Chapter 11
Is Connectivity a Desirable Property in Urban Resilience Assessments?

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11.1 Introduction

The need to look at environmental-related problems from a systemic perspective has been increasingly recognised during the past years. In resilience thinking (Kinzig et al. 2006) and sustainability thinking (Liu et al. 2015), coupled human and natural systems are treated in an integrated way so that nexus issues, cascading effects and spill-overs can be taken into account. It has no sense to consider problems only from one perspective (either environmental, economic or social) when there might be other interacting variables that could affect the system and alter future scenarios.

Urban areas as complex adaptive systems (hereafter CAS) (Alberti et al. 2003) are formed by coupled human and natural systems (Ernstson et al. 2010; Liu et al. 2007) and thus their resilience and sustainability should be conceptualised, developed and planned also following this systemic integrated thinking. From a theoretical point of view, the system or network perspective in resilience theory has been argued to be useful to assess system's characteristics i.e. robustness, connectivity and dependency (Janssen et al. 2006). In this line, some systemic

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approaches to resilience assessment have been proposed for different purposes such as to assess the robustness of infrastructural systems (Hosseini et al. 2016; Labaka et al. 2015) or ecosystems health (Alberti and Marzluff 2004), but also to evaluate the social network capacities (Wallace and Wallace 2008). However, so far, and to our knowledge, the implications of these networks within urban complex dynamics have been loosely addressed and discussed from both theoretical and evidence-based studies.

To contribute to this debate, this chapter focuses on the connectivity of the urban system as a potential measure of resilience, and discusses the role that this feature may have in the resilience management of the system, i.e. including its transformability. We use a case study on urban energy resilience in the city of Bilbao (Spain) to illustrate the discussion.

Next section elaborates on the conceptualisation of urban areas as complex adaptive systems and its implications for connectivity assessment. Section 11.3 explores how connectivity has been treated in the resilience literature and specifically in urban resilience assessments. Section 11.4 describes the network perspective in socio-ecological research and the main characteristics of networks including measurements of connectivity. In Sect. 11.5, we describe the case study of Bilbao where Fuzzy Cognitive Mapping methodology is used to generate an integrated map that accumulates existing knowledge on the system. Sections 11.6 and 11.7 present the results and discussion and Sect. 11.8 draws some conclusions on the implications of connectivity for resilience management.

11.2 Urban Systems' Complexity

Complexity is an embedded characteristic of urban systems (Portugali 2000), arising from the interdependencies of social, infrastructural, ecological and economic realms which cascade into different spatial and temporal scales. Both quantitative sciences (e.g. Allen 2012), through models from the late 40 s and mainly from the 70 s onward (see "cellular automata", "agent-based modelling", "fractals" propositions) and qualitative sciences (e.g. Castellani and Hafferty 2009) have addressed complexity in cities.

Urban complexity starts with the characterisation of the urban area itself. Urban areas vary in terms of size, economic profile, urbanisation patterns etc. These differences are often influenced by geo-political needs, history and cultural heritage among other factors. Together with lifestyle patterns, they determine to a large extent the energy and material consumption levels that can be credited to urban areas. Resource availability and environmental conditions in urban areas are critical factors for supporting urban metabolism and resilience to gradual environmental changes or unexpected shocks. These factors are influenced by contextual characteristics such as location and orography. However, even when the huge divergences in urban areas' social, ecological, economic and institutional contexts and their development stage are acknowledged, not all urban areas have the same level of complexity or are complex in similar ways. This means that equal challenges and targets that urban areas might be facing could be solved differently or if the same mechanisms are utilised, they may have different outcomes. This is the result of seeing urban areas as CAS.

Certainly, one of the most important characteristics of considering urban areas as CAS is that complexity may be hidden in a very simple system, and that complex global systems patterns may emerge from interactions at local level. This is called emergence in complexity thinking (Lansing 2003). Emergence translates into an unpredictable adaptive behaviour of the elements of the system which evolve responding to exogenous and endogenous drivers (Levin et al. 1998). Complex systems are those composed of many individual parts that interact. These groups of interacting entities show a collective behaviour that might be different from the one manifested at individual scale or the one expected by scaling it up to the group level (Samet 2013). As CAS, urban areas are seen as microstructures that coalesce to form systems of cities that function better and are more adaptive as a macrostructure rather than individually. This leads to a series of cross-scale interactions between urban technical and social networks generating those energy, material and information flows (Ernstson et al. 2010). Because of this, in order to assess the consequences of potential interventions, urban areas, as inclusive systems, should be analysed considering their multiple constituent parts (infrastructures, norms, agents…). Other issues that need to be considered are contextual enablers (environmental, social and economic capital…) and internal or external connections.

In fact, defining the boundary limits of an urban system is difficult. In this endevour, the physical scale of the social and economic network that affects urban areas becomes relevant. This is particularly the case regarding the implications for energy, material and information flows. These system dynamics cause a higher degree of complexity which results in urban areas presenting multiple challenges to decision-makers and therefore to those that aim at studying urban change (Grimm et al. 2000; Pickett et al. 2001; Ruth and Coelho 2007).

The view of urban areas as CAS is required to encapsulate the dynamics of at least these three dimensions (Olazabal 2017): (i) natural biophysical processes and metabolic flows generated by the demands of urban users; (ii) the effects of exogenous changes in the flow of ecosystem and human services on human well-being; and (iii) the gradual reactive socio-technical and economic adjustment of cities to shifts in their contextual landscape such as those that may arise in the context of global economic and environmental change.

Although urban complexity research is not new (Batty 2007, 2008, 2013a; Castellani and Hafferty 2009; Portugali et al. 2012), it is not sufficiently spread between disciplines and it is not appropriately operationalised. This has prevented the research community from fully understanding urban areas and therefore, to manage them in the practice (Bettencourt 2013). In this regard, the analysis of the implications of connectivity within the system is one of the many steps that should be advanced.

11.3 Connectivity and Resilience

Urban complexity links with resilience through the evolutionary patterns of cities development, characteristics and capacities to deal with change. However, addressing resilience translates into the difficulty of operationalising this vague and metaphorical concept (Brand and Jax 2007) which in the last decades sprawled across policy frameworks from local to global scales (UN-HLPGS 2012). Indeed, as Bohland et al. (2017) recently argued that there's a "resilience machine"—referring to the seminal "The City as a Growth Machine" (Molotch 1976)—building on the value-neutral diffused perception about resilience in order to legitimize business-as-usual urban development projects. Different authors have put forward in this last decade their critical perspectives about resilience contesting its normative positive nature (Chelleri and Olazabal 2012; Meerow et al. 2016; Vale 2014). This aligns with the "non-equilibrium view" of resilience, and puts emphasis on dynamics and evolution rather than on returning to the equilibrium state (Pickett et al. 2004). In this line, the critical study of resilience attributes, their theoretical and their real-world cases' testing, becomes a central issue for advancing our understanding of cities as CAS.

With this in mind, it is important to recognise that any practice related to resilience could imply trade-offs (Chelleri et al. 2015) or social un-justice (Anguelovski et al. 2016), making relevant pose the questions of urban resilience for whom (Vale 2014) and why (Meerow and Newell 2016). The emergence of these trade-offs are a result of relate to the multiscalar dimensions of resilience and thus, examining the interactions of the elements of the system at different spatial scales are theoretically and in practice (Chelleri et al. 2015) a good strategy to manage resilience.

This said, connectivity as a characteristic of the urban system that explains the interactions of its elements is therefore a key aspect to be explored and assessed in cities.

Connectivity can be examined in the context of, and also across, different fields such as energy circulation, communication, transportation and mobility and landscape ecology (Ahern 2013; Sharifi 2016; Sharifi and Yamagata 2016). Therefore, it can be discussed in terms of the movement of various agents including, but not limited to, humans, vehicles, information, and species. Connectivity is an important feature in socio-ecological dynamics and therefore in socio-ecological resilience (Elmqvist et al. 2003). Connected socio-ecological systems are believed to provide better ecological functions and to exhibit higher capacity to survive, adapt and evolve (De Montis et al. 2016). In ecology, connectivity might be defined as "the degree to which habitat for a species is continuous or traversable across a spatial extent" and it can be classified in structural and functional connectivity (Andersson 2006, p. 3). In order to maintain resilience of socio-ecological systems it is important to develop management practices that enhance landscape connectivity so that services such as recreation, air and water regulation etc. can be maintained (Andersson et al. 2014; Elmqvist et al. 2003). Landscape connectivity (through well-connected blue and green networks such as rivers, parks, etc.) supports biodiversity which in turn facilitates a variety of benefits such as flood control and stormwater management, air pollution mitigation, reduction of the urban heat island effect, passive cooling, urban food production, environmental education, human stress alleviation, aesthetic improvement, property value enhancement, and urban safety (Ahern 2013). Ling and Dale (2011) argue that being placed along ecological edges (such as rivers, lakes, and mountains), and landscape connectivity can be considered as a measure of resilience and liveability of cities. They argue that the high quality of life, sense of place, economic vitality, liveability and creativity of Vancouver in Canada can be attributed to the permeability between the city's built environment and the mountain and sea landscapes beyond the built environment. Over time, the city has made efforts to maintain this connectivity and permeability of the city and avoid development plans that undermine this feature (Ling and Dale 2011).

In the specific case of cities as intensively managed coupled human and natural systems, maintaining connectivity of ecological units is challenging, therefore, putting at risk the ecological resilience of the system. Degradation or loss of connectivity may have severe short-and long-term consequences. Human interference in the landscape and ecosystem can disrupt the natural flow of energy and resources between landscape units and affect the natural evolution of ecosystems. For instance, a modelling study conducted in Italy (Gobattoni et al. 2011) shows that a 30% urban sprawl in the Traponzo watershed can have critical negative impacts and even completely remove the "exchange of biological energy". One of the main consequences of urban sprawl is fragmentation of the landscape leading to negative impacts on biodiversity and a reduction or even elimination of energy and matter exchanges. Maintaining connectivity is, therefore, essential to ensure tipping points related to natural equilibrium points of the landscape are not crossed (Gobattoni et al. 2011).

Probably as a consequence of the social and ecological origins of resilience thinking as illustrated above, connectivity is often taken as a key feature of resilience in the urban resilience literature (see e.g. Ahern 2011; Ernstson et al. 2010). Ahern (2011) argues that because cities need to continue functioning after shocks, the connectivity of an urban system's is generally high. It therefore correlates positively with increasing resistance, i.e. protecting the urban system against unexpected impacts. However, as put by Holling (2001) a system that is too tightly connected can potentially lead to undesirable outcomes as a result of a rigid control. The optimal structure of the system may vary depending on the underlying purposes. For instance, maximizing connectivity can provide benefits in terms of movement of people and species. However, over-connected systems (e.g. streets/transit systems) could also intensify undesired effects and cause issues such as swift spread of diseases (epidemics) (Batty 2013b). Based on this and in line with the discussion on the trade-offs of resilience, we argue that more empirical evidence is required in this regard.

11.4 The Network Perspective

> There is no such thing as the "right" way to represent the social-ecological network of a given system, just useful and not so useful ones (Janssen et al. 2006, p. 3).

One of the challenges for urban human-ecological studies is to overcome the 'black-box' approach. Urban systems are characterised by elements (or nodes), processes (or functions) and distributive channels (or connections) of material, energy and information fluxes. This resembles the ecological view where "a network flow model is essentially an ecological food web (energy–matter flow of who eats whom), which also includes non-feeding pathways such as dissipative export out of the system and pathways to detritus" (Fath et al. 2007, p. 50). According to Zhang et al. (2009), ecological networks are divided into "compartments" and "pathways" where each compartment has a specific function, and pathways distribute materials, energy, and currency across compartments. Urban landscape ecology research (Pickett et al. 2011) argues that in the city, despite fragmentation, ecological processes may continue through patches and corridors. How these patches and corridors spatially distribute influence the actual performance of the city, in the face of shocks, by protecting it from natural disasters and climatic impacts (Aminzadeh and Khansefid 2009). Adapting this idea to social-ecological networks in urban areas, one could say that for example, the more robust the social connectedness is among citizens, the less vulnerable it becomes to natural disasters (Wallace and Wallace 2008). This opens the ground for expanding the study of urban systems' performance in relation to the webs or networks, which should not necessarily be restricted to the field of ecology. Social sciences, information, communication and technology-related research, mobility-related research and a range of different fields examining urban systems dynamic have already undertaken this kind of research perspective on cities (Batty 2013b; Castellani and Hafferty 2009).

In the context of resilience thinking, it is argued that a network perspective is helpful to analyse complex environments, given that it focuses on the interaction between components and how those interactions affect the system behaviour (Janssen et al. 2006).

In this chapter, we use the seminal paper by Janssen et al. (2006) as the main reference for the study of resilience from a network approach. Although their discussion very much relies on their ecological perspective, their approach can be useful and applicable to urban areas as CAS. Recognising the challenges of representing a CAS network, Janssen et al. (2006) identify three types of social-ecological networks (see p. 6): (1) ecosystems that are connected by people through flows of information or materials (for instance, in the urban context, a lake and the urban fauna), (2) ecosystem networks that are disconnected and fragmented by the actions of people (i.e. urban forests), and (3) artificial ecological networks created by people (i.e. irrigation systems). In theory and practice, all of these typologies would be possible to find in urban systems.

According to Janssen et al. (2006), **nodes** can represent both social (human-related nodes including built infrastructure) and ecological components, and **links** can represent physical flows between physical units or the exchange of information between social actors. It is possible that, some nodes and links are "asleep" in normal times or that they disappear in times of disruption. During a disruption, change or shock, a resilient system is able to maintain the capacity to reactivate nodes and links (Janssen et al. 2006) or to create new nodes and links to maintain functions if the original ones disappear (Walker et al. 1999).

Janssen et al. (2006, pp. 4–5) also introduce some metrics and characteristics of socio-ecological networks: **level of connectivity** which can be represented by "the **density** of the links within the network, that is, the number of links divided by the maximum possible number of links" and "the **reachability** or the extent to which all the nodes in the network are accessible to each other"; and "the **level of centrality** which covers not only the distribution of links among the nodes in the network but also their structural importance".

11.5 Case Study and Method

This section presents a case study in the city of Bilbao (Spain), which deals with the planning and management of urban low-carbon transitions, i.e. transformation strategies to reduce urban energy use. This case is useful in exploring the relationship between complexity, connectivity and resilience through the analysis of the networks that can potentially build energy resilience.

Located in the Bizkaia province of the Autonomous Community of the Basque Country, Bilbao is a city of 41 km^2 and 353,300 inhabitants (Basque Government 2013). Traditionally based on the steel and shipbuilding, Bilbao turned itself into a service-led city after the industrial crisis of the 1980s. This caused a successful transformation of its economic structure and urban regeneration in the 1990s considered an example of sustainable renovation (Gonzalez 2011; Keating and Frantz 2004). As discussed by Olazabal and Pascual (2015), the efforts of City Council to reduce energy consumption through plans and programmes have not been successful indicated by the increasing use of energy and the low share of renewables in the city.

In order to analyse the links between connectivity and resilience in an urban area, we use the results of the case study developed in Olazabal and Pascual (2016) that performed a Fuzzy Cognitive Mapping (FCM) study in Bilbao. By applying FCM, the study of Olazabal and Pascual seeked to reveal the complexity of the energy system in the city of Bilbao with the final purpose of understanding indirect and unidentified impacts of potential transformative low-carbon interventions.

FCMs are fuzzy graphs that represent causal reasoning through "hazy degrees of causality" (Kosko 1986). One of the main advantages of FCMs is that their graph structures facilitates merging different FCMs, coming, for examples, from different participants describing the same or complementary phenomena (Kosko 1986).

The design and means of the elicitation process is defined depending on the objectives of the experiment (Özesmi and Özesmi 2004; Isak et al. 2009). FCM can be used to integrate views of diverse experts and stakeholders and thus provides an integrated lens on the 'perceived' mechanisms of a system. FCM has proven its potential for the analysis of systems' structure, scenario building, decision-support and knowledge co-production (see Gray et al. 2015; Kok 2009; Vanwindekens et al. 2013) and has been used in the context of resilience (Gray et al. 2015; Olazabal and Pascual 2016).

In FCM, concepts relate to each other through directed, signed and weighted arrows representing causal relationships, thus forming a cause-and-effect diagram. The quantitative part of FCM takes the form of signs (positive or negative) and weights (e.g. from 0 to 1) that are assigned to each connection. In a FCM exercise the analyst collects individual maps or networks and later, treats this data to produce an aggregate network. The network that results from a FCM exercise can be described mainly in terms of its **density (D)** and the **centrality** of its components **(Ct)**. D indicates the general connectivity of the network and relates actual connections with the total potential connections among existing nodes. Following this, a larger number of concepts indicate a larger number of potential connections. It is thus often assumed that a higher density indicates more possibilities for change, as there are more connections in the network. However, change is only possible if these connections are perceived by the actors of the system, turning them into "catalysts of change" (Özesmi and Özesmi 2004). Ct not only indicates the level of connectivity of each concept but also the strength of such connections (i.e. how much and how strong the concept is connected). Ct is an additive function of the concept's in-degree (I) and out-degree (O). 'I' is the result of aggregating the strength of concepts entering the concept being analysed and 'O' is the result of aggregating the strength of this concept on other concepts (Özesmi and Özesmi 2004). Such strength is calculated as an additive function of the weights of the connections to or from the concept under analysis. This way, the larger the number of connections to or from a concept, the larger the possibilities are for Ct having a higher value, i.e. the concept being characterised as having higher connectivity within the network. In other words, a network with high levels of Ct among its elements, suggests a high-density level, i.e. a high level of network connectivity, and vice versa (Table 11.1).

The FCM case study of Bilbao used face-to-face interviews with 14 experts in various issues related to energy, such as energy production, consumption, planning management, and energy business. Participants included representatives of the local authorities, energy facilities, social communities, energy cooperatives, researchers and others. Each individual was asked about their view of the factors that influence energy consumption in Bilbao and its impacts on other social, economic and environmental aspects of the city. With the help of the analyst, they translated their responses into a cause-effect map. Each connection was weighted on a scale from 0 to 1, or from 0 to 10 if the interviewee felt more comfortable with this scale. These weights were after normalised.

Table 11.1 Network characteristics in FCM (from Olazabal and Reckien 2015)

	Equation	Description
Equation 1	$\boldsymbol{D} = \frac{\sum C_i C_j}{N}$	Density (D) is calculated by dividing the number of actual connections (C_i C_j) by the number of total possible connections. It is an indicator of connectivity
Equation 2	$\boldsymbol{Ct_i} = \boldsymbol{O_i} + \boldsymbol{I_i}$	Centrality (Ct) is the sum of a concept's in- and out-degrees (I and O respectively). It denotes the individual importance of a concept in respect to other concepts in the network
Equation 3	$O_i = \sum_{\boldsymbol{k=1}}^{\boldsymbol{k}} \boldsymbol{\bar{W}_{ik}}$	O_i is a the out-degree of a concept. It is calculated by adding up the absolute weights of all outgoing connections of a particular concept. It is a measure of the strength of the influence of one concept C_i on other concepts in the network
Equation 4	$I_i = \sum_{k=1}^{k} \bar{W}_{ki}$	I_i is the in-degree of a concept. It is calculated by adding up the absolute weights of all incoming connections of a concept. It is a measure of the dependency of a concept on other concepts in the network

11.6 Results

The 14 individual maps were digitalised, treated and later aggregated (for further details on the aggregation process see Olazabal and Pascual 2016). The final aggregated map conforms the final network which has been analysed in terms of its network characteristics. Network characteristics that represent connectivity such as D and Ct have been calculated. The final network is shown in Fig. 11.1.

The density (D) of the network calculated through Eq. 1 is 0.022. The maximum possible density is 1. This would mean that all concepts are linked to the rest, adding up to 7396, which is the total number of potential connections. The 14 stakeholders interviewed identified only 161, i.e. 2.2% of total potential connections. With no similar experiments to compare, it is difficult to reason if this is a high or low density. Clearly, not all connections have a sense in the urban context. This will be a good way of theoretically setting a threshold for density, but however, not reflecting real opportunities in the case study. For this reason, we will focus on the other metric related to connectivity: Ct.

To cluster the elements according to their importance, Fig. 11.2 displays the results of the Outdegree (O) and Indegree (I) indices calculation (centrality—Ct- is the sum of the two, see Eqs. 2, 3 and 4) in decreasing order for Ct > 20% of the maximum Ct found in the network (13.25 for "Energy price (households)").

Elements with higher Ct are located in the left-hand part of the graphic. However, the source of their Ct may come from different reasons: some of them are mainly transmitters i.e. high O (e.g. energy lobbies) some other are mainly receivers i.e. high I (e.g. energy efficiency). We observe the same pattern in Fig. 11.3 that goes deeper in the analysis and classifies 4 types of elements based on their Ct.

In the energy network of the city of Bilbao as perceived by stakeholders there are some elements that have clearly more importance than others. Results show that

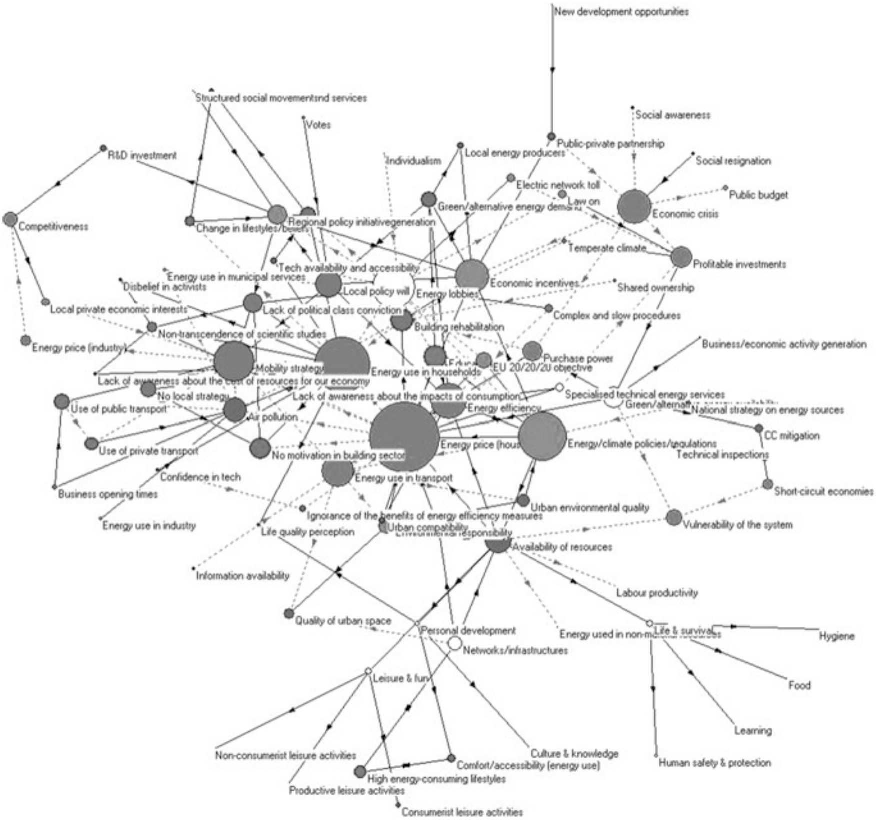

Fig. 11.1 FCM of the energy network of the city of Bilbao (adapted from Olazabal and Pascual 2016; Olazabal and Reckien 2015). The size of the Ci concepts denotes the number of connections of Ci to other variables and also indicates the degree of centrality (Ct). Dashed arrows indicate negative connections (negative wij) and normal arrows indicate positive connections (positive w_{ij})

some of the variables have a high Ct due to a high O and high I (set here as higher than 4 in both cases), such as 'energy price (households)' and 'energy use in households' (see top-right area in Fig. 11.3 and actually both elements obtaining the maximum scores in Fig. 11.2). Both represent very important aspects of the energy system in Bilbao as the size of their nodes indicates in the network shown in Fig. 11.1. However their potential role as transmitters or receivers is uncertain. Other variables have a high Ct caused by a high O but a low I (e.g. 'mobility strategy', 'energy/climate policies/regulations' and 'energy lobbies'). This means that these variables could potentially act as drivers of change in the system as they have a high level of influence on other variables, and would allow to control de process of transformation, given that they receive low influence from other (low I). Another group of variables have a high Ct caused by a high I but a low O (e.g. 'energy efficiency', 'air pollution' and 'no motivation in the building sector'). This

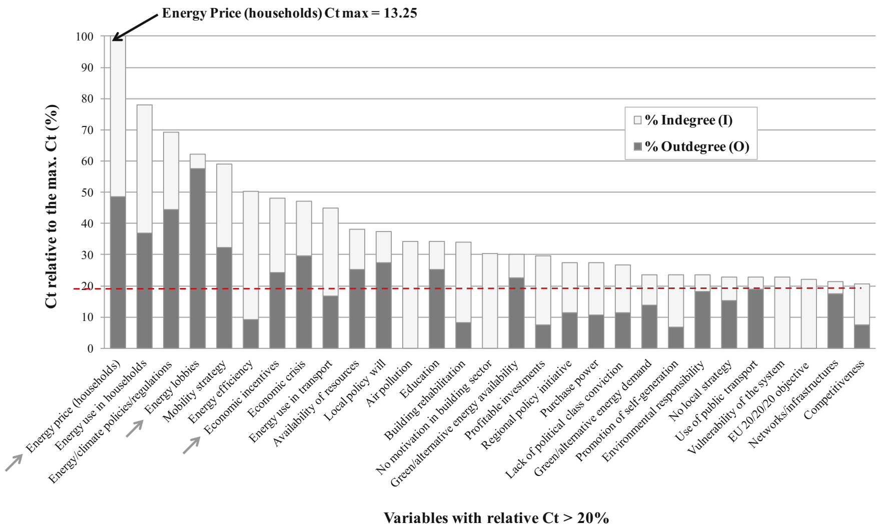

Fig. 11.2 Network indices: Out-degree (O), In-degree (I) and Centrality (Ct) = O + I. Only elements of the network with Ct > 20% are shown. (Olazabal and Pascual 2016)

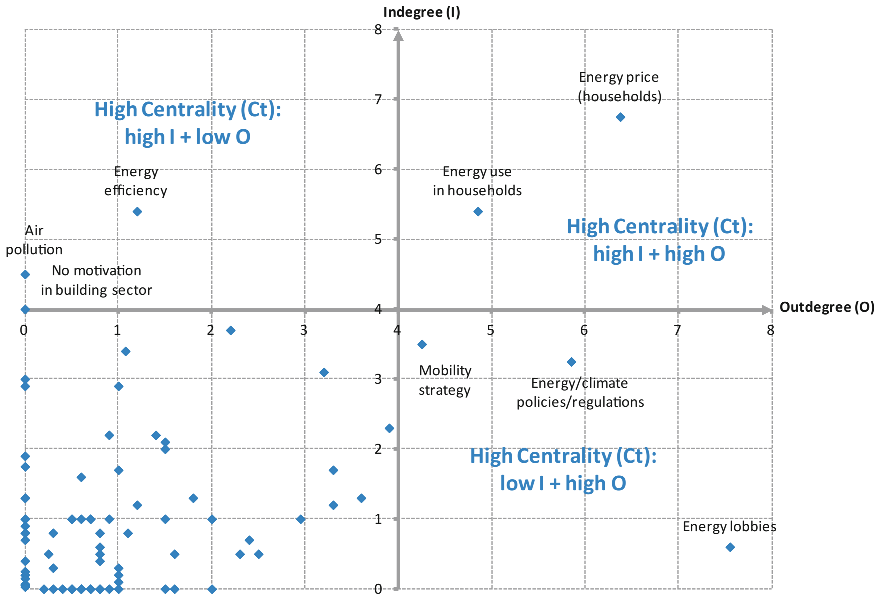

Fig. 11.3 Centrality (Ct) of the elements of the system (Olazabal and Reckien 2015)

means that these variables are receptors of change and impact when other variables of the system vary.

11.7 Discussion

Indicators and metrics are common instruments used for assessing resilience. As pointed out by Albers and Deppisch (2013), some of them may have tradeoffs and conflicts with each other. In networks research, centrality (Ct) and density (D) are two frequently used measures of connectivity. Connectivity is often seen as a positive characteristic of urban resilience: intra- and inter- connectivity of cities is a key characteristic in resilience thinking (Ahern 2011; Ernstson et al. 2010). As above argued, context-specificity is an important aspect to consider when assessing connectivity and resilience. In the case study of the urban energy system of the city of Bilbao, we cannot make concrete claims on the level of connectivity of the whole system (D = 2.2%). For making such claims either a reference system with exact same characteristics or longitudinal baseline assessments of the case study city is needed. Having the density of the system assessed in different points in time would help to compare structures and evaluate the benefits of high or low connectivity under different scenarios. As previously raised, it would also help to establish a theoretical limit for density if one identifies feasible connections to other elements. However, this theoretical exercise would involve many uncertainties derived from the bias of the analyst and the need to contextualised the feasibility of such connection in the case study.

For the urban energy system of Bilbao, in a classification of four, we identify three types of high centrality (Ct) (high connectivity of the elements in the system): they differ on the combination of sources of Ct: outdegree (O) or indegree (I) i.e. outgoing or incoming connections. We observe that the system is highly driven by the offer and demand since the two more connected elements that have both high O and high I are "Energy price" (representing offer) and "energy use" (representing demand). Elements with high Ct resulting from a high O are good examples of elements that can be used to drive the system into another different state (urban strategies, regulations and policies and lobbies). Elements with high Ct resulting from a high I are those that will be highly impacted (efficiency and pollution).

Results demonstrate how exploring the concepts' cause-effect relationships helps better understanding patterns of stability or transition.

The map (Fig. 11.1) and most influential concepts (either because of high I or high O, see Figs. 11.2 and 11.3) illustrate how enabling sustainability transitions may require a focus on business-as-usual practices to guarantee agency of desirable change.

From the results, we can extrapolate critical factors determining Bilbao's business-as-usual energy practices, for instance (see Fig. 11.2):

(i) local political will is perceived less influential than lobbies but more influential than regional policy initiatives,
(ii) green alternative energy availability is more influential than demand, and demand would be hardly turn into an agent of change because its high role as receptor (high I related to O),
(iii) environmental responsibility scoring seems very low, and, finally
(iv) energy is not seen as a profitable investment and competitiveness is scoring last regarding its importance in the system.

These results enable the process of understanding how to inform policy makers and manage factors which should be relevant for sustainability transitions, but that currently are not perceived as key. It should be noted that this network represents the aggregated knowledge on how the system works so it would always reflect a view closer to reality.

Results also indicate that increasing the number of connections per se is not obligatory related to better resilience performance. Increasing connectivity leads to an increase of non-linear feedbacks and thus, of the complexity of the system. When planning for transformation, more variables and connections among variables would need to be considered and the number of possible futures might increase exponentially. Seen this way, the connectivity of the network might not be necessarily desirable (Olazabal and Pascual 2016). For this reason, building scenarios based on potential policy options that consider cascading impacts and the systemic perspective of cities can be helpful for decision-making.

So far, we have argued and discussed connectivity in terms of its role during intended transformations. We find that connectivity may support the agency of change, however, a trade-off might also exist in cases of undesirable transformations resulted from unexpected shocks. A high connectivity might also translate into a situation where a shock spreads more widely and quickly and produces a higher number of failures due to a high number of connections between its elements. Again, this proves the double-edged sword that connectivity represents for resilience of the system.

11.8 Conclusion

In this chapter, we have examined connectivity as a characteristic of the system and its role in the management of the resilience of the system. To do this, we used a network approach and fuzzy cognitive mapping as a methodology. We used the case study presented by Olazabal and Pascual (2016) to provide a deeper analysis on the theoretical and practical implications of connectivity in the system.

We demonstrated how FCM can be utilised to identify system elements that can play essential roles in driving transformations. The technique can also be used for determining those characteristics of the system that are likely to be act as drivers of change or be influenced by changes in the system configuration. Therefore, this technique should be considered as an effective decision-support and learning tool for planners and policy makers that would like to assess and enhance the resilience of their urban system. Results of FCM also show the relative importance of different elements of the system and this feature can help planners decide which elements (factors) should be prioritized in future plans.

A closer examination of the case study provides evidence that increasing the connectedness of the energy sector as a business-as-usual strategy will further consolidate the current patterns, while no space is left for transition. Networks and connectedness principle should be handled in the same way: information on connectivity (measured by centrality, outdegree and indegree) should serve as a strategy-guiding map, in order to act with the most appropriate policies that are able to reverse perverse interactions and feedbacks. In line with the objectives of adaptive management, this should be done in an iterative way, until the desired configuration of the network, e.g. that one that provides higher opportunity options and higher low-carbon reductions in an equitable way, is achieved.

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