus' perspective, which assumes that environmental flows of WEF interact and relate to one another in achieving urban sustainable development. This paper contributes to theorizing the urban nexus and to understand its emergence and governance from a more socio-material perspective. It offers a conceptual framework that helps to shed light on the social and material flows shaping connections between the sectors of WEF, and the actors facilitating these connections. The paper suggests that switchers and programmers link and configure the socio-material flows of WEF facilitating the emergence of nexus governance networks and nexus programs. In doing so, the paper provides three examples of cities to test the conceptual framework by analyzing their main challenges and examples around the nexus. It demonstrates that material and social dimensions of WEF might not play an equal role in steering synergies or trade-offs—either material or social flows and their agents can be central in facilitating a nexus or in preventing it to take shape. The paper argues that material-focused methodologies need to be complemented with a social flows analysis that pays attention to the daily practice, policies, ideologies, networks or any kind of socio-cultural meaning shaping WEF provisioning.

Keywords Urban nexus · Environmental flows · Urban governance · Networks · Water–Energy–Food

Introduction

Sustainable use and supply of natural resources are becoming increasingly complex in a time of rapid urbanization and climate change (Hoff 2011; Childers et al. 2015). Cities concentrate the largest share of the human population and they conglomerate people with the provision of services and goods for consumption (Hoff 2011). Cities thus depend on larger quantities of resources, such as Water–Energy–Food (WEF), whilst at the same time these resources become increasingly scarce (Vogt et al. 2014). The urban setting thus represents a challenge and opportunity for understanding and steering resources into more sustainable configurations (Vogt et al. 2014; Webb et al. 2018).

Effective and sustainable governance of WEF requires innovative and cross-sectorial systems of provisioning. Systems that for instance address sustainable infrastructure operation beyond a single-system-view, and towards understanding each system connectivity with other related systems—for example—connections between WEF (Knoeri et al. 2016). However, urban planners have often treated resources such as WEF as separate domains, while ignoring their interconnectedness (see discussions in Hellegers et al. 2008; Hoff 2011; Scott et al. 2011; Bazilian et al. 2011; Bizikova et al. 2013; Howells et al. 2013; Howells and Rogner 2014). Therefore, what is missing is an 'urban nexus' approach, which assumes that socio-material flows interact and relate to one another in achieving urban sustainable development. By adopting this perspective, WEF

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sectors could benefit from having a more integrated and comprehensive understanding and decision-making process to avoid cross-sectorial trade-offs while promoting synergies and enhancing sustainable resources usage (Smajgl et al. 2016).

The urban nexus approach; however, still needs to be operationalized and theorized. Most of the literature concentrates on the global, national or rural nexus, but little attention has gone into how the nexus plays out in urban settings. The main objective of this paper is to add to the theorizing of the urban nexus to understand its emergence and governance from a more socio-material perspective. It brings together materialistic flow's literature focused on natural resource systems and infrastructures, with social flow's literature focused on questions of the daily practice of provisioning, policy, discourse, power and (in) formal regulation; by balancing these two thoughts into a socio-material analysis. It does so by further conceptualizing the socio-material interconnections between environmental flows that circulate in the city. Specifically, it offers a conceptual framework that helps to define and identify interconnections of the social and material flow shaping connections between the sectors of WEF, and the actors facilitating these connections. The paper suggests that material and social dimensions of WEF are not necessarily equal in creating synergies or trade-offs—either material flows or social flows and their agents can have a more prominent role in facilitating a nexus or in preventing it to take shape. In the urban context, this paper argues, it is in particular social interventions that lead the way towards more cross-sectorial provisioning of water, energy and food.

The paper is structured as follows. Section II provides a background into the literature on the nexus with a focus on social and materialistic approaches and introduces their interconnections through engagement with socio-ecological systems (SES), environmental flow's literature from sociology and literature on sustainable urban development. Section III offers a conceptualization of an urban nexus approach from a socio-material perspective focused on WEF provisioning in cities. To build this approach, it brings together different strands of the literature, including material flow analysis, environmental flows and Castell's network society. This section furthermore illustrates these arguments through the use of examples on the nexus in European cities. Section IV concludes.

The urban nexus: connecting material and social flows

The nexus has emerged as a concept to improve sustainable usage of natural resources. The nexus stands for cross-sectorial decision- and policy-making, mostly in the domains of Water–Energy–Food (WEF) provisioning, to overcome trade-offs and to stimulate synergies in sustainable development. A key problem it seeks to overcome is working in silos (see discussion in United Nations 2014). For instance, policy makers focus on one sector at the time (e.g., energy) without accounting for how their respective policies negatively or positively affect other sectors (e.g., water). Indeed, when it comes to resources governance '…policy makers have continued to address and formulate policies in silos that do not guarantee simultaneous attainment of WEF security as well as environmental sustainability' (Bhaduri et al. 2015:726). The governance of such resources attainment and its related infrastructure has often been underestimated or it has been as well difficult to address in practice (Knoeri et al. 2016).

Much of the literature has already addressed the question how a nexus between WEF can be achieved. Most papers stress the lack of attention to the material connections between water, energy and food and provide new methodologies examining these connections (see e.g., Bazilian et al. 2011; Howells et al. 2013; Nair et al. 2014; Endo et al. 2015; Daher and Mohtar 2015; Chen and Chen 2016; Smajgl et al. 2016; Tevar et al. 2016; Ramaswami et al. 2017). For instance, Bazilian et al. (2011) analyze the linkages of WEF for the case of ethanol production. They do so by tracing the industrial processes taken for producing ethanol and their relations with energy, water, land and climate. For example, they illustrate the water flows needed to irrigate land and the energy flows required for the production of ethanol. Alternatively, papers focus on the social side of the equation and discuss for instance how institutional coordination can help to establish a nexus between WEF (see e.g., Scott et al. 2011; Harvey 2014; Foran 2015; Bhaduri et al. 2015; Gain et al. 2015; Halbe et al. 2015; Biggs et al. 2015; Smajgl et al. 2016; Boas et al. 2016). Very few articles or literature strands examine both material and social dimensions when understanding or assessing the nexus of WEF. Meanwhile, material and social dimensions of sustainable development interact as the provisioning of services is not just dependent on the resource itself, the industrial processes and infrastructures at work, but also on the policies, daily practices, informal rules, discourses and actors at play. This becomes particularly crucial when considering the policy and decision-making of cities as socio-material systems (Webb et al. 2018). Cities represent the places in which actors, networks, infrastructures, and resource flows get connected in specific socio-material urban contexts (Hodson et al. 2012).

The interaction of social and material characteristics of sustainable development has featured in older discussions on Socio-ecological Systems (SES) literature, environmental flows, and sustainable urban development. SES literature (see, Anderies et al. 2004; Ostrom 2007; Janssen

et al. 2007; McGinnis and Ostrom 2014) posits a 'theory-neutral framework' to analyze the linkages and relations of an ecological (non-human, physical or material) system with one or more social systems (Anderies et al. 2004; Ostrom 2007; McGinnis and Ostrom 2014). These scholars suggest that 'tiers' within the SES such as actors (e.g., producers or users) and governance systems (e.g., government and non-government organizations, monitoring rules, etc.) interact and connect with resources units (e.g., m^3 water flows) and resource systems (e.g., water sector)—and vice versa—into specific action situations (e.g., drinking water provisioning) (Ostrom 2007; McGinnis and Ostrom 2014).

This paper does acknowledge—and align with—the core argument of addressing environmental problems/situations from a socio-material perspective as argued by the schools of thought of Ostrom and SES. Nevertheless, SES literature has been criticized for delivering a simplistic or reductionist perspective of its 'social' tiers. Such 'social tiers' proposition bypasses an adequate theorization, operationalization, and conceptualization of its social dimension rather than proposing a more profound sociological-based foundation for these tiers (Stojanovic et al. 2016). What is seen in practice is that such social tier's proposition in SES research relate more to economic or quantifiable units (e.g., employment, tourists number, population, etc.) or to less quantifiable components such as social learning and land use (see, Stojanovic et al. 2016). Rather than focusing on the significance of social components such as the power, politics, social practices, networks dynamics, institutions, and dynamics that go along through material flows (Mol and Spaargaren 2006a); which have been neglected by the SES (Stojanovic et al. 2016). The framework this research aims to look forward to capturing the dynamism of flows (perspective) moving along processes and networks shaping WEF provisioning; in this sense, flows are under the spotlight as the unit of analysis of this nexus research framework.

Environmental flows address the interactions between social and material layers of flows (Mol and Spaargaren 2005, 2006b). Environmental flows are more than material substances units or infrastructures and are also the social organization that goes along with the flows in question (Mol and Spaargaren 2005, 2006b; Mol and Dieu 2006). For example, natural resource systems supply urban areas in the form of flows. Flows are the continuous stream of objects, materials, resource units, ideas or information, or any other form that moves along, at least, between two points. These can be either material flows (e.g., 1 L of drinking water) or social flows (e.g., policies for drinking water provision). A material additions-and-withdrawals perspective is, therefore, insufficient. It needs to go further into a more sociology-based analysis of flows, which focuses on the role of policies, institutional arrangements, networks and social meanings shaping urban provisioning of resources (Moss and Marvin 2001; Mol and Spaargaren 2006b; Guy et al. 2011). Along these lines, Moss and Marvin (2001) have also proposed a more socio-technical flows management of urban utilities. It goes beyond material approaches and examines social, technical, environmental, economic and institutional factors affecting the utility services in cities (Moss and Marvin 2001; Hodson et al. 2012). Their contribution is essential since flow's management literature has invested on materialistic approaches rather than investigating the social factors shaping resources use and consumption (Moss and Marvin 2001; Urry 2003; Binder 2007a; Oosterveer 2015).

Such a more socio-material informed flow analysis is; however, often ignored when analyzing interconnections between WEF in cities. Only a few studies have addressed the environmental flows of WEF resources from a more balanced socio-material perspective (see, Binder 2007b; Scott et al. 2011; Pahl-Wostl et al. 2013; Schiller et al. 2014). When they do so, they often do not adopt a nexus approach by studying only one resource flow at the time. For example, the literature review conducted by Binder (2007a) collects different social approaches that attempt to be coupled with material flows analyses. In this review, Binder (2007a) discusses and concludes that those approaches instead relate mostly to economic approaches such as microeconomic modeling for instance, which relate more to a single-system perspective. More recently, Binder et al. (2013) reviewed a larger diversity of socio-material approaches that address natural resources analyses including natural step, DPSIR analysis, earth systems analysis, ecosystems services, and others. When looking closer into their results of how such approaches address their social dimensions (e.g., social dynamics), those mainly reflect that the social dimension is not (adequately) conceptualized. Moreover, it is worth noting that Mol and Spaargaren (2006a) discuss how those approaches continue to address flows only or primarily from physical or biological terms. Although those approaches do provide a step forward in providing methodologies for socio-material analyses and perspectives, what is missing is an approach that understands the social significance of different flows and the way these get configured through WEF networks and flows of provisioning. This research then posits networks and environmental flows as a suitable analytical perspective for emphasizing that the nexus is about the connectivity of resources flows and their embedded social relationships around WEF.

The paper thus argues that the analysis of the urban nexus should not just focus on creating cross-sectorial synergies or identifying cross-sectorial trade-offs, but also on bridging the material-versus-social divide that has for

long characterized systems of urban provisioning. The paper argues so not only because cross-sectorial provisioning in cities includes both social and material dimensions, but also because understanding and explaining how the nexus unfolds in the first place requires attention to both its social and material dimensions. In the next section, the paper will outline this argument in more detail. It will demonstrate how cross-sectorial urban provisioning can emerge and takes shape from connections between material flows affecting the social organization of provisioning, or the other way around, namely, from new connections made by entrepreneurs leading to new visions and ideas (thus a change in social flows) leading to a different usage and circulation of material flows.

Conceptualizing the urban nexus

Building on the above literature, this section seeks to conceptualize material and social interconnections into cross-sectorial provisioning of WEF in cities, in short, the urban nexus; including what it consists of, how it emerges and how its governance takes shape. The paper explains it in three steps, starting with (1) the material flows, followed by (2) the social flows, and finally (3) how these can come together as the urban nexus.

Material flows of WEF provisioning

Material flows are the continuous stream of natural resources extracted and moved along by infrastructures for the provisioning of services in the city. Natural resources enter, move around and leave the city, or are created and circulated continuously within the city, in the form of flows facilitated and directed by hardware (the infrastructures). The methodology of material flow analysis (MFA) is one of the most established ways to trace such flows and their possible impacts on the environment. It is, therefore, used to examine the material interactions of WEF (see examples Bazilian et al. 2011), for instance, to trace the relations between urban wastewater flows and the energy that could be recovered from these flows.

Wallsten (2015) and Fischer-Kowalski (1998) discuss the origins of MFA, which they place at the study of industrial metabolism of materials and energy flows in cities. MFA studies the material composition of the resources on which a city relies and how these are processed. MFA is useful for investigating the physical activity of materials, for tracing how materials are allocated to feed cities and for tracing possible inefficiencies in their production systems (Wallsten 2015). It does so by analyzing the material flows going along through processes of extraction, production, consumption and disposal. In other words, the processes and flows needed to sustain urban provisioning of utilities (Fischer-Kowalski 1998).

Tracing and analyzing material flows through MFA are essential parts for understanding the urban nexus. First, this is to identify the origins of WEF resources, e.g., do they originate from within or nearby the city or do they come from abroad? Second, from this point of origin onwards, it can be examined how these resources are extracted, converted, transported and provided to consumers by infrastructures. This results in an overview of the urban metabolic processes taken for the provisioning of WEF, including how WEF are related to each other along the processes that WEF provisioning takes. Third, MFA gives insight into the environmental impacts of these material flows.

Whilst giving insights into the origins, directions and consequences of material flows, MFA has struggled to provide relevant and understandable input for policy and decision-making (Binder 2007b, a). For example, as argued by (Binder 2007b) understanding material flows per se does not provide sufficient feedback for policy makers as to how the effects or relations of their policies affect the material flows. Also, MFA can be criticized as an analytical tool that quantifies materials in a summarized manner as it simplifies reality into inputs and outputs of resources within a determined system (Wallsten 2015). These make it difficult to actually implement findings from MFA into the sustainable upgrading of, for instance, the WEF domains (Binder 2007b). Along these lines, Knoeri et al. (2016) argue for the need of understanding infrastructures (and any material flow) not only as material systems supplying resources, but rather as a more socially balanced end-user centered infrastructure which addresses the consumption practices and needs of end-users for resources services. Therefore, the need to complement MFA with social approaches that help to understand resources in a more informative way for policy-making, for decision-making, and for scientific research (Moss and Marvin 2001; Urry 2003; Binder 2007b, a; Schiller 2009; Guy et al. 2011; Oosterveer 2015).

Social flows of WEF provisioning

The provisioning of WEF is not just about material substances, physical objects, and infrastructures. It is also about social flows. Social flows can take the shape of ideas, ideologies, images, information, discourses, practices or policies (Appadurai 1996, 2001) flowing through the different processes of resources provisioning. Castells (2010:442) defines flows as "the expression of processes dominating our economic, political and social life". These social expressions (e.g., ideas or information, or governance systems) shape the continuous stream of physical

substances (e.g., water, energy or food as resource units and systems) and their resource provisioning systems in cities (e.g., transmission of these resources via infrastructures). For example, regulations and social practices (as examples of social expressions of governance systems) shaping the uptake of domestic water-saving appliances lower the flows of water flushes (a continuous stream of a physical substance).

Conducting a social flow analysis would go beyond the material aspects of flows and instead center on the social organization, actors, networks, policies, ideologies, discourses and any kind of socio-cultural meaning that goes along with the material flows of WEF (Mol and Spaargaren 2005, 2006a, b; Mol and Dieu 2006; Guy et al. 2011). For instance, in case of examining the provisioning of water, it means to not only examine the quantity and quality of drinking water or its provisioning infrastructure, but also the regulations shaping this provisioning. Or even a step further zooming-up into examining the social context explaining the lifestyles of individuals pursuing their daily life activities such as e.g., showering, cooking, or dwelling, or in other words, the social practices of being an end-user of water, energy and food (Spaargaren 2003; Knoeri et al. 2016). This provides a more holistic understanding of resource provisioning by examining (different aspects of) its social embedding and it explains how social processes shape resources provisioning.

Understanding the role of the social flows is crucial to obtain a full picture of how the provisioning of WEF works and for possibly steering these in a more sustainable manner. Ignoring the practice, policy and politics of the provisioning of WEF risks that technical solutions will not be implemented or that those have a different effect than the anticipated.

The urban nexus of WEF provisioning: analyzing socio-material interactions

The above steps discuss the material and social processes involved in the urban provisioning of water, energy and food, but do not yet show how this all comes together as a nexus approach. The urban nexus is about the interaction between WEF provisioning in cities consisting of socio-material flows (see, Fig. 1). This third step reflects on how this interaction takes shape or fails to take shape, and how this can be detected and understood.

The paper argues that there are two ways in which material and social flows of WEF can come together and constitute a 'nexus'. The first is where the material flows are the main driver in creating a nexus between WEF provisioning in the city. In these instances, social flows will follow and organize themselves in such a way that they facilitate synergies between the provisioning of water, energy and food. To detect those, it is most effective to trace the interconnections of material flows of WEF and examine how they are or have become socially embedded. The second way in which a nexus can come about is when cross-sectorial linkages are more socially driven; the nexus is then a result of social interventions such as a new policy or strategy for the provisioning of energy to a certain neighborhood requiring changes in infrastructures and the circulation of material flows. In this case, it is a network of actors, such as utility managers, municipalities, and entrepreneurs, that have the capability to link, configure and steer the material flows of WEF in a cross-sectorial manner through collaboration, policy-making, discourse or other social flows. In such instances, the analysis can start with tracing such actions and initiatives and how these (re)shape the (material) provisioning of WEF in the city. This paper will elaborate on both types below and illustrate them by means of examples of cross-sectorial provisioning of WEF in different European cities.

Materially driven nexus

First, a nexus between water, energy and food in the city can most simply be achieved in case material flows easily connect, or ideally have a natural connection. When materials, substances, physical objects, processes and infrastructures match, it is just a manner of effective planning and provisioning to achieve cross-sectorial management of natural resources.

A good example of such a nexus is the case of Reykjavik. Reykjavik has benefited from the presence of geothermal activity due to its geographical location. Hot water, as a primary energy source, has historically powered Reykjavik mainly using the heat and steam of water coming from geothermal reservoirs (National Energy Authority; C40 Cities 2011). The environmental flows of water and energy are thus synergistically interlinked in Reykjavik. Reykjavik energy is the public utility company that produces and provides electricity and heating to the city (OR Orkuveita Reykjavikur). To gather hot water (as primary energy source) this power generation company has built wells as infrastructures for its extraction (OR Orkuveita Reykjavikur). After hot water is extracted, one of the first processes is the separation of steam from hot water. Then, each of these flow resources has a different use. Hot water can be directly provided as a service for heating spaces such as houses, and the steam is used as an input source to spin electric turbines for electricity generation. Once electricity is produced, it is transmitted and distributed in the city, making electricity load available for domestic consumption (National Energy Authority; C40 Cities 2011). Whilst this nexus is mostly about the material connections between water and energy, there is also a link

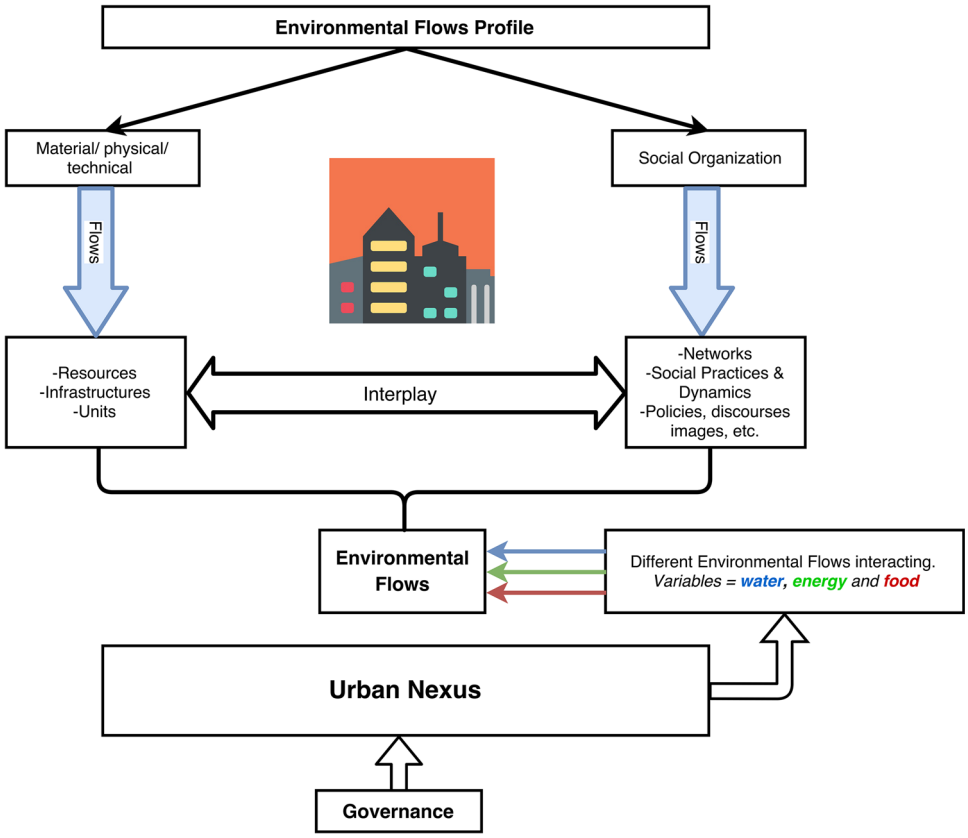

Fig. 1 Environmental flows in the nexus

to food; yet outside the boundaries of the city. As argued by Iceland's National Energy Authority (National Energy Authority): 'Apart from space heating, one of Iceland's oldest and most important usages of geothermal energy is for heating greenhouses. For years, naturally warm soil has been used for growing potatoes and other vegetables.' In this way the material flow connection between hot water and energy also links to the production of food, making geothermal energy a highly efficient and sustainable source relevant for all three resources constituting the nexus.

In this example, it is thus the material conditions that are central to allow for a nexus between water, energy and food to emerge. It is even fair to say that for Reykjavik this nexus is almost a given and taken-for-granted context, which has shaped how utility provisioning is organized. As it is such a natural, relatively straightforward process, it also does not require a complex governance structure. Instead, there is one single organizational unit of production, the public utility company Reykjavik energy, for generating hot water, heating and electricity. Such organizational structure is the result of a historical merge of different utility companies providing separately electricity and heating (both sourcing from hot water) (OR Orkuveita Reykjavikur). Such merge is, in part, a result of the referred interlinked material conditions and the overlapping functions delivered by two different utility companies. Another element from the social flow that has been important in further developing the geothermal industry in Reykjavik (and Iceland) is the introduction of the energy fund back in the late 1960. The introduction of such policy instrument has stimulated the exploration, drilling, and use of geothermal resources (C40 Cities 2011).

It is important to note that finding a materially driven nexus in an urban context is rare, especially if looking for connections between all three resources of water, energy and food. This research, therefore, struggled in finding other suitable examples. One reason may be that in the European urban context provisioning of WEF has already been highly planned and organized since the industrial revolution. Moreover, as argued by (Hodson et al. 2012:796): 'Cities are actually gigantic networks of interlocked infrastructures that have been built over many years to manipulate vast and varied flows of resources that enter into, circulate within, and exit from them in support of human prosperity.' Thus, unless material flows have the space to naturally connect, or in case urban planners were aware of their interconnections decades ago and structured the infrastructural provisioning accordingly, a lack of cross-sectorial provisioning is deeply ingrained in the way cities function and operate. This brings us to the next point that in most instances, the urban nexus is socially driven, a result of concrete social interventions.

Socially driven nexus

When material settings do not simply allow for a nexus to take shape, usually social flows have a more important role to play. The nexus then becomes a result of a social intervention. Initiating and steering of environmental flows in a cross-sectorial manner is dependent on the actors and new practices and ways of doing provisioning—and in that sense is inherently socially driven. When successful, cross-sectorial actors and the associated practices, (informal) rules and regulations, will constitute a nexus governance network. Sørensen and Torfing (2009:236) suggest that a Governance Network stands for 'a stable articulation of mutually dependent, but operationally autonomous actors from state, market and civil society, who interact through conflicting ridden negotiations that take place within an institutionalized framework of rules, norms, shared knowledge and social imaginaries… and contribute to the production of public value in a broad sense of problem definitions, visions, ideas, plans…'. Similarly, the nexus is a governance network in which actors from the WEF sectors are mutually dependent, interrelated but autonomous. This nexus constellation includes actors from different sectors and they interact in the quest for understanding and framing what nexus problems (trade-offs) and opportunities (synergies) are for urban sustainable development. This nexus constellation operates within an existing framework of policies, norms and shared knowledge, while at the same time adding new ideas, practices and regulation to align efforts towards the sustainable provisioning of WEF in the city.

Whether and how a nexus between WEF provisioning unfolds is in part a result of the structure of the nexus governance network. This governance network consists of a set of interconnected nodes (which can be actors or central points of provisioning) which are characterized by their number of links, the density of connections and symmetry of communication among nodes (Castells 2010). Consumers, producers, distributors, or regulators, are examples of "actor" nodes in the network (e.g., of a network for drinking water distribution). Each of these nodes relates and each of them is dependent on one another for the effective provisioning of services. For instance, consumers depend on the supply of a service, while the producers respond to patterns of consumption and both of them depend on regulations set by different actors from different sectors (e.g., water and energy). From this example, one could argue that regulations from one sector (e.g., water) might affect more sectors (e.g., food) and these regulations can also affect the way a service or product (e.g., food) is provisioned and consumed. The more interconnections there are between the nodes—not just within one network but also between the networks of WEF—the more these governance networks become cross-sectorial and thus a nexus governance network.

In the making of the nexus governance network, actors from the WEF sectors contribute to its creation. This is the role of 'switchers' and 'programmers' from each system (WEF) exercising their 'network making power' to create a new network and to (re)program the values, rules, arenas, power and actors of this new network (Castells 2009). For example, as illustrated in Fig. 2, actor nodes (e.g., producers, utility managers, consumers or municipalities) from different sectors could play the role of switchers and reconnect a new network configuration by linking efforts, resources, meanings, decisions and information towards a more nexus-thinking of the urban governance of WEF provisioning. At the same time, these actors can be programmers by deciding on the rules and values that this nexus governance network will pursue.

By establishing such nexus governance networks, actors overcome silo-based decision- and policy-making approaches. This can be an unintended outcome of more cross-sectorial collaboration. In the current context where the nexus has become a highly popular concept in the domain of sustainable development (see e.g., The World Bank 2013; Vogt et al. 2014), some governance actors may take conscious and explicit steps to work on a more cross-sectorial level. This may include a systematic assessment of socio-material interconnections of WEF and a plan of action to pursue the breaking down of silos. Then, when switchers and programmers configure the nexus (as a program) they bring a new configuration to the linked-up network(s) by changing imaginaries, rules, arenas, power relations, values, problem definition and framing, targets and actors. As a result, there is a new constellation of actors from the WEF sectors, which is linked in a cross-sectorial basis, aligning and mobilizing resources, visions, policies and actors from different sectors.

To make it tangible how such nexus governance network emerges and operates, it is relevant to consider the example of sustainable provisioning of food in the city of Bologna. Bologna is well-known for its culinary traditions and for its role as a food producer and distributor in Italy. Bologna has been working towards more sustainable and resilient options for the urban provisioning of food, by connecting it more effectively with the provisioning of water and energy (City of Bologna 2016). Mutually dependent, but operationally autonomous actors have emerged and collaborated across sectors by trying to integrate WEF policies and central points of provisioning into one food project. The municipality of Bologna in cooperation with the urban centre Bologna, the food centre Bologna (CAAB), renewable energy companies, and food companies, have worked on a food project which tries to integrate in one site all the processes taken in a food supply

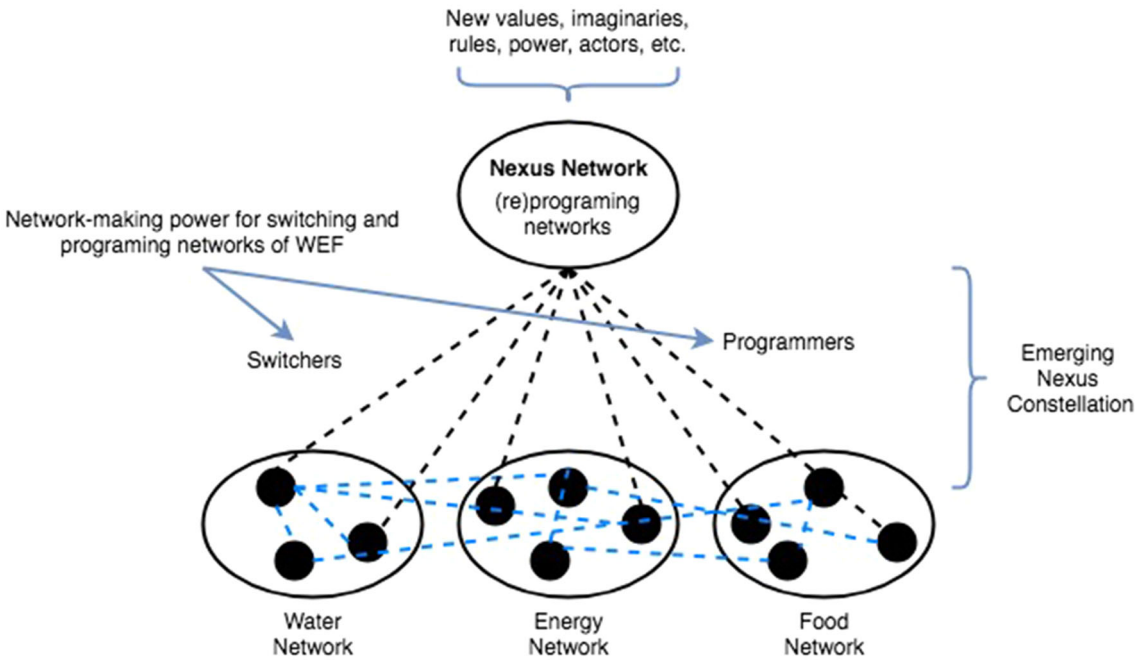

Fig. 2 The nexus governance network

system (including production, processing, wholesaling, distribution, consumption, and waste management) (CAAB; FICO Eataly 2015). These actors collaborate in creating an alternative to the conventional food supply system and in that manner act as switchers to create a new type of provisioning network. This alternative is the development of a food and agriculture park named FICO (Italian Farming Company). FICO aims to produce local food and to provide services such as catering, retailing, marketing, research and educational activities. It aims to reproduce the whole food production chain (CAAB; FICO Eataly 2015).

FICO links more than actors and policies and generates a new vision about how to manage material flows and new resources to accomplish that. This vision is about creating a synergetic nexus of WEF to become sustainable and self-sufficient. To materialize this, one of its partners 'CAAB' (CAAB is the food center for logistics, warehousing and wholesales which shares facilities with FICO) has installed, on-site, 43,750 solar PV panels with a production capacity of up to 11,350,000 kWh a year. The aim is to power the site's operations of both CAAB and FICO. The renewable energy surplus is aimed to power vehicles transporting people or goods coming in or out of FICO. With regard to water usage, one of the strategies within the FICO project is to re-use wastewater and use rain water to minimize the dependency from the conventional water supply service (Urban Centre Bologna 2016). In this way, the FICO project is a perfect example of how agents of change set up and create a new governance network to provisioning food in a nexus way leading to a transformation in the use and circulation of material flows. It has done so not just by connecting efforts, but also by acting as programmers to generate new visions and ideas about what urban provisioning of services should be like. FICO also resembles an intended linking of WEF into a nexus governance network in which actors consciously tried to integrate WEF, processes and actors into a specific project.

An emerging nexus governance network does not have to be so well-planned and neatly organized. In contrast, very often changes start bottom-up resulting in some change agents leading the way, not necessarily centrally organized but instead working from a networked set of entrepreneurs. Take the case of food provisioning in Amsterdam and its nexus with energy use. In contrast to the FICO project in Bologna, cross-sectorial efforts here are less intended and more fragmented. In this case, it started from bottom-up with entrepreneurs seeking opportunities and experimenting with innovative methods to make urban management more efficient and sustainable. In Amsterdam, a number of entrepreneurs have started food distribution services using normal bikes or electric bikes as opposed to using cars or trucks for delivery, making food distribution dependent on mobility systems that require no energy sources at all or cleaner energy sources. At the same time, it also reduces the congestion of cars, scooters and trucks in the city, thereby reducing levels of air pollution and CO_2 emissions. These entrepreneurs thus stimulate nexus thinking as to how food distribution should look like by setting goals and operationalizing them into new ways of

distributing food and new sources to power this transport. These actors re-connect the food system with the energy system in a way that will help to de-carbonize and de-congest distribution of food. It is not clear whether this is indeed also the intent of these actors. For instance, the primary objective of entrepreneurs such as Uber or Deliveroo may just be to create a new market of bike delivery in a city where bikes are actually much quicker than cars in reaching destinations, plus allowing a larger group of people to work as delivers as all you need is to own a bike. These innovations in delivery services are nonetheless increasingly being picked up by multiple actors, including by established players in the Amsterdam network of food provisioning such as the food centre Amsterdam which is the main distributor, warehouse and wholesaler in Amsterdam (Amsterdam Smart City 2015). Thus, whilst still a bottom-up, innovative and open development, a wider nexus governance network around the use of new mobility systems is gradually emerging including both entrepreneurs and established actor nodes, possibly in leading to a more rigorous application of these new delivery services and an expansion of its use from the food sector to other sectors of provisioning as well.

Whilst the above cases resemble positive storylines on the emergence of an urban nexus on WEF, it is more the exception than the rule. A nexus governance network does not easily unfold. In the quest of the nexus, there are many hurdles and complexities related to policy and decision-making to overcome. These may concern limitations resulting from administrative boundaries (city, regional or national scale); the scale of the management of WEF (municipal, regional or national) (Bhaduri et al. 2015; Biggs et al. 2015; Weitz et al. 2017); and disarticulation in the policy and decision-making (Gain et al. 2015). Actors in the quest of making the nexus thus constantly have to co-frame sustainability related goals, co-define problems, or contest perceptions with regard to effective policy making or even what a nexus governance of WEF is like. It is, therefore, also of interest to examine such cases to understand why a nexus does not come about or fails to come about and how that can be explained through understanding how both material and social flows are historically organized in a city. For instance, Villamayor-Tomas et al. (2015) provide an example of how the allocation of wastewater use incentives for agricultural irrigation has triggered perverse incentives and outcomes. They address the case of the city of Braunschweig (Germany) in its attempt to link wastewater with food and energy. They explain the historical modernization of the wastewater treatment management for addressing the synergy between a growing urban population producing larger quantities of wastewater with the agricultural needs of water for growing crops. Such synergetic agreements between the city, the wastewater association, and farmers (from the peri-urban area) provided a desired, but temporal outcome. Factors such as the supply of affordable and sufficient wastewater to irrigate agriculture triggered then an increase in the growing of crops and in particular, for that case, the production of energy crops. Such events of synergies turned out to be a case of trade-offs, which brought the city and the wastewater association back to negotiations with farmers to coordinate their cropping plans and their irrigation schedules to stop the exceeding water intake from groundwater sources. The authors then argue that the main institutional challenge for the nexus in this case was to coordinate goals and values around food cultivation, energy supply (and the event of energy crops cultivation and energy production) and (waste)water consumption (for irrigating crops and energy crops) across sectors and policies (see, Villamayor-Tomas et al. 2015). Competition of goals and visions towards the management of WEF could also then result in poor integration of the nexus of WEF as seen in this example and further argued in Binder (2007b); Scott et al. (2011); and Gain et al. (2015).

Whether a nexus between WEF provisioning is materially or socially driven, in the end, both material and social dimensions constitute the urban nexus. Cross-sectorial governance of WEF in cities, or a lack thereof, cannot be understood without identifying and analyzing both social and material dimensions of utility provisioning.

Conclusion

This paper contributed to the debate of the theorization of the urban nexus by outlining a conceptual framework that helps to identify interconnections between different systems of provisioning—WEF—and between the social and material flows shaping these connections. Whilst material flow analysis (MFA) provides a crucial overview of the metabolic processes that constitute the urban provisioning of WEF and their interrelations, it does not show how these processes are socially embedded. The paper, therefore, argued that material-focused methodologies, such as MFA, need to be complemented with a social flow analysis that pays attention to the socio-cultural meaning shaping WEF provisioning. It subsequently argued that either material or social flows could be central in driving the creation of the nexus, with the material flows affecting the social organization of cross-sectorial WEF provisioning or vice versa. In the quest for understanding the urban nexus of WEF, cities are crucial places in which environmental flows get configured and linked through governance networks. Cities are nodes where cross-sectorial actors, resources, infrastructures, policies and utility services come together for the provisioning of water, energy and food.

Whilst this paper made a start in conceptualizing how material and social flows interplay in the nexus of WEF provisioning, there are limitations to this study as well. For one, the paper only focused on the nexus within the boundaries of the city. Further research can elaborate on studying the nexus at different scales or administrative boundaries, for instance by understanding how WEF flows in the rural hinterland interact with urban provisioning and vice versa. Similarly, more research needs to address in-depth issues of overlapping accountability and faculties as barriers and opportunities to further gain on nexus governance knowledge. As well, further research can develop this conceptual framework for the study of different components of the social (e.g., discourses, social practices, or power dynamics through WEF networks) and material (e.g., disposal processes) flows, or it might be applied as well to different natural resources (e.g., waste, nutrients or minerals).

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