Distributed Renewable and Interactive Energy Systems in Urban Environments

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Abstract. European Policies consider a multitude of Low Carbon Technologies to transform cities to Low Carbon Cities. Some of these technologies can form distributed systems. These are new forms of Energy Networks which can contribute to reducing the vulnerability and homogenization of urban patterns as they evolve to become part of the urban infrastructure. This evolution process also involves computerizing elements of the infrastructure, and thus relates to the Smart City concept. In this sense, a Distributed and Renewable energy system becomes interactive promoting a set of novel system properties. Following a qualitative approach, this paper presents an innovative conceptual framework in order to establish, communicate and disseminate these new system properties.

Keywords: Low Carbon City, Smart City, System Innovation, Urban Patterns, Ecological Approach

Reconciling urban patterns and smart systems

Currently, the Smart City concept is recognized as a relevant theme in understanding the trajectory of urban development (European Commission, 2012). Smart city solutions are those that integrate technologies from Energy, Transport and Information and Communication Technologies (ICT). Although this concept is considered fundamental for the evolution of urban environments in the literature, its relationship with different urban patterns is not sufficiently investigated.

The term «Smart City» was introduced by the Strategic Energy Technology Plan (SETplan) in 2009 (European Commission, 2009) as a strategy for Low Carbon Cities (LLCs). It concerns the computerisation of the energy infrastructure, which has manifested new opportunities (Bribri and Krogstie, 2017). These opportunities can revolutionise the existing Energy Networks, which had been considered immutable until relatively recently (La Porte, 1994).

A large part of the literature at the intersection of Smart Cities (SC) and urban patterns, which are defined as the way in which different functions and elements of the settlement form are distributed and mixed together spatially (Lynch, 1981), focusses on the impact of the latter on energy consumption and carbon emissions (Benjamin, Tan and Razon, 2015). Other studies investigate the SC concept essentially in terms of innovative technologies and smart systems (Angelidou, 2015). The relationship between the SC concept and urban patterns, which is difficult to unravel, is largely neglected. Two key issues should be dealt with: the old, large socio-technical systems' resistance to change; and the synchronization between the individual resident's energy choices and the system's organizational principles and characteristics (Basosi, Casazza and Schnitzer, 2017). Alternative energy systems, such as the Distributed Renewable and Interactive (DRI) energy systems, are thus needed. The components of these systems can work as ecosystem service categories (i.e. supporting service[1]; provisioning service[2]; regulating service[3]; cultural service[4] (MEA, 2005).

Ackermann, Anderson, and Söder, (2001) defines a DRI as a low-medium voltage electricity system, connected directly to the place of consumption. Interactivity of the system is enabled through the diffusion of informatics devices and software, which is revolutionizing the sense of "making infrastructure". It is a system property that involves all components in multi-level interactions. At the same time, interactivity validates the concept of micro-grid as a fundamental part of the debate on energy evolution (Soshinskaya et al., 2014). It is a system property that can connect the energy system to the specificity of the local context.

The Virtual Power Plant (VPP) is the main device for managing interactivity. It is a technological system aimed at synchronously managing the information and energy fluxes. The dimensional and localization logics managed through VPP are completely different from the traditional fossil-based energy systems. Many studies have considered interactivity from the perspective of optimizing the integration of different renewable technologies by using information systems (Dimeasand and Hatziargyriou, 2007, Siano, 2014).

These studies contributed to the discourse on a new energy infrastructure system from different points of view, but an all-encompassing framework to conceptualise it has not yet been developed. Issues around their incompatibility with the old notions of infrastructure and its classification have not been explored. Given this situation, the traditional definition of infrastructure and associated indicators (Hansen, 1965) faltered.

Evolutionary integration of the alternative systems into existing urban patterns rely on an innovative approach to transforming cities to LCCs. The new approach is founded on new mechanisms for infrastructure evolution. The literature refers to these mechanisms as evolutionary mechanisms and synthetizes them in the three pertinent facets:

- The co-evolution process: synchronization of new technologies, market models, eco-system practices and final users (Foxon, 2011).
- Multi-level interactions: inter-linking the technical system and urban patterns and vice versa (Geels, 2005).
- The dynamics between the main actors of the technical innovation processes (Foxon et al., 2013).

These evolutionary mechanisms describe the general inalienable conditions in which the DRI systems are called to operate so that an innovative approach to the LCC can be constructed.

Aim and innovation profiles

A new conceptual framework is needed for the above integrated vision to be developed and embraced. It is deemed more consistent with the purposes of integrating sustainable energy services and systems with local peculiarities of settlements. This paper proposes such a novel conceptual framework, which is based on an innovative approach to the LCC and the concept of DRI Energy Systems in Urban Environments. The key concepts in this context are: urban patterns, the SC concept and DRIs (Fig. 1). The evolution trajectory of a

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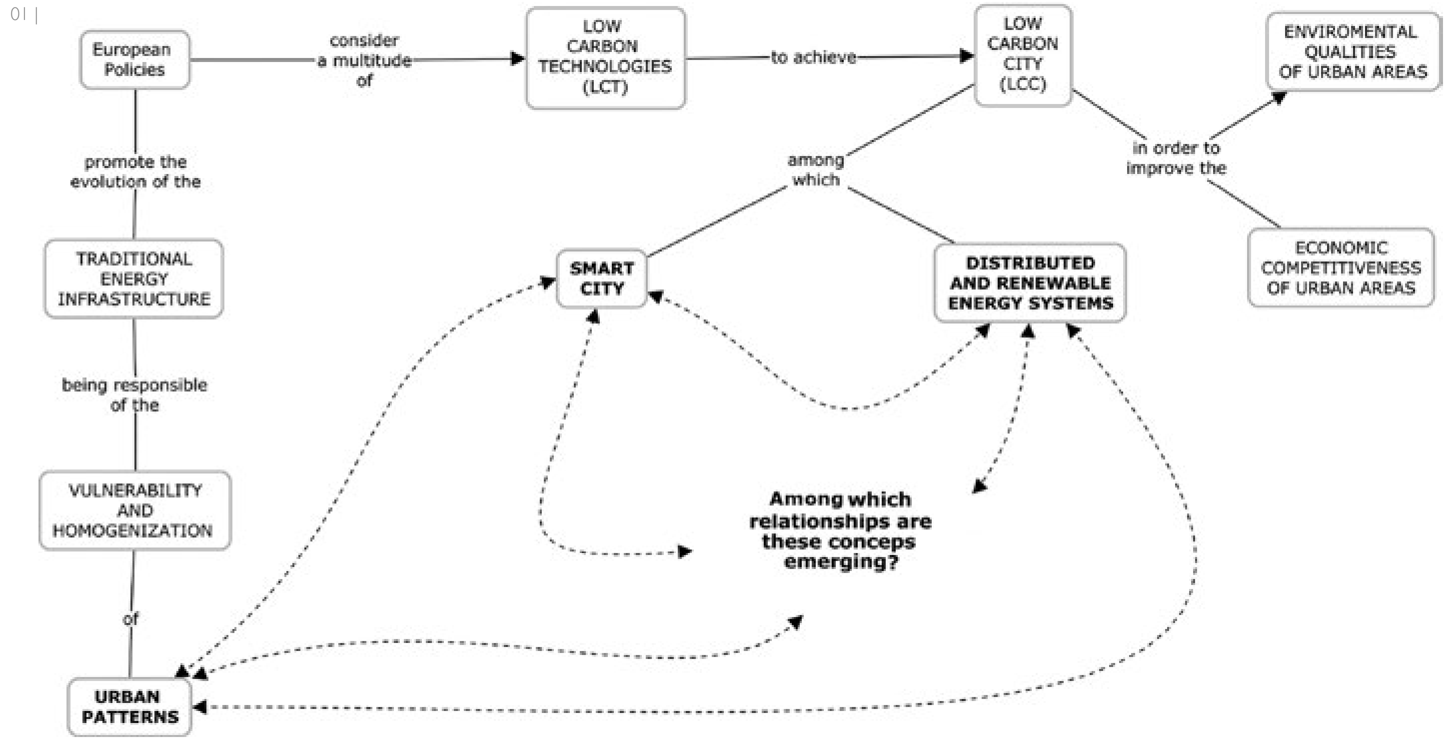

01 | Key Concepts and research question

DRI energy system will also be defined in order to synchronize the evolution of settlements with the computerization processes, embracing a broader view of the SC concept and an ecological approach toward the LCC.

This study starts by marking the mechanisms through which infrastructure evolves; circumscribes the research investigation towards the DRI system and its main features; proposes a novel conceptual framework on the DRI system; and introduces an operational framework for the DRI system, pointing out a specific socio-technical role for the Virtual Power Plant (VPP). To conclude, the authors illustrate how the new conceptual framework can enhance the SC concept.

Methodological approach

A qualitative approach has been adopted to build the conceptual framework. Qualitative content analysis of the existing literature is conducted to define the problem and identify the concepts which have the potential to offer a viable solution (Jabareen, 2009).

A process of theorization, which uses grounded theory methodology rather than description of the data and the targeted phenomenon (Jabareen, 2009), is utilised to build the conceptual framework from existent multidisciplinary literature. This framework is developed as a network of linked concepts. The proposed methodology comprises the following main phases:

Phase 1 - Identifying the DRI concepts: Concepts relevant to the energy infrastructure evolution are identified multidisciplinary literature. Hughes' (1987) Large Technological systems (LTS) concept, Zeleny's (2012, 1986) approach to the management of High Technology Components (HTCs), and Harrison and Donnelly's (2011) approach to characterising the SC are identified as the foundations of our conceptual framework.

Phase 2 - Integrating the DRI concepts: LTS, HTCs and SC are integrated. The definition of LTS is the starting point. It is deemed more consistent with the purpose of restoration of energy ecosystem services within the regulatory framework for territorial infrastructure. Hughes (1987) marks a radical change from the past and current patterns of homogenisation and vulnerability. Zeleny's approach (2012, 1986) is used to describe the evolutionary phase, in which the DRIs are called to operate. Harrison and Donnelly (2011) offer an opportunity to synchronize the algorithms and digital protocols with unique urban patterns, by improving local technological literacy, including understanding the functionalities of the VPP.

Phase 3 - Validating and rethinking the conceptual framework: The proposed conceptual framework is discussed. It denotes a multidisciplinary approach to the evolution of the energy infrastructure. It may be revised according to new insights, emerging literature, and reveals the need for a new generation of energy policies for DRI energy systems.

Phase 1. Identifying the DRI System concepts

In this section the concepts identified as the foundations of a new energy infrastructure conceptual framework are introduced. The results in Table 1 illustrate the LTS as the foundation of a DRI. Table 2 explains the HTCs. Table 3 illustrates the SC concept, pointing out the concrete possibility of synchronizing the algorithm and digital protocols within a local context and with a unique urban pattern.

Category: Large Technological System (LTS)
Concepts: Infrastructural apparatus; Vulnerability; Homogenization; Infrastructure Evolution; Local context; Reverse salient; Components.
Description: Hughes' (1987) LTS concept contrasts this obsolete infrastructure definition, and opens the debate on the relationship between technical and cultural aspects of the energy infrastructure evolution. LTS is an open system; it is ready to interact with the conditions of the local context. Its functionality is determined by the local conditions. It, therefore, has the ability to enhance the territorial re-composition process. Hughes (1987) uses the term «reverse salient» to denote the system when one or more of its components are in the outside phase, less efficient and thus retard the evolution of the system. When the outside phase affects the whole system, we have to deal with its involution.
Comments and connections: The traditional view of the fossil-based energy infrastructure is largely indifferent to the local geographical conditions. The «reverse salient» concept expresses the dynamic character of the new energy infrastructure, in which nothing is static and where the components behave as a system. It is an indicator to assess the evolutionary status of the infrastructural apparatus according to Hughes (1987). Zeleny develops a technological model to describe the evolutionary mechanisms for the components of the infrastructural apparatus. The «components» of the system is the link between Hughes' conceptualization of a LTS and Zeleny's work which identifies these components and the stages through which such systems evolve.

TAB. 1 | Large Technological System (LTS) as the foundation of a DRI

Category: High Technology Components (HTCs)
Concepts: Infrastructural apparatus; Infrastructure evolution; Components; Hardware; Software; Brainware; Technology Support Net.
Description: Zeleny (1986) states that any technology has three clearly identifiable components: Hardware describes the physical apparatus (H); Software concerns the collection of rules (Know-how, programmes and algorithms); Brainware (or Knowere) involves the scope. Technology evolves through three fundamental stages: Stage 1: the appropriate technology. The Technology Support Net is neutral because the technology apparatus is fully accepted, under the cultural, environmental, political and social conditions. Stage 2: one or more components can be improved from the functional or efficiency points of view. The Technology Support Net does not modify its cultural and technical structure, but is able to use the available technologies in a more efficient way. Stage 3: High Technology. Substantial revision both of the structure of the organization and the components. It is possible to operate in an alternative and more efficient way. More importantly, it is possible to do new things (Zeleny, 2012).
Comments and connections: Infrastructure can be conceptualized as a technological system using Zeleny's components. Hardware also describes the rationale with which the components are used. Rules regard the conduct of the components. Brainware involves applications of Hardware and Software. These components interact within a specific administrative and cultural structure. Innovation mainly changes Hardware and Software. Brainware would remain unaltered if innovation was isolated. To avoid this, innovation has to change the Technology Support Net, which consists of work rules, task rules, requisite skills, work content, standards and measures, styles, culture and organizational patterns (Zeleny, 2012). Brainware cannot be transferred, because it has to be developed in situ. Knowledge has to be produced within the specific local context and the corresponding Technology Support Net (Zeleny, 2012).

TAB. 2 | High Technology Components

Category: Smart City (with relation to the energy infrastructure theory)
Concepts: Computerizing System Processes; Infrastructural apparatus; Creative class; Synchronization.
Description: Harrison and Donnelly, (2011) provide evidence on how the pattern concept (Alexander, 1979 quoted in Harrison and Donnelly, 2011) has become the main reference for the engineering software and ICT sectors (Gamma et al., 1993 quoted in Harrison and Donnelly, 2011), even if it has not had much effect on the design and planning disciplines. SC concept can be linked with a generation of creative people and innovative tools able to observe the urban metabolism in detail. Harrison and Donnelly, (2011) explain the success of this concept with regards to the opportunity to attract the creative class. In this context, the creative class represents the digital generation that can manage the new technologies and remodel the old apparatus of the city.
Comments and connections: In the first instance, this relationship could appear to be only a cultural reference, but in reality it shows a concrete possibility to synchronize the algorithm and digital protocols within a local context and with a unique urban pattern. Creative class concept is particularly interesting in the case of the DRI system, with which the rules and the tools to construct a local urban pattern can be changed. The main DRI features, alongside the computerizing process, can help to enhance the physical and environmental local conditions in order to develop a contemporary concept of urban form.

TAB. 3 | Smart City (with relation to the energy infrastructure theory)

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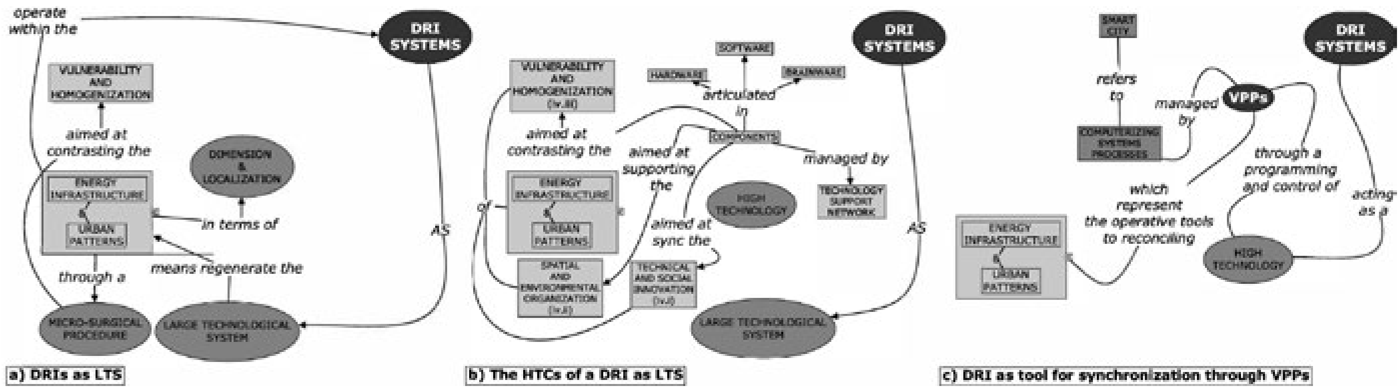

02 | Map of the Integration process of DRI features

Phase 2. Integrating the DRI System concepts

The main concern of this study is the construction of a new pattern of energy infrastructure, based on the critical evaluation of the definition of LTS, HTC and the synchronization of a computerizing algorithm and local urban settlements. This evaluation highlights the DRI evolution trajectory according to the evolutionary mechanics and the main DRI characteristics. Such DRI evolution trajectory is described as follows:

- DRI system as a LTS. Here, the way the new energy system can be adapted and implemented in relation to the local conditions is underlined in order to contrast the indifference toward the local geographical conditions, and in particular towards the vulnerability and homogenization of energy infrastructure and urban patterns.
- The HTCs of a DRI as LTS. The hypothesis within which the DRI system is called to operate in order to revolutionise energy infrastructure are described.
- DRI tool for synchronization. The VPP as a main tool to implement the new pattern of energy infrastructure is associated with the aforementioned proposition.

These cross-cutting issues are used to define a novel conceptual framework on energy infrastructure. A DRI system in order to support a LCC vision in ecological perspective can thus be developed and communicated.The results of the integration process are presented in detail below.

Firstly, defining the DRI system as LTS means regenerating the energy infrastructure concept in terms of dimensions and localization (Fig. 2-a). The dimension of the system is never defined a priori. It depends on two main factors: the local demand for energy and the technical capacity to organize the system. The localization of the system is highly dependent on the physical and environmental local conditions. Localization is highly dependent on the local energy availability, which concerns the efficiency of the system. In this context, the term «efficiency» refers to the application of the highest diversity technology, which has to be compatible with an environmental context. Following the LTS evolution, small-scale changes are introduced through a micro-surgical procedure (Table 4, point 1).

Secondly, the DRI system is defined through its material and immaterial components, including its main technical and non-technical features. The HTC, i.e. Hardware, Software and Brain-

1. DRI system as a LTS	Following the LTS evolution, small-scale changes are introduced through a micro-surgical procedure.Thus, there is a technical solution in the short-to-medium term. During this period, the DRI system can co-exist with the old energy infrastructure. At the same time, its components can be expanded to cover the extent of the urban area. In fact, one of the main DRI system features is its capacity to be adapted and implemented through space and time, from the micro to the macro scale.Therefore, the DRI system can fulfil its primary role, i.e. energy provision, as determined by the local geographical conditions.
2. The HTCs of a DRI as LTS	The three characteristics, which should underpin the construction and organization of the DRI system, are described below: - The DRI system acts as a High Technology System through evolution of the Support Network as a result of technical and social innovation; - The DRI system is organized through the interaction among Hardware, i.e. the spatial and environmental characteristics of the settlement, and Software, i.e. energy supply devices. Both components function according to local rules; - The DRI system is specifically aimed at supporting an ecological and efficient Brainware (i.e. cultural service). The homogenization and vulnerability of the urban settlements, which result from their reliance on fossil fuel-based energy systems, are addressed through the use of diverse and appropriate technology.
3. DRI tool for synchronization	VPPs become vehicles for the energy infrastructure evolution: - VPP programming and control, enables the synchronization between technical information and social aspects of the energy system (i.e. regulating service).The DRI system thus acts as a HTS. - The DRI system is organized through the interaction between Hardware and Software.The VPP services manage this interaction.They can optimize the eco-efficiency of spatial and environmental characteristics of the settlement; the integration of energy supply devices; and facilitate the elaboration of specific local energy infrastructure rules. - The DRI system is specifically aimed at valuing ecological and efficient Brainware, through the VPP. The VPP is an adaptable tool, which can regulate the complex local energy and information flows in a dynamic and multidimensional manner.

TAB. 4 | Integrating DRIs concepts

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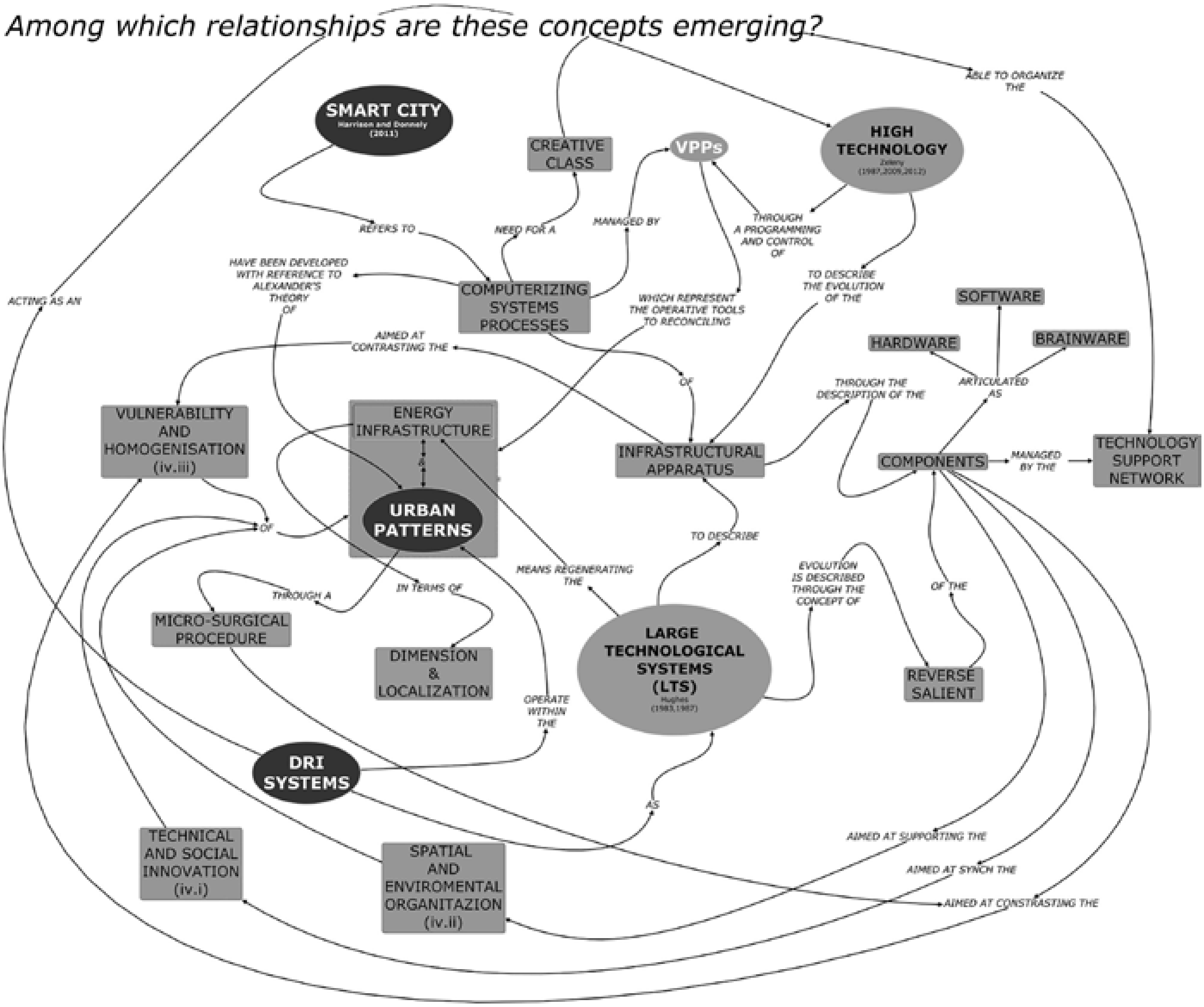

03 | DRIs conceptual framework. The figure shows the complex relationships on SC, DRI and Urban Pattern disclosed with the support of the qualitative methodological approach

ware, are introduced to describe the premise in which the DRI system is called to operate as a LTS (Fig. 2-b). The three characteristics are described in Table 4, point 2.
Thirdly, three factors emerge as relevant for synchronization: the VPPs are capable of assembling different sustainable energy systems in one profile; the new devices are located to exploit the energy production potential which is dependent on the interaction between the settlement layout's spatial features and immaterial fluxes; the new devices can help counter-balance energy demand and supply.
Such interpretation, which is founded on the technical possibilities widely offered by VPP, brings about a new energy infrastructure concept in terms of dimensions and localization. More specifically, VPP appears as an appropriate tool to configure and assess the DRI system as a LTS, reconciling urban patterns and smart systems (Fig. 2-c). In fact, these factors are aimed at the greatest technological diversity in order to prevent the infrastructural uniformity, which is typical of the fossil-fuel based systems. From these facts, the relationship between the energy system and the settlement's morphological and typological conditions can be deduced, becoming the new likely rules for the territorial infrastructural process. Moreover, the result of such reading of the VPP provides an expanded characterization of the hypothesis of energy infrastructure evolution (Table 4, point 3).
Finally, the inalienable DRI features on which the construction and organization of the DRI system must be based are described in Table 4.

Validating and rethinking the conceptual framework

The most significant contribution of this study is the conceptual framework which illustrates the relationships that are emerging between DRI energy systems, SC and urban patterns. These relationships support the hypothesis of the evolutionary trajectory of an energy system (Geels, 2005; Foxon, 2011). The conceptual framework takes into consideration a network of connections between material and immaterial factors, which define the main features of DRI systems, and in particular, how DRI systems should work in order to support an ecological approach to the LCC, strengthening the SC concept (Fig. 3).

The relationships revealed by the conceptual framework fill a gap in terms of how DRI systems can function as an ecosystem service with all its categories. The state of the art review on SC has shown that a large part of this literature focuses only on the computerizing process (Angelidou, 2015; Bibri and Krogstie, 2017). While it is evident that computerizing processes improve the regulating services (Dimeas and Hatziargyriou, 2007), their relation with the other categories remains sidelined. This study takes a long term vision, in which the new generation of infrastructure will be called to integrate all energy service categories.

This study is a first step for modelling the DRI systems as an ecosystem service, offering an integrated vision for DRI systems in order to reinforce their capacity to be adopted at scale to help deliver Low Carbon Cities. In this sense, the analogy that is drawn between a DRI system and a LTS, becomes a necessary condition to achieve the integration between ecosystem service categories. Consequently, the conceptual framework reinforces the vision of DRI systems as supporting services in the first place, because, DRI systems are not only an energy supply system, but also tools to re-establish the altered relations among cities, societies and landscapes.

Thus, the transition towards new energy infrastructures creates the need for a robust investigation of how such infrastructure impacts on the physical settlement. This relationship is an inalienable part of the human culture. Accordingly, this study establishes that the knowledge dissemination processes requires a cognitive apparatus, which can be used as a reference. The proposed DRI conceptual framework can provide such an apparatus, encouraging a common vision to deal with the evolutionary trajectory of the LCC taking the social and technical transformations of settlements into consideration.

Conclusions

A new conceptual framework for a distributed, renewable and interactive energy system has been proposed in order to support an ecological approach to delivering LCC. The paper has demonstrated how this conceptual framework can help: pursue an ecological path of distributed and renewable energy systems in order to counteract the LCTs that do not pay regard to the local conditions; enhance the SC concept in order to reinforce the relationship between urban patterns and computerized systems; promote the large-scale enhancement of local levels of technology literacy in order to socially construct a DRI. The conceptual framework describes the context in which the DRIs are called to operate.

In the future, a series of case studies will be conducted to test the conceptual framework in order to develop a new theory of evolutionary energy infrastructure.

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NOTES

[1] Ecosystem services that are necessary for the production of all other ecosystem services.

[2] Products obtained from ecosystems.

[3] Benefits obtained from the regulation of ecosystem processes.

[4] Non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

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