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The nexus of ‘urban resilience’ and ‘energy efficiency’ in cities

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ABSTRACT

In the realm of major continuous challenges cities are key leverage points in the quest for global sustainability due to their high consumptions and waste and contain hotspots of vulnerability. Their exposure to increasing environmental, economic, health, societal or other risks make them susceptible to continuous threats with uncertain impacts. In face of these hazards, the increasing use of the connotation of ‘urban resilience’ in worldwide commitments and discourses is a promising approach to increase efficiency and stretch for integrated solutions. Despite its importance, the nexus of the concepts is yet not unveiled in the existing literature. In this work and in an attempt to interconnect the terms, this study provides an insight to the emerging concept of the urban resilience to represent the city durability and to mutualize it with the complexity of the ‘green’ energy transition. This study reveals the major limitations in the inadequacy of interchangeable approaches of climate change adaptation in designing strategies of Energy Efficiency to satisfactorily address plausible chocs. Using a dynamic perspective, this manuscript draws upon a range of emerging literature on climate change actions and resilient strategies in selected case studies. The paper concludes with suggesting complex matrixes addressing the energy shortage and analyze the intricate issues for resilient and safe strategies. Further research, knowhow sharing and experiences to quantify the benefits of these strategies but also exploring the cooperation and governance models are prioritized for forthcoming studies of the topic.

1. Introduction

In the face of global warming and climate change, which will induce intensified variations and extreme phenomena, the frequency of them have increased over the last 30 years related to unexpected disasters (floods, heatwaves, windstorms) (Field et al., 2012), expected to affect two-thirds of the European population by 2100 (Forzieri et al., 2017). Such extreme conditions project to affect the two-third of the European populations by 2100 with unmeasurable social, environmental or economic impacts (Sharifi and Yamagata, 2016), while inadequate climate-focused plans influence as well the energy security. Cities have not escaped from these effects generating a variety of malfunctions and discomforts for their populations and threaten their equilibrium, specifying that urban systems are largely responsible since they consume more than 70% of the world’s energy (World Bank, 2018), produce more than 50% of the world’s waste, 60–80% of GHG emissions and more than 70% of the resources’ consumption (United Nations, 2015) and undertake interrelated efforts on energy-focused, decarbonization and adaptation plan (Ohshita and Johnson, 2017). The 5th Assessment Report by the IPCC (IPCC, 2014) forecasts a temperature rise as high as 4.8 °C between 2080 and 2100 (Fig. 1).

Unprecedented urban growth has transformed the planet from 10% in 1990 (Fig. 2) to more than 50% urban in just two decades (UNDESA, 2010);(United Nations, 2018) with tremendous increasing trends by 2050 (UN-DESA, 2014).

The notion of ‘resilience’ is gaining increasing prominence (Leichenko, 2011a, 2011b);(Pierce et al., 2011) and its attractiveness stems from its positive connotation (McEvoy et al., 2013);(O’Hare and White, 2013). Yet, resilience often is more of a ‘buzzword’ than an operational paradigm (Linkov et al., 2014a, 2014b). Frequently found terms of ‘climate resilient’, ‘climate-proofing’ or ‘resilient city’ underline the importance of cities to bounce back from the climate rising stresses. At the same time, rigorously, a plethora of more theoretical publications on the meaning of resilience and its relation with concepts such as *vulnerability*, *sustainability*, *risk*, *adaptation, mitigation* or *recovery* have appeared in the academic manuscripts in the past years (Davoudi and Porter, 2012);(Pendall et al., 2010);(Walker et al., 2004).

In this frame, Europe prioritizes its strategies to nourish resilient territories along with a climate-resilient society by 2050 fully adapted to

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Nomenclature

GHG	Greenhouse Gas (Emissions)
IPCC	Intergovernmental Panel on Climate Change
EU	European Union
SDG	Sustainable Development Goal
COP	Conference of Parties

the unavoidable impacts of climate change by reinforcing the adaptive capacities and minimizing the vulnerability in line with the European Climate Law (European Commission, 2020b). EU has already taken action to breakthrough resilience under the Adaptation Strategy as a key reference for adaptation to uncertainties and climate risks (European Commission, 2018); (European Commission, 2021) and the 2030 mission (European Commission, 2020a) to meet the targets of a climate resilient future. Yet, policy makers and city stakeholders use the term of 'resilience' as an inspirational planning idea, while agreements widely acknowledged, such as the Sustainable Development Goals (17SDGs) (United Nations, 2015), the Sendai Framework for Disaster Risk Reduction (United Nations Office for Disaster Risk Reduction, 2015) or even the Paris Agreement (COP21) (European Commission, 2015) call for resilience (Roberts et al., 2015). Nonetheless, it remains paradox in this sphere to implement this agenda within an operational implementation and the transition to the practice especially in pre-planning phases, in which recognized tools are insufficient, whilst their materialization and the interaction of the climatology and urban conception is vital for cities. Failing to address the energy efficiency and to create robust and resilient territories, is a great risk for communities to withstand future variations and enable the sustainable transition. Understanding the impacts of these uncertainties is challenging because of the multivariate and multiscale changes requiring a reliable and multifaced assessment considering a wide range of actions in robust processes. The analysis of the Climate Risk Index 2020 (Fig. 3) (GERMANWATCH, 2020) confirms the gravity of the problem, in particular for the industrialized countries and the need to strengthen the implementation of measures concerning the future damages.

Climate change will also introduce modifications to the energy systems affecting varied aspects of the flows from the generation to the demand (Thorsteinsson and Bjornsson, 2012), most of which will lead to considerable risks and uncertainties for populations, resources, infrastructure, etc. (Fig. 4).

Ciscar and Dowling reviewed the approaches for impact assessment of climate change and energy sector considering qualitative economic and energy models with top-down or bottom-up approaches; some of which result from short- or long- term changes (Ciscar and Dowling, 2014). As Table 1 presents, the uncertainties derived from climate change have great impacts on demand and supply of the energy systems along with cost, autonomy, CO2 emissions and RES use. The outcomes of the analysis provided is developed in respect to diverse methods including deterministic, stochastic or other relevant approaches.

This paper seeks for the understanding of the notion of *urban resilience* from the plurality of approaches, theories and applications. The concept embraces the importance of strategies against the climate constant changes, the rapid urbanization and the increasing needs on energy. To the authors' knowledge, few reviews and scholar works yet on the importance of resilient territories to cope with the challenge of the resources' scarcity exist; thus, the aim of this work is to recap the understanding of its origin and its disparate facets and to question its framework on contexts that have yet to be conclusively answered, such is its nexus and importance to the energy efficiency. To better understand how the term has been defined and used across disciplines and fields of study, this paper reviews academic literature on the backdrop of the concept. The remainder of this paper focuses on the attempt to link the concept of urban resilience to the energy efficiency as an umbrella for territories to sustain and combat against various challenges and especially the climate change mitigation. Proposing this matrix and embraces the two terms in a comprehensive approach, the paper aims to contribute to a research field, which is yet under exploration. To this end, the final section summarizes the main findings of the review and discusses the future perspectives.

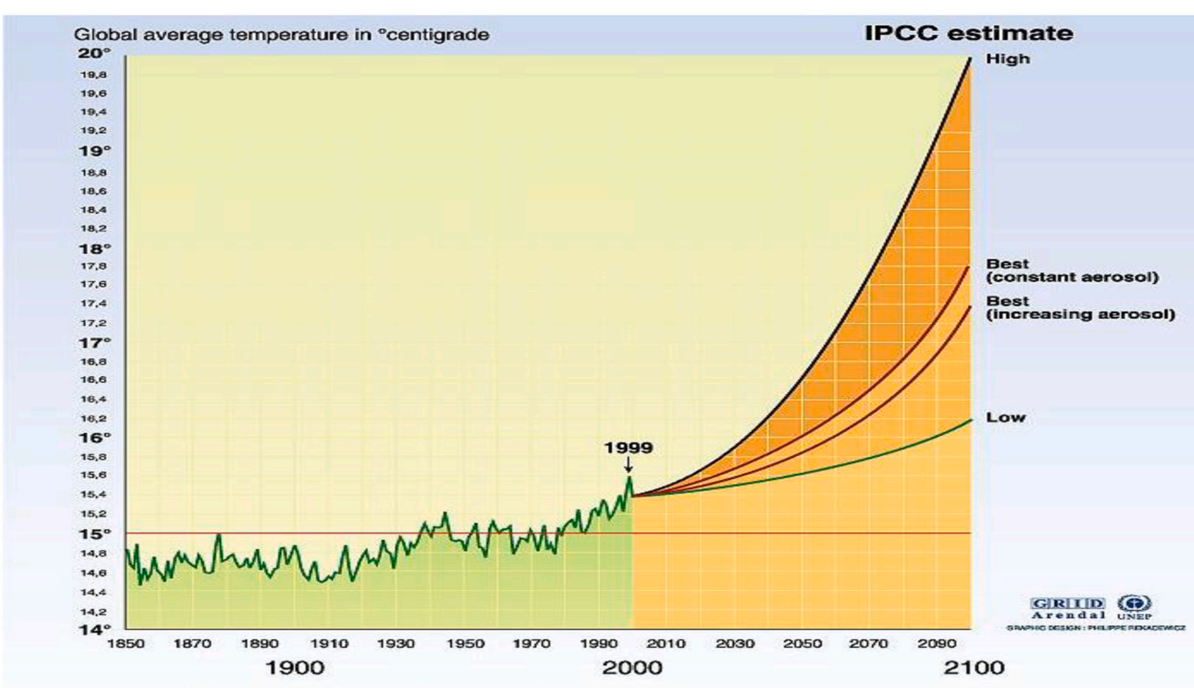

Fig. 1. Projected changes in global temperature (1856–1999) and projection estimates to 2100 (UNEP, 2015).

2. Overview and understanding of 'resilience'

The word ***resilience*** originated in the 17th century from the Latin term '*resilire*', which means to 'spring back' (Fraccascia et al., 2018). The concept, however, was theorized by the ecologist C.S. Holling in 1973 in this manuscript *'Resilience and stability of ecological systems',* emphasizing the influence of **change** or 'disturbance' on ecosystems and defined the concept as the *'persistence of relationships within a system and a measure of the ability to absorb the changes and continue persisting on them'* (Holling, 1973). Building on this definition, Holling introduced different understandings of the concept, such as the 'engineering resilience' or the 'ecological resilience' focusing on the 'magnitude of disturbance that can be absorbed before the system changes its structure and as a measure of the persistence of systems to absorb the change while retaining the relationships between the populations and their variables' (Holling, 1973). Later, Holling distinguished two interpretations of the concept: (1) the engineering resilience, implying how fast a systems returns to a steady-state after a disturbance and (2) the ecological resilience, which is the ability of a system to cope with changes on its natural development (Holling, 1996). Nonetheless, since the mid of 90s, this adaptive process is more applicable and associated to the urban design (Wu, 2013); this can be attributed to the fact that cities are facing the impacts of a wide range of hazards. Even though the concept exists in the literature since a long time, it was introduced in many complex socio-ecological issues, it has been recently introduced in the city planning and the thinking on complexity and vulnerability (Pickett et al., 2004). As a scientific concept, its origins are quite ambiguous and complicated (Adger, 2000b); (Lhomme et al., 2013a, 2013b); (Pendall et al., 2010). Brand and Jax emphasize on the difficulties of operationalizing the concept on a common terminology or to generalize metrics for its measuring (Brand and Jax, 2007).

Nevertheless, the term and its derivatives have a long history, as Alexander investigates at his etymological journey in which he cites that Quintillian *(Marcus Fabius Quintilianus, Istitutio Oratorio, 12, 10.56)* used the term in sense of 'avoid', while Pliny the Elder *(Natural History 9.71, 11.39)* to refer to the 'leaping of fleas and frogs' and Cicero for 'rebounding' (Alexander, 2013). Later, the term passed into middle French (résiler), in which it came to mean "to retract" or "to cancel". However, everyone involved in these research activities agrees that it is a multidisciplinary and transdisciplinary concept (Serre et al., 2012). The multidisciplinary nature of resilience makes it clear that system resilience is not another specialty but rather a collaborative effort among many specialties (Jackson, 2013).

Since the first definition, the concept of resilience has been the subject of several additional studies (Lhomme et al., 2013a, 2013b). Considerable research had led to the development of both general as well as field-specific definitions, for example, in engineering, ecology, psychology, sociology and economics.

Guided by an analytical review of the term, the paper identifies the most influential publications of the concept. The increasing trends of the popularity of the term in scientific works and published papers analyzing the databases of 'Web of Science' (Web of Science, 2018) and 'Science Direct' (Science Direct, 2018); (Jesse et al., 2019) (Fig. 5).

The concept is originally associated with ecosystems' capacity *'to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes'* (Folke, 2006). Although the meaning of resilience remains widely debated, it is typically associated with the process of 'adaptation' and the ability to increase capacities for 'learning' (Carpenter and Folke, 2006). Thoma introduces the concept as *'the ability to repel, prepare for, take into account, absorb, recover from and adapt ever more successfully to actual or potential adverse events, catastrophes or processes of change which can have human, technical or natural causes'* (Thoma, 2014). Bruneau et al. argue that the concept is encompassed along with four interrelated dimensions: the technical, the organizational, the social and the economic (Bruneau et al., 2003). Allan and Bryant consider that the *'resilience is based on the shifting relationship between scales and the autonomy on the one hand and the connectivity on the other'* (Allan and Bryant, 2011). Generally, the concept can be defined as *'a property of the urban system that enables it to survive against the uncertainty, the adversity and the change, which requires continuous efforts of the system during all the phases of the change (i.e. mitigation, preparedness, absorption, recovery, response and adaptation)'* (Sharifi and Yamagat, 2018).

In our days, resilience is an increasingly widespread concept to identify the risk reduction and to provide strategies of adaptation from investments or individual behaviors to entire communities or economies (Béné et al., 2014). Notwithstanding, the notion of resilience goes beyond the problematic of reducing the risks and it is a lever for a range of disturbances, such as the energy crises, as a complement to the concept of 'adaptation', in which we include also the capacity not only to withstand the different shocks and the uncertainties, but also to recover from them. It is, therefore, a multi-faceted term (Satterthwaite and Dodman, 2018).

Table 2 traces the perspectives of different authors across the concept: (See Table 3.)

In conclusion, resilience is a multidimensional concept with

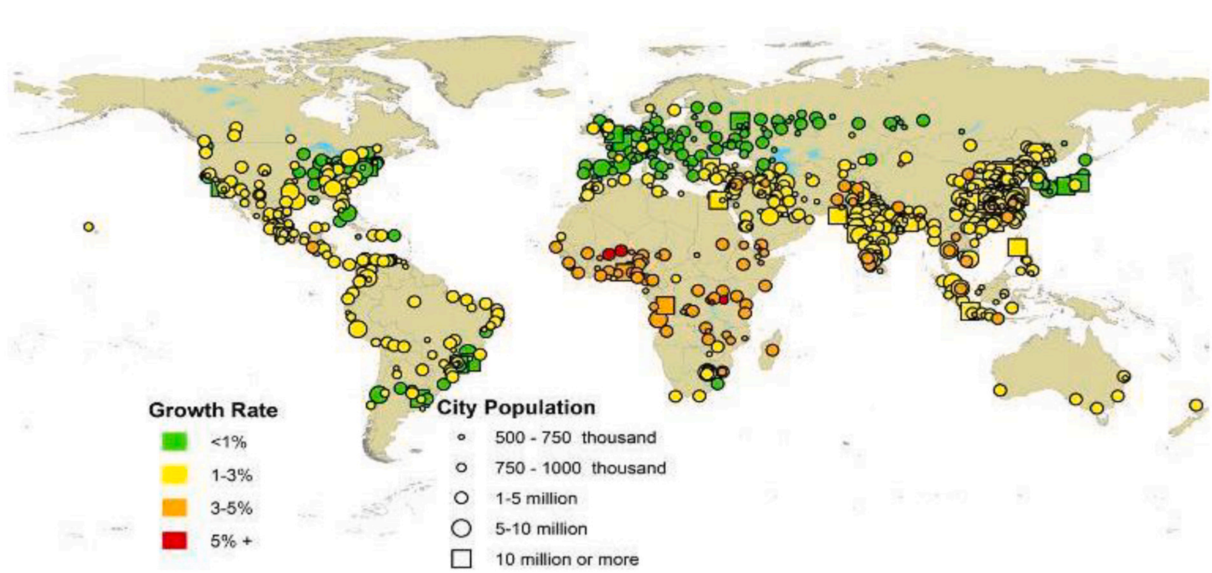

Fig. 2. Growth rates of urban agglomerations by size class 2014–2030 (United Nations, Department of Economic and Social Affairs, Population Division, 2014).

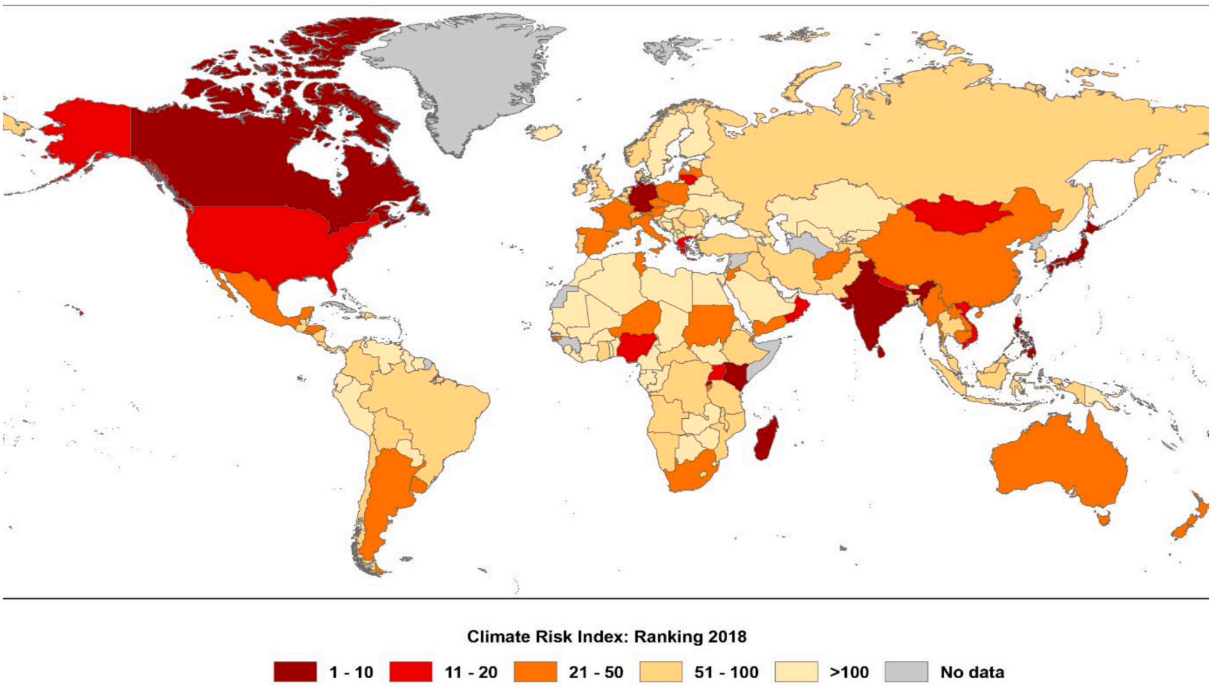

Fig. 3. Climate risk index 2020, world map ranking 2018, (©) www.germanwatch.org/en/cri

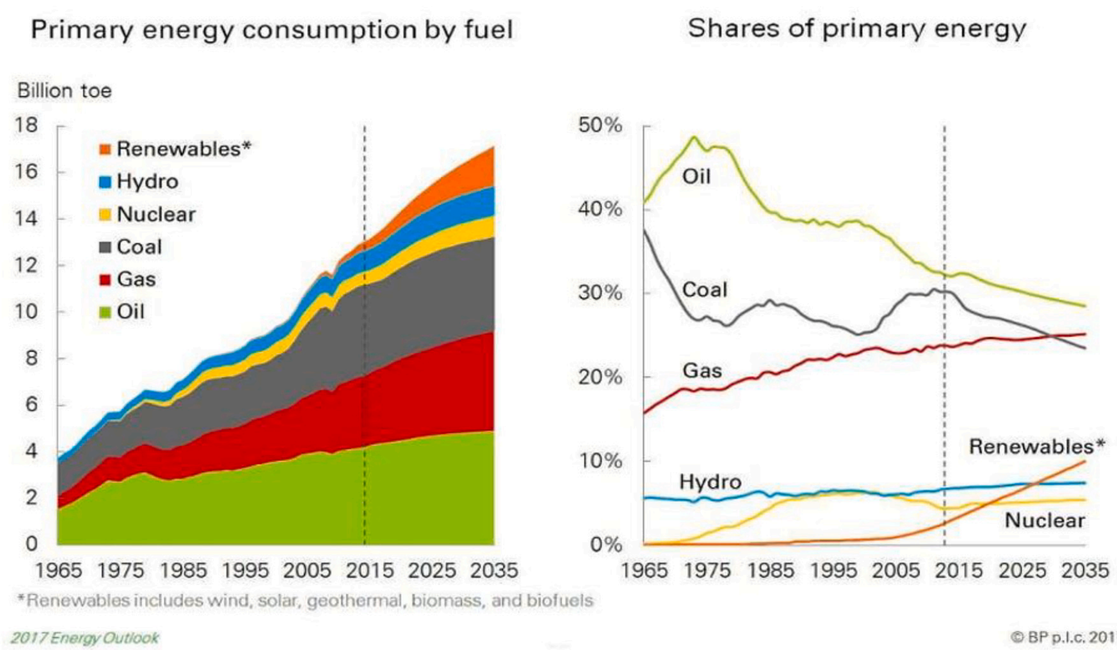

Fig. 4. Energy outlook: global energy demand to grow 30% to 2035 (Arias et al., 2018).

undoubtable qualities and benefits for its end-users included in diverse domains and sciences. Alexander in his works summarizes the position of the concept in modern sciences as a promising concept, which accumulates a rich spectrum of meanings (Alexander, 2013) (Fig. 6).

2.1. *Integrating 'resilience' thinking into city planning*

In any definition, resilience is based on the notion of a system, so it can be applied to any systems. Considering that city or, more generally, urban issues can be perceived as a complex system, resilience has also emerged in the urban context, especially in the field of risk management, in order to meet the needs not satisfied by the current measures and strategies. Given the current situation concerning natural disasters and social disturbances affecting urban systems, urban resilience is presented as one means by which urban systems can cope with unexpected shocks and achieve sustainability over time. Indeed, resilience, as the ability of an urban system to adapt to disturbance, appears to satisfy the needs for operationalizing a sustainable city (Toubin et al., 2014). Managing for resilience enhances the likelihood of sustaining development in changing environments where the future is unpredictable and surprise is likely (Folke et al., 2002).

To clearly understand the term of 'urban resilience', it is critical to

Table 1
An overview of some research works about the impact assessment of climate change on energy systems.

Reference(s)	Uncertainties	Extreme climate scenario	Impact change on		Time horizon	Methodology considered	Criteria
			Demand	*Supply*			
Perera et al. (2018)	Climate	√	Heating/ Cooling	Solar & wind	Hourly	Deterministic, stochastic and robust techniques	Cost, autonomy, CO2 emissions, utilization of renewable energy
Mavromatidis et al. (2018a, 2018b)	Climate	X	√	Considered	Hourly	Deterministic, stochastic and robust techniques	
Bistline, 2015	Climate	√	√	Considered	Three-hour	Mixed integer linear problem	
Chen et al. (2019)	Cost & Policy	X	X	No	Hourly	Stochastic	
Guerra et al. (2019)	Climate	X	X	Solar, Wind, Hydro	Three segments per year	Considered by using chance constrained method	
Santos et al. (2016)	Climate	X	X	Considered	Yearly	Combining Monte Carlo simulation with a deterministic model	Cost
Yu et al. (2016)	Climate	X	√	Considered	Monthly	Dual possibility-based approach	
	Climate	X	√	No	Yearly	Stochastic	
Perera et al. (2020)	Climate & Costs	X	Heating/ Cooling	Considered	Hourly	Stochastic	

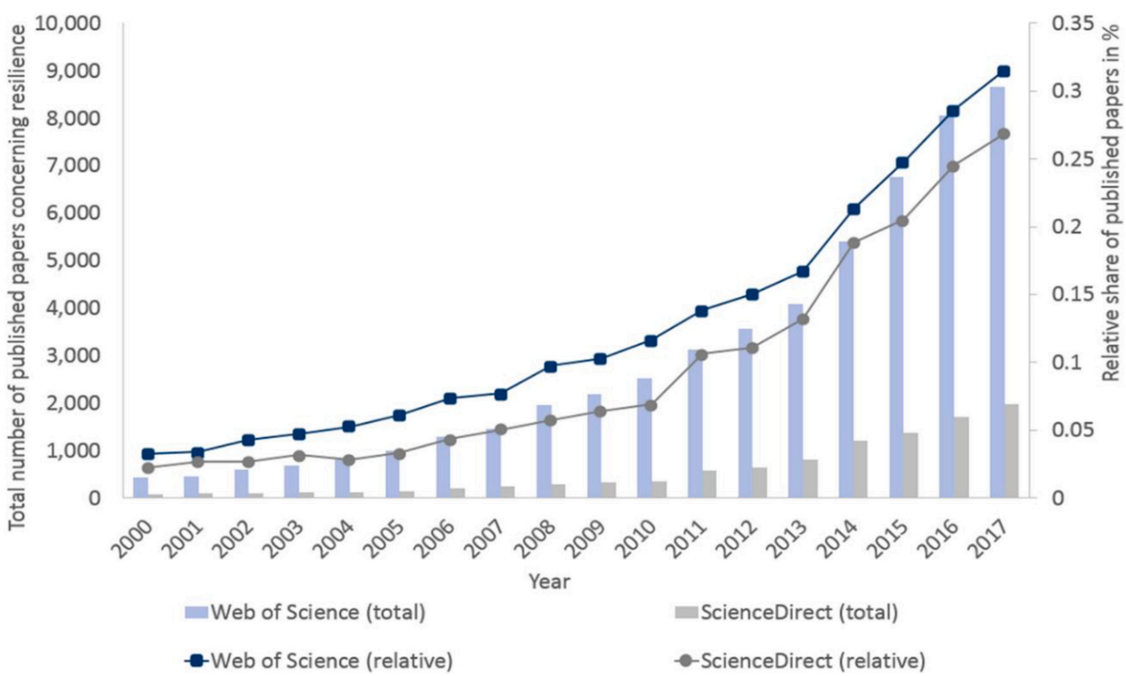

Fig. 5. The increasing trends of scholars on the concept of 'resilience' (Jesse et al., 2019).

specify what is 'urban', a term which varies depending on its discipline. Despite the undeniable positive impacts of resilient territories and the uniform portrait of a desirable planning objective, the wide spectrum of its multitude definitions and embraces a broad 'umbrella' of explanations for the adaptation to change. Studies tend to be categorized on those of radical changes due to unforeseen events ((Coaffee, 2009; Pelling, 2003a; Savitch, 2008)), while others explore the processes of transformation in slower rhythms (Muller, 2010), while they are typically seeking for 'how' cities recover and identifying the 'vulnerability'. From this first overview, the complexity of the concept and the need for robust strategies and methodologies for its implementation become widely recognized.

The main problematic of the notion of 'equilibrium' to return to a steady state is the evaluation of its original state; certain conditions may be undesirable yet not resilient ((Gunderson and Holling, 2002); (Scheffer et al., 2001).

Certainly, resilience is a concept that has advanced in relation to the dynamic development of complex adaptive systems with interactions across temporal and spatial scales (Folke, 2006). From the perspective of complex adaptive systems, urban resilience can be expressed by different processes at different spatial levels (Fig. 7).

This idea leads to the concept of *Panarchy*, developed by Gunderson and Holling (2002), that explicitly takes fast/slow dynamics and cross-scale interactions and interdependencies into account (Gunderson and Holling, 2002). A first process corresponds to urban system resilience following a disturbance which caused damage at a local urban scale. It seeks to improve the system's capacity to respond to disturbances. Resilience is here considered to be a property, an inherent quality of a system. On the other hand, on a more global scale, the second process takes into account the long-term impacts of disturbances. Resilience is now defined as a process which leads to a condition of resilience. Consequently, the final goal is to respond to short-term challenges

Table 2
Overview of the research of the 'resilience' concept in the literature.

Research Perspective	Author (or Institute)	Definition/Analysis
Ecological Resilience	Holling (1973)	Resilience is the ability of an ecosystem to absorb, change, and return to a stable state when subjected to shocks and disturbances
	Horne and Orr (1998)	The ability of a system to withstand stresses of 'environmental loading.
	Lance et al. (2002)	An ecosystem adaptation cycle model and an evolutionary dynamic mechanism model
	Fiksel (2003)	The essence of sustainability […] the ability to resist disorder.
	Alberti et al. (2003)	The degree to which cities tolerate alteration before reorganizing around a new set of structures and processes
	Tierney and Bruneau (2007)	Both the inherent strength and ability to be flexible and adaptable after environmental shocks and disruptive events.
	Ernston et al. (2010)	To sustain a certain dynamic regime, urban governance also needs to build transformative capacity to face uncertainty and change
	Ahern (2011)	The capacity of systems to reorganize and recover from change and disturbance without changing to other states … systems that are "safe to fail"
	Brown et al. (2012)	The capacity to dynamically and effectively respond to shifting climate circumstances while continuing to function at an acceptable level. This definition includes the ability to resist or withstand impacts, as well as the ability to recover and re-organize in order to establish the necessary functionality to prevent catastrophic failure at a minimum and the ability to thrive at best
Engineering Resilience	Wildavsky (1988)	The ability of the system to rebound, adapt, and return to normal levels in the event of an unexpected disaster
	Gunderson et al. (2002)	The speed of return to the steady state following a perturbation […] ecological resilience […] is measured by the magnitude of disturbance that can be absorbed before the system is restructured
	Godshalk (2003)	A sustainable network of physical systems and human communities
	Asprone et al. (2014)	The system is able to adapt and respond to events with fundamental damage
Social Resilience	Mileti (1999)	Resilience means that after a natural disaster in a certain place, it is not necessary to rely on a large amount of external assistance to minimize damage and ensure basic productivity and quality of life
	Adger (2000a)	The ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change.
	Paton and Johnston (2001)	A system's ability to maintain its normal functioning and cope with challenges and changes in the face of external disturbances
	Pelling (2003b)	The ability of an object to handle or adapt to dangerous stress
	ISDR (2005)	Resilience is a system's ability to resist, absorb, adapt to, and recover from its effects in a timely and effective manner, including protecting and restoring its necessary infrastructure and functions.
	Campanella (2006)	The capacity of a city to rebound from destruction
	Cutter et al. (2008)	Resilience is the ability of a social system to respond to and recover from disasters, including the system's absorption of impacts and response to disaster events and post-event adaptation processes.
	Brown et al. (2012)	Resilience emphasizes the city's ability to block and withstand disasters and the ability of cities to recover and reorganize to achieve the lowest levels of catastrophic losses.
Economic Resilience	Asprone and Latora (2013)	The capacity to adapt or respond to unusual often radically destructive events
	Rose and Shu-Yi (2005)	The inherent ability and adaptive response that enables firms and regions to avoid maximum potential losses.
	Wardekken et al. (2010)	A system can respond quickly to disturbances through its own characteristics and measures to reduce damage and to quickly adapt to interference and obtain recovery
	Wamsler et al. (2013)	Four characteristics for resilient cities: To reduce current and future hazards, to reduce sensitivity to disasters, to establish disaster response mechanisms and structures, and to establish post-disaster recovery mechanisms and structures.
Urban Resilience	Wildavsky (1991)	The capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back.
	Comfort (1999)	The capacity to adapt existing resources and skills to new situations and operating conditions.
	Allenby and Fink (2005)	The capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must.
	US Department of Homeland Security Risk Steering Committe (2008)	• The ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions that may cause harm, destruction or loss of national significance. • The capacity of an organization to recognize threats and hazards and make adjustments that will improve future protection efforts and risk reduction measures
	Lhomme et al. (2013a, 2013b)	Resilience is the ability of a city to absorb and recover from disasters.
	American Rockefeller Foundation (2013) ARUP (2019)	Urban resilience index, which includes four dimensions: Health and welfare, economic and social, infrastructure and ecosystem, and leadership and strategy

(continued on next page)

Table 2 (*continued*)

Research Perspective	Author (or Institute)	Definition/Analysis
	Suárez et al. (2016)	Diversity, modularity, tight feedback, social cohesion, and innovation are the five most important factors affecting urban resilience and serve as evaluation criteria

Table 3
Review on the 'resilience' and 'urban energy system' (adapted by: (Nik et al., 2020)).

Resilience is defined as the ability of an energy system to…	Reference(s)
absorb, adapt and respond to change after a shock or extreme event	Desouza and Flanery (2015)
respond to change and getting back to equilibrium or stability	Boykoff et al. (2010)
avoid or minimize interruptions of service during an extraordinary and hazardous event	Keogh and Cody (2013)
plan for, recover from and adapt to adverse events over time	Linkov et al. (2014a, 2014b)
tolerate disturbance and continue delivering affordable energy services to consumers	Chaudry et al. (2020)
have a secure energy supply chain that withstands shocks	Gracceva and Zeniewski (2014)
anticipate, absorb, adapt to and/or rapidly recover from a disruptive event	Cabinet Office (2011)
maintain reliability at extreme events	Fu et al. (2018); Zhou et al. (2018)
meet performance levels as it is in normal operation during a disruption	Moslehi and Reddy (2018)
…	

promoting short-term and local adjustments that can be assimilated on larger scales, leading to their transformation and long-term adaptation of urban systems in order to respond positively future stresses. The fast levels allow invention, experimentation and testing; the slower levels stabilize and conserve accumulated memory of the past, successful experiments (Gunderson and Holling, 2002).

From the other hand, the literature reveals a focus of the term on 'persistence' reflecting its engineering aspect and the importance of 'resisting' and retaining the status quo (Chelleri et al., 2015). Despite the pluralism of the different glimpses of the ability to recover and rebuild, the mechanism of change and adaptation is inevitably related to the 'time' scale. The resilience framework proposed by Béné et al. focused on three components: 'resistance in a period of small disturbance, period of adaptation in case of greater disturbance and finally a period of 'transformability' (Béné et al., 2014).

The concept is a 'metaphor' to describe the way the systems absorb the hazards and recover and simultaneously maintaining their behavior. Methodologically, the practitioners of 'resilience' search for preparation strategies of their systems for a broad range of 'threats' and to a quantitative understanding of how these threats may generate the harmful consequences for their systems (Hynes, 2019) in an effort to avoid inferring several meanings of the term. To sum up, the resilience includes a comprehensive and integrative thinking viewed in regards to a context-agnostic and uncertain environment in which various phenomena can happen interchangeably. Linkov et al. as a function of a 'system performance' over time, which is exposed to previous shocks but it obtains the ability of recovering and adaptation to minimize future ones (Fig. 8a) (Linkov et al., 2014a, 2014b). Complementary, Carlson et al. propose four categories to assign the crucial points in time: preparedness, mitigation to manage the consequences of the threat and recovery (Fig. 8b) (Carlson et al., 2012), while other scholars highlight as well the importance of adaptation to post shock activities (i.e. Allenby and Fink, 2005). Enacting the term of 'urban resilience' is a challenging process including varying – and sometimes conflicting- stakeholders in a power dynamic pathway across spatial, social, economic and temporal

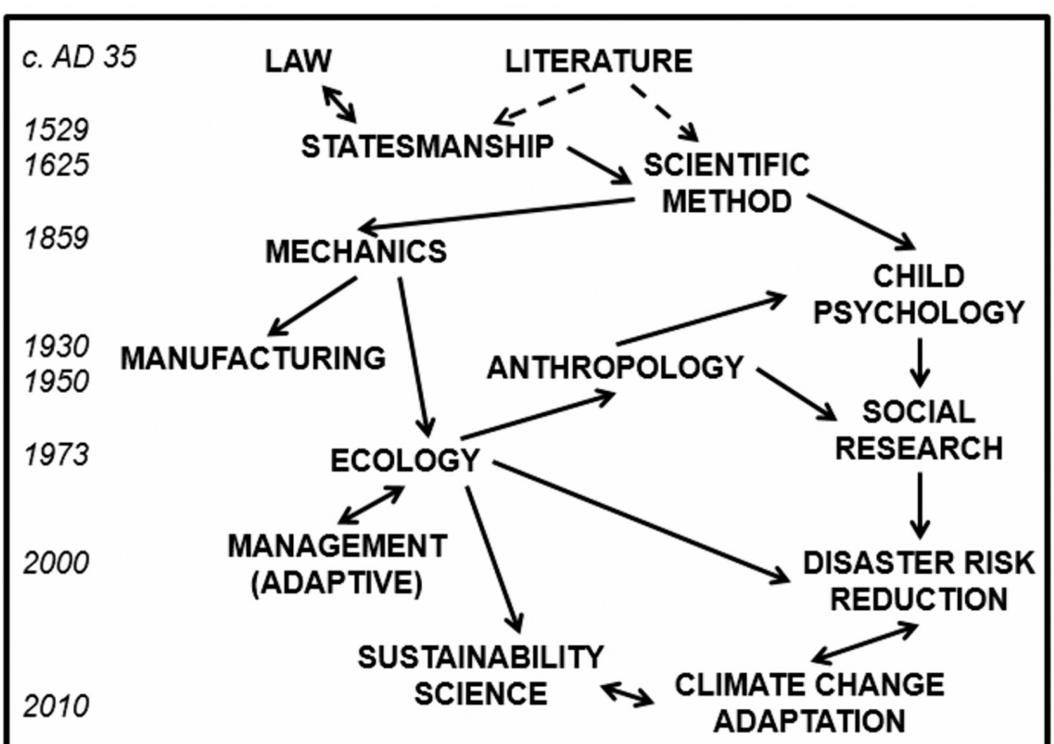

Fig. 6. Schematic diagram of the evolution of the term 'resilience' (Alexander, 2013)).

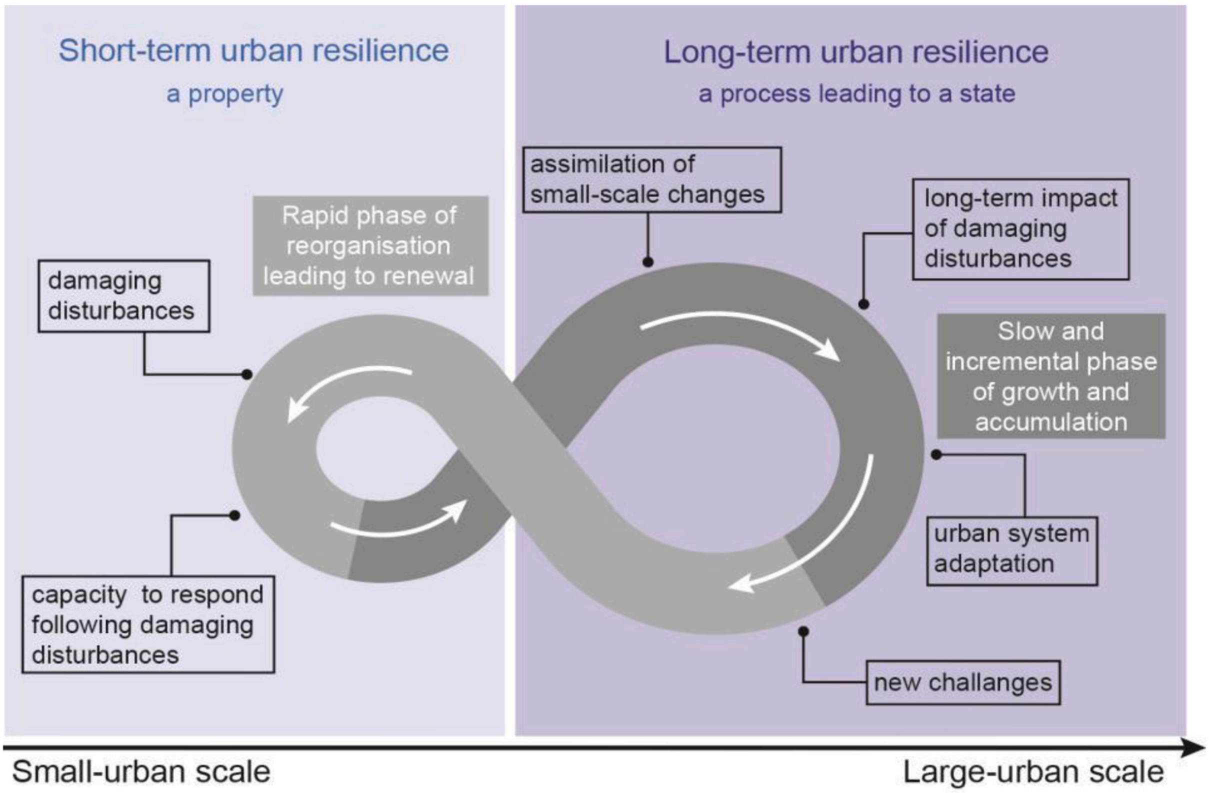

Fig. 7. The Gunderson and Holling (2002) panarchy idea adapted to the urban resilience.

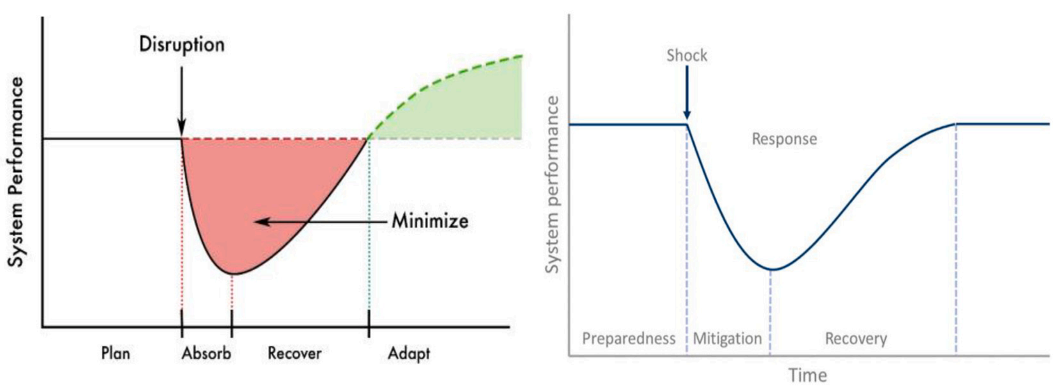

Fig. 8. (a and b, from left to the right). 'Time' is one of the main indicators for the understanding of 'resilience'.

dimensions. Therefore, questions of ***'for whom, what, where, when and why'*** need to be rigorously studied and stress their importance to the adaptation process (Brown, 2013);(Carpenter et al., 2001);(Elmqvist, 2014);(Vale, 2014).

3. Linking urban resilience and energy efficiency

The concept of resilience within its nexus to the energy systems' efficiency is complex and multifaceted (Panteli and Mancarella, 2015). Yet, there is no standardized definition for the resilience of an energy system (block, district, etc.) and it varies depending on the context, the hazards and the objectives (Table 4).

Commonly, a resilient energy system recovers speedily after a shock and provides remedies to guarantee the continuous demand by its users (buildings/citizens) (Chaudry et al., 2020). Analysis frameworks for climate change impacts on energy efficiency of urban systems focus on hazards, risks, ecology, physical infrastructure, integrating some (or all of them) reviewing emerging metrics conducted by Hammer et al. (Hammer et al., 2011), Leichenko (Leichenko, 2011b); Cutter et al. (Cutter et al., 2008) among others. Boykoff et al. argue the importance of the climate stresses which threat the equilibrium of an urban system in regards to its efficiency (Boykoff et al., 2010), Table 4 provides some of these examples.

As a first view, the concepts of urban resilience and resource efficiency provide different languages, codes and objectives. Exploring the concepts both independently and in relationship allows stakeholders, city actors and decision-makers to identify parallel blueprints and synergies between the two. Considering the two concepts reciprocally, we acknowledge the persistence and transition to approaches far from business-as -usual and explore more paths of common actions in a comprehensive planning. Hence, the two agendas are complementary with similar values and targets; to this, there are two critical issues to define (UN Environment, 2017):

Table 4
Examples of climate impacts on urban energy systems (adapted by: (Ohshita and Johnson, 2017)).

Climate hazards and effects	Energy system affected (end-use)	Impact or shock	Potential impacts on the city
High temperatures, heatwaves, etc.	Building cooling systems	Increase in energy demand and overload of the grid	Power disruptions
	Power generation (supply)	Insufficient cooling	Reduced electricity supply
Floods, hurricanes, etc.	Energy systems for space heating and DHW	Damages on roofs; floors; walls; etc.	Loss of electric power
	Envelope for energy efficiency		Increased demand
Decreased precipitations or water quality	Thermal power generation; hydropower	Decline on hydropower supplies	Decline or loss of electric power
	Electricity supply	Higher demand	Disruption to transportation systems
	Distribution systems Water pumping stations	Inundations	Possible GHG emissions

1. How to link the process of building resilience in line with the energy efficiency and what are the potential opportunities for urban areas?
2. What are the potential outcomes if the two strategies are jointly implemented?

More recently, the ubiquity of the resilience concept has been attributed as a normative concept to achieve the transition to cleaner energies and reach the long-term objectives of the European agenda by increasing the levels of energy efficiency in contemporary cities. The concepts of resilience are tightly interconnected to sustainability and energy as key features of the resilient urban system to ensure *availability, accessibility, affordability* and *acceptability* under diverse conditions of uncertainty (Sharifi and Yamagata, 2016). In fact, visualizing interchangeably the resilience and the resource efficiency is an insight to evaluate short, mid and long-term challenges and the understanding of the risks and unpredicted threats and building the reinforcement upon lessons-learnt of the past, which will frame the anticipation for forthcoming disruptions. In reality, resources' efficient strategies underpin the optimization of their use, while resilience explores paths for reducing the dependency and advocates on the principle of 'circularity' corresponding with the threat of scarcity. At the same time, Torrens Resilience Institute (Torrens Resilience Institute, 2009) recognize the mutual connection of the notions for the notion of risks in uncertain events. As explained previously, the reflection of risk is one of the core principles on the resilience science and its evaluation and management are crucial to reduce the probabilities of the disturbances. However, building resilience against risks is also part for the recovery after a crisis or a shock laying on the phase of preparedness to avoid inequalities or further degradation by being proactive. Dodman et al. summarize the areas of common actions between the two concepts (Fig. 9) (Dodman et al., 2017).

Thoroughly, literature bases the nexus on the system's nature of resisting, adapting, preparing and recovering and the combination of the attributes of robustness, resourcefulness, recovery and adaptability, resistance, etc., most of which do not articulate the climate mitigation (Panteli and Mancarella, 2015) (Nik et al., 2020).

Approaching strategies of energy efficiency from a resilience perspective requires pathways outside the traditional definitions of the energy systems in communities. Ribeiro et al. interpret the scheme of energy efficiency as an opportunity for resilient thinking with

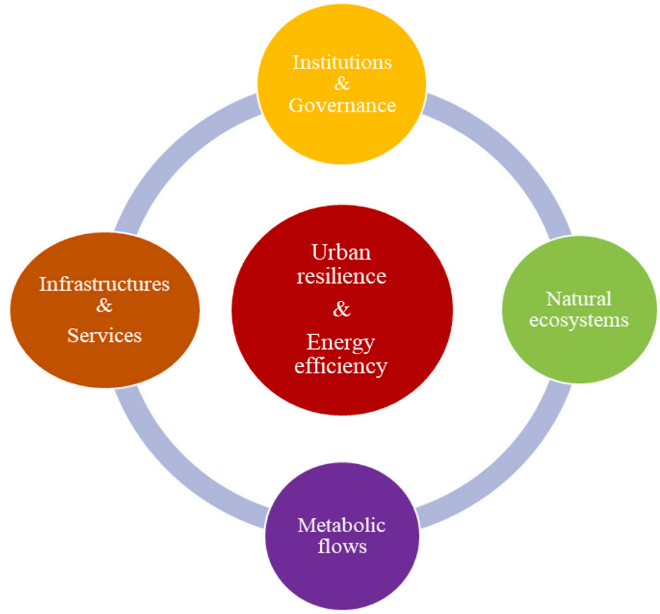

Fig. 9. Areas of actions to link urban resilience and energy efficiency (adapted by: Dodman et al., 2017).

unquestionable environmental, economic and social benefits (Table 5) as drawn in for communities to strengthen their systems and cope with unanticipated events of climate change impacts (Ribeiro et al., 2015).

Resource efficient systems find diverse definitions in literature. Dawkins et al. (2010) concentrate on the issue of exceeded consumption and define the 'resource efficiency' as *'the supply-side measures tackling with inefficiencies'* (Dawkins et al., 2010), while in a more official definition EU includes the term in its agenda as *'the economy to create more with less, delivering greater value with less input and using the resources in an intelligent and sustainable way to minimize the impacts on the environment'*.

3.1. Exemplar cases of 'resilient-energetically efficient' cities

A resource-efficient city is associated to the resource exploitation and the socio-economic and ecological impacts in long-term horizons (GI-REC, 2012) aiming at energy and financial savings. Elmqvist (2014) argues that resilience is part of a system and not a locality (Elmqvist, 2014), while on the opposite side, Martin-Breen and Anderies (2011)

Table 5
Resilience and energy efficiency benefits (adapted by: Ribeiro et al., 2015).

Benefits	Energy efficiency (outcome)	Connection to 'urban resilience'
Response and recovery (1)	Reduced electricity demand	Increase in reliability and preparedness to future shocks and unexpected events
	Efficient buildings and robust and flexible energy systems	Ability to maintain energy supplies during disruptions
	Alternative means of transportation systems, less GHG emissions, etc.	Alternative travel options with environmental benefits
Social and economic (2)	Use of local resources (in-situ) for production (reduced prices, less need for imports)	Stronger local economy
	Improved quality and emissions of fewer local pollutants	Fewer public health stressors
Climate mitigation and adaptation (3)	Reduced GHG emissions from power sector	Mitigation of climate change
	Cost-effective efficiency	Maximization of resilient strategies including adaptation measures

makes it necessary to consider the term in multiple scales and in a coherent manner (Martin-Breen and Anderies, 2011).

In this line, Peter and Swilling emerge the importance of meeting a range of axes to ensure resilient urban systems, among them the energy resilience, water resilience for re-use and recycling systems and the ecosystem resilience to integrate strategies for the ecosystems' equilibrium (Peter and Swilling, 2012). Methods to cope with this kind of challenges to improve the resources' efficiency and achieve resilient systems encompass a wide range of difficulties, including the technical and cost challenges. Hereby, some of these are presented (UN Environment, 2017):

- **Energy and resources:** recognizing the increasing trends of demand by a globally growing population, different initiatives are adopted by cities, especially on the fields of buildings, industry and transport and are included on local, regional, European or worldwide agendas. A typical example in respect to this is the 'New Urban Agenda' (United Nations, 2016), which identifies *'building performance codes and standards, renewable portfolio targets, energy efficiency labelling, retrofitting of existing buildings, and public procurement policies on energy, among other modalities'*.
- **Water:** for this axis, the Agenda promotes the conservation and sustainable use of water by rehabilitating the resources, promoting the re-use and increasing the retention and storage.
- **Waste:** in order to avoid the hazards derived from a poor waste management, linear visions of its re-use is necessitated in response to the circularity and the prevention from site and human contamination.

Nonetheless, as cities are continuously growing, their systems are becoming more and more complex. In particular, attaining resource efficiency in cities depends on integrated urban planning to promote density, mixing and compactness, transport projects and design strategies (Floater et al., 2014). The need for cross-sectoral and comprehensive patterns in echoed already in the 'New Urban Agenda' stating that *'we recognize that urban form, infrastructure and building design are among the greatest drivers of resources efficiencies with economic benefits and by fostering energy efficiency, resilience and productivity, we will achieve environmental protection with parallel economic growth'* (United Nations, 2016). Attempts to integrate energy efficiency to their climate mitigation strategies are present to different cities worldwide, following some exemplar:

3.1.1. Washington DC, USA

In 2002, Washington was struck by a harsh storm caused severe damages in the electricity grid of the city with subsequent effects on infrastructures and related fails. In reply and beyond to this shock, the city launched solutions to maximize both resilient strategies and GHG reduction with its strategy of 'Clean Energy DC' to address how the city will mitigate the climate change impacts by incorporating the energy efficiency and yield the prioritization of the adaptation plan (DC Sustainable Energy Utility, 2016).

The strategy included a comprehensive assessment of the infrastructure and the public facilities' vulnerability including a multidisciplinary group of actors comprised of local agencies, planning organizations, public and private utilities, etc. and is summarized on the following key points (Ohshita and Johnson, 2017):

- Identify a stabilizing strategy for the power grid to equal distribution of resources including storage, renewable energy and micro-grids.
- Ensure a climate-risk assessment for future investments in new or upgraded infrastructure.
- Provide back-up power in case of emergencies at all city facilities and pursue energy efficiency for all buildings by reducing in parallel the demand at peak periods.
- Identify the grid modernization as critical to enable the penetration of renewable to the district scale.
- Explore strategies for distributed solar with battery storage and distribution system planning.

3.1.2. Copenhagen, Denmark

Copenhagen is known for its low-carbon climate resilient strategy along with its 2009 Climate Plan which embraces quality life strategies and a pledge for carbon neutrality by 2025 (City of Copenhagen, 2009). Planning and adapting quickly after a cloudburst event in 2011with massive infrastructure damage (cost of nearly 1billion euros) (Kabell, 2016). The adaptation processes emphasized on blue-green infrastructure, stormwater management, natural cooling of the Urban Heat Island Effect, etc. recognized by C40 award (2016) (Scruggs, 2016). The plan manages risks of heatwaves with passive cooling techniques underlying that resilience is inherent in its integrated heat and power systems reinforcing a mix of energy supply at multiple scales (Ohshita and Johnson, 2017).

3.1.3. Shenzhen, Guangdong, China

Shenzhen is a fast-growing Chinese city with notable efforts to balance the energy demand of its population focusing on remarkable strategies on low-carbon development as was the first to pilot a carbon trading program (2013) led to a 17% GHG emissions' reduction (Scruggs, 2016). The city faced multiple threats from the climate change with intensified storms and typhoons resultant to severe heatwaves, saltwater intrusion with worsening problems and ecosystems' damages. Shenzhen has been one of 30 cities joined the pilot of 'sponge city' for flood management, nonetheless, it has not yet developed a comprehensive climate resilience plan focused on its urban system (Ohshita and Johnson, 2017).

4. Conclusions

Resilience offers a crucial meeting point among different yet essentially similar paradigms in urban development. Its importance has a rising scientific and realistic meaning and its rising engagement is present to global commitments related to sustainability, energy efficiency and carbon neutrality. Since its appearance in 70s, the concept of 'resilience' has been connected with diverse research fields, like the psychology, the social, economic or ecological sciences, however, now more than ever its context is promising and prominent to incorporate the human-oriented development and the fight against the climate change.

Resilience is defined by scholas in different contexts including ecological, engineering and social-ecological resilience. In the field of ecology, it is focused on the persistence of relationships within a system and is understood as a measure of the ability to absorb changes and disturbance and still maintain populations in whatever unexpected form for recovery or reorganization under other conditions. From the engineering angle, the concept is conceptualized within the concepts of robustness and resistance against external disruptions. Social-ecological resilience is related to the magnitude of shock that the system can absorb and remain within a given state depending on how the system organizes itself.

While the concept is intriguing and encouraging, this paper contributes to fill in the theoretical gaps of the literature by reviewing its backdrop and explaining the diversity of its approaches by scholars, while it aims at identifying the nexus with the energy efficiency and the resources' management as a channel for the cities to absorb, alleviate from shocks and combat their vulnerabilities. The scientific rising gravity to the topic of resilience is justified due to the exposure of cities to continuous changes and disruptions, hence, the adaptability is fundamental for ensuring the capacity of systems to recover and return to their previous situations. In fact, building resilience increases the ability of communities to withstand risks and reduce the vulnerability while enhancing their capacities to bounce back rapidly. On the basis of the above review, several crosscutting themes emerge with respect to the urban resilience and climate change:

- Climate change is of the major shocks that cities face and typically occurs in parallel with other stresses (e.g. economic or political), implying that the resilience requires a wide range of overlapping and interactive actions.
- Some of the key attributes of the resilient city include: diversity, flexibility, robustness, adaptation, mitigation, whilst are also hallmarks at the forefront of technological innovation.

Global cities' growth, economic and sanitary crisis, but mainly environmental changes ingraining 'resilience' as the core to address the vulnerabilities and uncertainties deriving from shocks and unexpected events, mitigate the fragility and increase the territories' capacities. In this line, building resilience is acknowledged as key element for enhancing effective strategies of comprehensive planning and meet the long-term targets. However, fostering the adaptation is a complex and difficult process to enhance the flexibility of urban systems – each of them is consisted of internal intertwining sub-systems with a high level of interactions closely linked- due to the need for inclusive and dynamic cooperation and synergies by all the actors and parties involved (authorities, investors, citizens, users).

Since resilience is by its nature an idea, which emphasizes on the 'adaptation' and 'flexibility', we reasonably assume that adopting a 'resilient planning' endorses the cities' capacities to reply to the forward challenges and facilitate the adoption of policies and agendas. Complementary, resilience is a concept for integrating discourses and bring together the practitioners with different targets working together upon the same objective.

In particular, in this paper we seek for the emphasis of the nexus of urban resilience to the energy efficiency of urban systems, a research area which still remains unexplored despite its rigorous benefits for integrated planning strategies. Enhancing urban resilience and addressing it in line with the resources' efficiency will grow awareness of the global populations and moderate the resources' scarcity and the dependency on fossil fuels and will enable the ecosystems to sustain. At the same time, enhancing urban resilience in an interoperable approach will be critical for issues, like the energy poverty or the economic crisis and these agendas are delivered by a range of commitments, beyond the New Urban Agenda, the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals. Nevertheless, an important statement from the research has been the significance of integrated and all-inclusive approaches to respond to this mutual connection of the concepts and their common objectives.

The paper concludes with suggesting an urban energy resilience matrix that addresses the energy shortage in a city to better understand and analyze the intricate issues for an energy-efficient, resilient, safer future city. Across the cities and the challenge of climate change, despite the diversity on their strategies across the phenomenon and its disastrous impacts, some common beneficial assets appear in respect to the resources' distribution, the strategies in energy performance and the involved actors' synergies and partnerships. Further research, knowhow sharing and lessons-learnt exchanges to quantify the benefits of energy resilience strategies but also exploring the cooperation and governance models are prioritized for forthcoming studies of the topic.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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