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COMPACT AND RESOURCE EFFICIENT CITIES? SYNERGIES AND TRADE-OFFS IN EUROPEAN CITIES

Abstract. Cities are the main consumers of energy and resources but at the same time are considered as centres for innovation which can provide solutions to unsustainable development. An important concept regarding energy and resource efficiency on the scale of the city and city-region is the compact city. Compact cities and compact urban development are thought to decrease energy and resource demand per capita and increase efficiency. At the same time trade-offs and potential rebound effects of increased resource efficiency question certain achievements of a compact urban structure. This paper reviews aspects of resource and energy efficiency in compact city development in a European context. We conclude that, if the idea of the compact city should have any effect on resource and energy efficiency, accompanying measures have to be implemented, such as e.g. efficient public transport systems to offer alternative travel modes. Also the allocation of efficiency gains due to compact urban development has to be taken into account in order to avoid direct and indirect rebound effects.

Key words: compct city, resource use, spatial structure, urban form, energy efficiency.

1. INTRODUCTION

Transforming cities' resource use to address the threats of climate change and resource scarcity is one of the main future challenges in urban development (Droege, 2011). Striving towards energy self-sufficiency, implementing regional resource cycles, retrofitting of the built environment as well as decoupling urban development and resource use are crucial for a city's future vulnerability and resilience against changes in general resource availability. The challenge gets more complex as resource and energy efficiency in a city are deeply interwoven with other aspects of urban development, such as social structures as well as the geographical context (DG Regio, 2011).

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In Europe this is high on the political agenda through the Europe 2020 strategy (European Commission, 2010) and its priority of "Sustainable growth", dealing with climate change and energy efficiency. As cities are the main consumer of energy and resources they are both problem and solution to tackle issues of efficiency and saving (Lewis, Hogain and Borghi, 2013). Furthermore, through innovation in green technologies and the removing of bottlenecks in network infrastructure, cities can enhance their competitiveness.

One widely used principle in sustainable urban development is the concept of the compact city. Compact cities are thought to decrease travel needs and increase resource efficiency due to shorter distances and higher densities. Different interrelations have been discussed in literature for several decades, both in conceptual and empirical studies. In this paper a short review of aspects related to resource efficiency and compact cities, including likewise potential drawbacks, is provided.

The compact city concept is applied in different forms – from the 'original' single-centred compact city to polycentric interpretations. These variations can be related to historical urban development, lifestyles, geographical context, city size, options to change urban form, as well as various specific development patterns taking place under the umbrella of global urbanization. In this paper we look at the compact city from a European perspective. Europe is characterized by predominantly polycentric settlement structures which attributes the city-region and the embedment of cities in a functional urban system (Nordregio *et al.,* 2005).

2. DEFINING RESOURCE EFFICIENCY AND THE COMPACT CITY

As a framework for this review we define the terms 'resource efficiency' and 'compact city' as follows: Resource efficiency means the ratio of services generated from resources to resource input. It means "getting the most out of every unit you buy" (Herring, 2006 regarding energy efficiency). Thus, resource efficiency does not necessarily imply a reduction in resource consumption as long as the overall economic activity is still increasing. However, many policy-related uses of the term go further, including the sustainable use of resources or an absolute decoupling of resource use compared to economic growth (European Commission, 2011; UNEP, 2013).

The EU's "Roadmap to a Resource Efficient Europe" (European Commission, 2011) considers the following resources: fossil fuels, material and minerals, water, air, land, soils, ecosystems/biodiversity, marine resources and waste. Some of these are in particular relevant in the context of a compact city discussion – especially regarding transportation, housing and infrastructure.

Regarding the use of resources it is important to include the city's functional urban area, which means looking at the city-region rather than at the city alone. A city's metabolism is deeply dependent on its urban-rural relationships and many resources which are used in the city are located or supplied in its surrounding region (e.g. water, land/soils, construction material, and possibilities for waste treatment). Furthermore many functional-dynamic relations as e.g. commuting are not limited to the core city but take place in a city's functional urban area. These functional relations form the city-region and describe cross-scale interactions.

The compact city is a very illustrative term and concept. However, providing a general definition of a compact city is not an easy task. Compactness or density is a matter of scale. Built-up structures can be compact on the plot level, the neighbourhood or district level or also the city level. Compactness on one of these levels does not equal compactness on the other levels. Also, a densely built-up structure does not mean the city can necessarily make benefit out of that. Different resource types are more or less relevant on each of the levels. For instance, district heating works often on district scale, while transportation issues (e.g. commuting) are very much related to the compactness of the whole city or city-region.

This paper does not provide a review on the various understandings of a compact city, but mainly focuses on a recent publication of the OECD (2011). The report summarizes key elements to consider when planning for a compact city, reflecting the complexity of the concept (table 1), and emphasizing that the compact city is more than density. To get the compact city work as it is intended – facilitating to increase resource efficiency and reduce consumption – it is important to secure public spaces, a dense public transport system and a mixed land use on the local scale.

Table 1. Three key elements of compact cities (OECD, 2011, p. 15)

Dense and contiguous development patterns	Urban areas linked by public transport systems	Accessibility to local services and jobs
Urban land is densely utilised Distinct border between urban and rural land use Public spaces are secured	Effective use of urban land Public transport systems facilitate mobility in urban areas	Land use is mixed Most residents have access to local services either on foot or using public transport

In this sense the compact city idea is not only translated into proximity but rather reflected in accessibility as well as mix of uses, which allows a more broad interpretation of the concept (Westerink *et al.*, 2013). It even gets more

difficult when the definition should be empirically applicable, as very different urban forms can appear as compact cities. Furthermore, urban form needs to be adapted to the local geographical context as well as it is dependent on earlier development as e.g. existing transportation corridors. Also, polycentric urban development can fulfil the requirements for compact city development if it is realized as decentralised concentration (Anderson, Kanaroglou and Miller, 1996).

Finally, compact city development is not only an issue of resource efficiency but can have high impact on the social and economic development of a city and its neighbourhoods. Thus, there is no simple, empirically applicable definition of a compact city. However, this also allows many cities to work with the concept and adapt it to their own context and needs.

3. THE RELATIONSHIP OF SPATIAL STRUCTURE AND RESOURCE USE

Urban form and spatial structure are strongly related to resource use. The arrangement of land use directly affects energy consumption, primarily in the transport and space heating/cooling sectors (Owens, 1986). As Salat and Bourdic (2012, p. 1) state, urban form "constrains cities' functioning (individual spatial behaviours, land use) and cities' flows (travel, energy, water) and, retroactively, their functioning modifies both their morphology and their structure." The enormous physical expansion of our cities in the last century and its implied problems especially regarding transport infrastructure and land consumption led to a renaissance of the compact city as an in ideal in urban planning. The debate often distinguishes between "urban sprawl" versus the idealised "compact city" as two opposite urban forms (Schwarz, 2010). Compact and dense urban development is supposed to directly translate into lower energy use and carbon emissions per capita, less air and water pollution, and generally lower resource demands compared to less dense, less compact cities (Beatley, 2003). The key to a more efficient use of resources lies in the 'heavy' or intense use – in terms of build-up density and activity – of a limited area.

The main benefits of compact cities, which are broadly investigated in the academic literature, are related to efficient land use and limited travel needs (Williams, Burton and Jenks, 2004). Additionally, a compact or dense city structure provides remarkable benefits in the energy supply of a city, both regarding energy distribution and network as well as energy consumption, e.g. for heating or cooling (Williams, 2004).

There are also a lot of arguments put forward to support the idea of compactness going beyond the issue of resource use. This includes more generally the reduction of transaction costs, enabling e.g. social interaction and integration or the support of the creative economy (OECD, 2011).

However, the relationship of compact urban structure and energy efficiency comprises also controversies, which are described as the compact city dilemma (e.g. de Roo, 1998, 2000) and address the conflicts between "environmental intrusive activities" like noise and air pollution and environmentally sensitive functions like recreation (de Roo, 1998, p. 1030). We will get back to that in section 4. In the following we discuss three potential benefits of compact cities related to resource efficiency:

– Compact cities save land, e.g. agricultural area

– Compact cities save resource (energy) use for transportation, including

– Save total transport needs (in km), and thereby reduce resource use for transport

– Strengthen more resource efficient modes of transport, e.g. public transport

– Compact cities increase efficiency of infrastructure and reduce resource consumption, e.g. by enabling the use of district energy systems

In terms of resources (according to the above mentioned EU Roadmap), those three benefits relate mainly to the use of fossil fuels and land, to a lesser extent to material and minerals, water, air, land, soils, ecosystems/biodiversity, marine resources and waste, although, depending on the energy system (e.g. district heating from waste) some of those are also directly related.

3.1. Compact cities save land

The most obvious effect of compact cities is the reduced need of urban land. The general trend in Europe, as in the rest of the world (Angel, Parent, Civco, Blei and Potere, 2011), is still a progressing dispersion of urban land. Although population is concentrating in metropolitan areas, urban land in these areas is growing at proportionally higher rates. Between 1990 and 2006 Europe's population grew by 7%, while the urban area in the same time grew by 37% (Fertner, 2012). Land is used less efficiently than before; we are consuming more and more land per capita. Although this is a general trend in Europe, the current land consumption per inhabitant can be very different between countries (Figure 1).

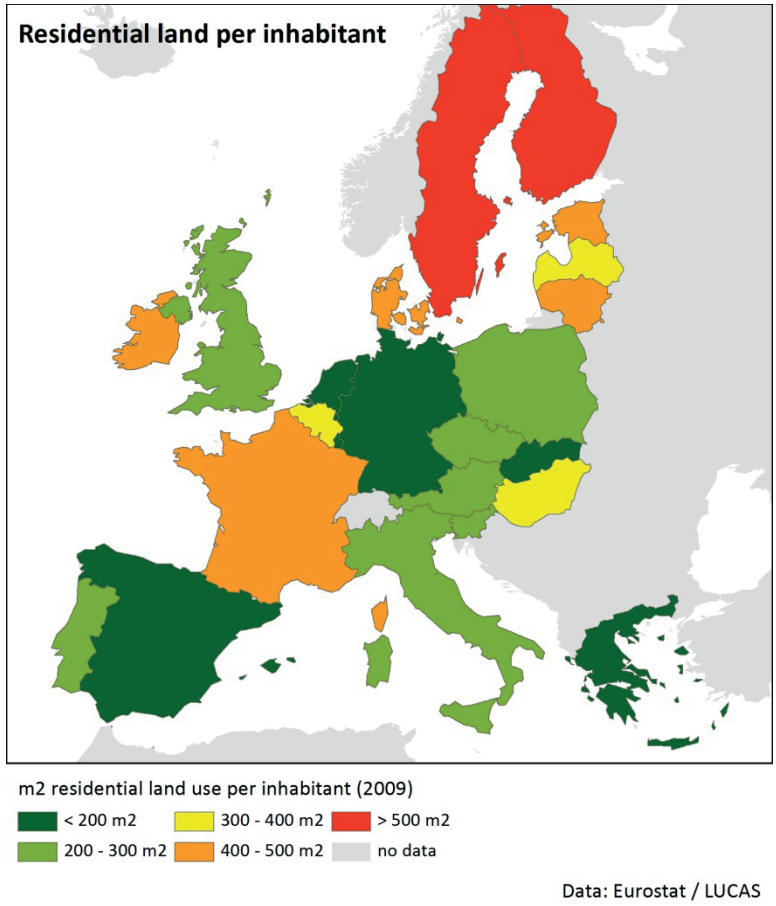

Fig. 1. Residential land (m^2) per inhabitant in 2009 in Europe

An important issue thereby is which kind of land gets urbanised. Cities are typically located in areas with the most fertile soils. Most areas getting converted to urban areas are agricultural land (European Environment Agency (EEA), 2006). Urban growth thereby directly affects urban-rural relationships as e.g. the local provision of food or resources. Higher densities of dwellings, jobs and other activities can reduce the (relative) need for new urban land. Decoupling of land consumption in relation to population or economic growth is a key issue. Furthermore, compact city development can reduce the fragmentation of the remaining areas, supporting more efficient agricultural practices, better connected nature areas and higher recreational potentials.

This process to achieve a compact city is described as 'urban intensification' by Williams *et al*. (1996), acknowledging the need for density and intensity of uses and activity likewise. Thus, intensification induces a sustainable management of

land (Williams, 2004). Urban regeneration ("recycling") is a key strategy towards compact and intense urban development and sustainable land use when e.g. applied in the dispersed suburbs. It refers to regeneration of land that was previously developed (European Commission, 2012). However, more often we can see a reuse of urban land for a different urban function, e.g. former industrial areas which get converted to housing areas. This 'brownfield development', especially in the inner urban areas, is an essential element of sustainable management of urban space. Even more as it does not only minimize new land take, but also contributes to the revitalization of inner city zones and creates mixed use development. Germany, for instance, considers the development of the city centres as key instrument in city development strategies ("Flächenrecycling"). The average new land take of 117 ha per day between 1993 and 2008 shall be reduced by means of this strategy to 30 ha per day in 2020, which corresponds to a targeted share of 3:1 of central compared to decentralized development (Lieber and Preuß, 2010).

More efficient use of land can be caused by geographical limitations (e.g. cities in valleys or limited by water areas) but also by general policies on urban development. In the European context ambitions towards management of spatial development are present at all policy levels from the structural and territorial cohesion polices at EU level to the national, regional and local levels. The first urban growth management policies go back as far as to 1900 when the first green belts were designated (Ali, 2008), following the garden city movement as well as the preservation of green areas around major European cities (Konijnendijk, 2010). Today some variety of growth management is part of a 'standard mode of operation' in spatial planning. There are, however, large national and regional differences regarding competences, administrative delineations, systems and public interests between different parts of Europe. Although, the need to control urban sprawl is widely accepted (Nuissl and Couch, 2008; van den Berg, Braun and van der Meer, 2007), except for a few cities, sprawl stays a general challenge in Europe (European Environment Agency (EEA), 2006; Reckien and Karecha, 2008).

Building densities are not only related to land consumption, but also to general energy consumption. Theoretical calculations show clearly, everything else being equal, detached houses can require as much as three times the energy input of intermediate flats (OECD, 1995). Such a trend would imply generally higher net densities, thus, there are also implications for the urban scale. Regarding energy for transport and heating the following two sections present some evidence.

3.2. Compact cities save transport energy

Another main argument for compact cities is the reduction of energy use (especially fossil fuels) for transportation. Compact cities can reduce the average travel distance by supporting mixed used development in neighbourhoods allowing

short distances between different activities. Furthermore, compact cities also allow a more sustainable modal split, favouring "green" modes of transport. Highly attractive public transport systems as metro lines can only work efficiently in areas with a minimum density of attractions (households, jobs …). So energy use is reduced through saving transport energy (by reducing length) and more efficient use (by using more energy efficient modes of transport).

Empirical studies show a correlation between urban form and transport behaviour. Newman and Kenworthy's study from 1989 is the most well-known, showing a relation between population density in cities and gasoline consumption per capita (Newman and Kenworthy, 1989). The study got though criticized for methodological flaws. A main problem is the difficulty of comparing across different contexts and bounding conditions (Stead and Marshall, 2001). This includes the question if it is possible to control for preferences people have in their travel behaviour. For example, we could assume that a person who likes to bike also prefers to live in an area where this is possible (e.g. the inner city) and is more reluctant to move to more car-dependent areas than persons with other transport preferences. Furthermore it is difficult to separate effects caused by other factors, like socio-economic factors (especially income), which are difficult to consider comprehensively in a study, but might be more significant for transport behaviour than parameters of urban form (Echenique, Hargreaves, Mitchell and Namdeo, 2012). Another concern is if the right elements of the urban form are represented in empirical studies. For example available parking space is crucial for the choice of transport mode, but is seldom included in empirical studies. This however can make a considerable difference in older and newer compact urban developments.

However, other studies focusing on single cases or cases within similar context come up with similar conclusions as Newman and Kenworthy. Clark (2013) found that per capita vehicle distance, vehicle energy use and vehicle emissions are inverse to population density in metropolitan areas in the USA. Stead's (2001) study from the UK shows that "socioeconomic characteristics typically explain around half of the variation in travel distance per person across different wards, whereas land-use characteristics often only explain up to one third of the variation in travel distance per person." An in-depth study by Næss (2006) of the metropolitan region of Copenhagen showed, while controlling for many non-urban structure variables, that energy use for transport is higher for residents living further away from the centre than of those living close to or in the centre.

In another study, Næss and Jensen (2004) showed that urban structural variables influence travel behaviour, even in a small town of around 30 000 inhabitants. On the micro scale, the neighbourhood scale, Schwanen *et al*. (2002) showed that high population and employment densities are positively related to the use of public transport. On a global scale, most recent a study across

cultural contexts including a dataset of 274 cities (Creutzig, Baiocchi, Bierkandt, Pichler and Seto, 2015), shows that economic activity, transport costs, geographic factors, and urban form explain 37% of urban direct energy use and even 88% of urban transport energy use.

Finally it has to be considered that some of the discussed effects might decrease or even inverse when reaching a certain city size (Morrill, 1970). E.g. the advantage of proximity is decreasing the larger a (single-centred) compact city becomes. Capello and Camagni (2000) argue, with a perspective on economics, that at a certain urban size, diseconomies of scale apply as congestion effects take place, decreasing the efficiency of an urban location. Also, one of the main criticisms against addressing transport needs from an urban form perspective is the slow rate of change in the urban form, which allows significant changes in travel demands only in the long term (Williams, 2004).

3.3. Compact cities increase efficiency of infrastructure and reduce resource consumption

Besides saving land and transport energy, compact cities can also increase the efficiency of infrastructure in general (e.g. by the more intense use of infrastructure) and contribute a reduction of resource consumption (e.g. in infrastructure construction, where less meters of infrastructure is necessary to supply the same amount of users). Particular technical infrastructure needs a minimum density of activities/users, as for example high level public transport or district heating systems. However, infrastructure investment and maintenance costs per person might also be cheaper in compact cities. Conversely, the provision of infrastructure services in less dense or sprawled regions is comparatively expensive and less efficient.

Salat and Bourdic (2012) write that "a city four times denser consumes four times less land and sixteen times less network infrastructure." They consider complex urban structures (e.g. redundancy in infrastructure networks) as structurally more efficient and resilient than simple ones. Compact city structures provide the necessary conditions to establish these complex urban structures. Higher densities also facilitate the implementation and introduction of sustainable technologies, like district heating (Williams, 2004, p. 45). Empirical evidence is however difficult to establish as there are many other factors influencing costs for infrastructure. Also, the increasing complexity of infrastructure development in densely built-up areas has to be considered, even though per capita resource use for construction and maintenance might still be lower than in less dense areas.

Spatial structure and urban form, like the general layout and orientation of buildings, have considerable influence on the heating and cooling demand of buildings. Futcher *et al*. (2013) found that compact urban development on neighbourhood/

building scale saves energy for heating and cooling in the single buildings, mainly through shading and insulation effects and influence on the micro climate. Næss (1997) names building types, local climate conditions and the grouping of buildings the most important spatial planning factors related to heating. Tereci *et al*. (2013) found that for a given urban site, compact, multi-family apartment blocks provide the lowest CO2 emissions per capita. However, they also found that shading, as a consequence of increased building density, can increase heating demand in heating dominated climates.

Large scale heating and cooling systems play an important role in several European countries. In the Scandinavian and Baltic States, district heating covers 40–60% of the heating demand (Connolly *et al.,* 2014). Often operating with Combined-Heat-Power (CHP) plants, these systems are only feasible at particular minimum densities because of the infrastructure costs. Furthermore, because of energy transportation losses, the low-grade energy (e.g. heat) has to be produced relatively close to the end users. Also, efficient district heating/cooling systems need a mixed user structure, which both asks for low-grade energy (heat, hot water and steam) and electricity demand (OECD, 2011). This could be different kinds of industries, hospitals, hotels and residential areas, having not only different demands of the type of energy but also regarding the use pattern over the day, helping to smooth peaks of usage in the system. At the same time, district heating systems provide secure and efficient energy supply, with high flexibility in fuel use (e.g. Christensen and Jensen-Butler, 1982).

Regarding resource consumption, an important issue in district heating is the handling and conversion of energy. Introduction of CHP often is connected to a switch from high quality fuels to lower quality fuels, such as coal or biomass (OECD, 1995).

4. TRADE-OFFS AND REBOUND EFFECTS

There are a number of potential adverse effects of compact cities in environmental, social as well as economic terms (OECD, 2011; Westerink *et al*., 2013). These trade-offs regarding compact city development and resource use are not fully explored and subject to concrete planning measures because of their local complexity. They include:

– Potential negative effects on energy consumption, e.g. increase in energy consumption for cooling caused by urban heat island effects or inefficient energy use due to traffic congestion;

– Increased need of transportation and big infrastructure due to the reduced potential of on-site activities, e.g. farming on-site, waste treatment on-site, local water run-off, recreation on-site.

– High costs for infrastructure construction (e.g. underground metro instead of on surface).

Thus, the main problem is the definition of a compact city and that effects can be evaluated very differently depending on the applied scale. However, Næss (1997) concludes that there is, with goal-oriented and integrated planning, more complementarity than conflict between compact development on city (transport) level and on building (mainly heating) level.

Despite resource use there are other trade-offs with compact city development regarding social constraints. This includes housing affordability (Clark, 2013) but also issues related to quality of life, as traditional, local, environmental qualities. It can be questioned if it is possible to densify without destroying valuable nature or cultural heritage (Næss, 1997). Strategies that are often applied to deal with those "sustainability trade-offs" include urban renewal, limitations on car use, mixed land-use and life cycle residential strategies (Westerink *et al.,* 2013). Also, there are some critiques of the idea that compact urban form really makes a difference. Other factors might be much more significant for resource use, e.g. the influence of the socio-economic factors on travel behaviour (Gordon and Richardson, 1997).

Looking at trade-offs from a broader perspective it is also important to consider rebound effects and how efficiency gains (e.g. in terms of money or time available for each citizen) through e.g. a higher use of public transport can actually effect (increasing) resource use in other sectors. For example, a study from Finland showed that people living in compact urban settings tend to have a high use of summer houses (Strandell and Hall, 2015). The lack of open space increases the need of people to travel further for recreational purposes. Similar 'compensation effects' have been observed in Sweden. Axelsson (2012) showed that in the bigger cities like Stockholm, the ecological footprint of transport activities is only half than in many other places. However, for other activities as recreation and culture, the average Stockholmer has a much bigger ecological footprint than the average Swede. The impact of direct energy use (e.g. transport) is transferred to indirect energy use by consuming activities and products.

5. CONCLUDING PERSPECTIVES

Urban form and spatial structure is related to resource use, especially in regard to land use, transport energy and energy for heating/cooling. However, for a number of resources spatial structure and urban form play only a minor role. This includes especially consumption patterns related to lifestyle and economic wealth, like consumer goods use per person (including resource use for their production) or consumption of electricity for household appliances. Some resources might be indirectly connected

to urban form but are not further elaborated in this text. These include water use per person (might be connected to urban form and housing structure), and production of food. Compact urban development as e.g. in the form of urban growth management might ease the development pressure on agriculture and foster local production of food. However, dense urban structures can also complicate the cultivation of food in the city because of spatial limitations and shading effects.

Furthermore, urban density cannot be the only measure. If the idea of the compact city should have any effect on resource efficiency (and limit its trade-offs) other elements have to be implemented, as e.g. efficient public transport systems to offer alternative travel modes and cope with congestion.

This, however, does not mean we should not take action. Although and because the spatial structure of a city changes only very slowly, spatial planning has an important responsibility to avoid the risk of lock-in effects in the future. Buildings, communication and transport infrastructure as well as socio-technical systems have a long lifetime. Spatial planning can ensure a certain flexibility and farsightedness in urban development to be prepared for changes in the energy use (Næss, 1997). So, even though we implement behavioural measures (e.g. price incentives) which have immediate effect, the physical structures have to be included from the start, even if (or because) they cannot change that fast.

Regarding spatial planning principles, the example from Copenhagen (Næss, 2006) shows that to be energy-saving, sustainable and environmentally friendly, (1) most construction should be densification within existing urban area, (2) priority should be given to apartment buildings and terrace housing instead of detached single-family housing, (3) road and parking capacity should not be increased, but public transport strengthened and (4) densification should take place in areas already affected by technical infrastructure, to keep the urban green structure. To avoid potential trade-offs of compact city structures and to achieve the desired efficiency improvements, integrated, coordinated and tailor-made planning processes are necessary.

Finally, because of the different contexts cities are functioning in, it is important to see resource efficiency as a relative concept: that means not to be absolute efficient, but to become more efficient. In that regard it is very similar to how we work with the term sustainability. Still, even when we consider resource efficiency as a relative concept, eventually it needs to induce a decrease in the total resource and energy consumption in order to address the threats of climate change and resource scarcity. The allocation of efficiency gains has to be taken into account in order to avoid rebound effects. Indicators can play an important role to monitor progress when they also cover a temporal and systemic dimension to evaluate change.

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