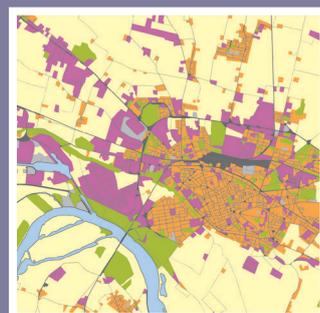


Urban sustainability issues — What is a resource-efficient city?

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1 What is this report about?

1.1 Policy background

Scarcity of natural resources poses a threat to the continued prosperity and well-being of the world's population. As the global economy and population grows and the standard of living rises, the demand for natural resources increases and this threatens the security of supply. Resources are defined as all inputs into the economy (EC, 2011a). 'These resources include raw materials such as fuels, minerals and metals but also food, soil, water, air, biomass and ecosystems' (EC, 2011b).

The current pattern of resource use leads to the depletion and resulting scarcity of natural resources, the degradation of ecosystems, and increasing and more volatile prices of natural resources. On a planet with finite resources, the challenge is to find a way of delivering greater value and more services with fewer inputs (EC, 2011a). That means developing more productive ways of using resources throughout their life cycle in order to decouple economic growth from resource use and its environmental impact.

Resource efficiency is now a key objective of the Europe 2020 Strategy. It is seen as a way of increasing competitiveness, securing growth and jobs, and innovating, all while managing resources more efficiently over their whole life cycle. A resource-efficient Europe is one of the seven flagship initiatives of the Europe 2020 strategy (EC, 2011a). The *Roadmap to a resource efficient Europe* provides a framework to support the transition to a resource-efficient and low-carbon economy in many policy areas, including agendas for climate change, energy, transport, industry, raw materials, agriculture, fisheries, biodiversity and regional development. The Roadmap also gives guidance on the design and implementation of actions to transform the economy (EC, 2011a). The seventh Environment Action Programme, 'Living well, within the limits of our planet', which will guide European environment policy until 2020 identifies a resource-efficient, green and competitive low-carbon economy as a key objective (EU, 2013a).

Traditionally, resource efficiency has been focused on production and consumption. However, cities are at the front line of managing change and the driving force for action to reduce the use of resources by taking an integrated approach and planning. Not only are they the engines of the economy and the home of their citizens, but municipalities also supply and control various public services to residents and businesses that influence the majority of resource use, energy consumption and harmful emissions.

1.2 Urban areas are critical to achieving resource efficiency

Cities and, more generally urban areas, are growing very fast. In 2008, for the first time in history, more than half of the world's population was living in urban areas. Urban areas are supposed to absorb all of the population growth anticipated in the future. Europe had already become predominantly urban by the beginning of the 1950s. Today, approximately 359 million Europeans — 72% of the total EU population (EUROSTAT, 2013) — live in cities, towns and suburbs, and this proportion will continue to increase.

Like living organisms, cities require natural resources, energy, raw material, food and goods to sustain the daily life of their inhabitants and their economic activities (Kennedy et al., 2007). The urban system generally depends on its neighbourhoods, and often from afar, for both supply and disposal of materials. The material and energy needs, as well the emissions, congestion and waste production, of an urban area depend on the components of the urban system. One of the major challenges to overcome to achieve sustainable cities is minimising the use of resources and developing a circular model that recovers local waste closely in line with the needs of the local economy.

Owing to the density and proximity of the population and businesses, the urban system is a resource-efficient one that brings benefits such as reduced commuting distances, a smaller

spatial footprint, optimisation of infrastructure and increased innovation. It allows economies of scale in citizen-oriented services (utilities) such as collective transport, power, water and sanitation services, waste management and district heating. There is no conflict between better resource efficiency and quality of life. Green open spaces, which bring considerable health benefits, can be preserved, and even developed, in densely populated urban areas. Achieving resource efficiency and urban sustainability not only have benefits for the well-being of the population but also significantly reinforce its prosperity.

The potential to reduce urban flows depends not only on urban management and planning but also on factors such as compactness, urban morphology and urban form. These factors significantly shape resource use, not just because they determine the way the population moves and lives but also because they define the need for maintenance, in particular the rate of deterioration of buildings and roads, and the quality of and way in which services are provided. Badly planned cities can be a permanent drain on resources.

A city has to continuously maintain its existing building stock and infrastructure. Even if the urban structure cannot be easily changed, the 'grey infrastructure' may be effectively managed and retrofitted to enhance its performance. Utility suppliers, urban managers and planners, and local governments can develop integrated urban strategies and resource-oriented policies. Action to improve resource efficiency can be taken on different spatial and temporal scales. The optimisation of urban cycles starts at the building unit, as that is where most urban resources are consumed, followed by the urban block, the district and the city. To achieve the greatest benefits, it is important to manage each resource on its optimal scale (Agudelo-Vera et al., 2011).

It is important to avoid conflict between policies when managing and planning urban areas to achieve resource-efficiency. Each policy needs to be developed on the appropriate spatial scale (district, city, neighbourhood, region) and in a way that avoids conflict when different scales are addressed at the same time. Policies have to consider the whole system and its interactions and remain goal oriented in the long term, even in the event of political change. Cities are embedded within larger scale engineered infrastructures (e.g. electric power, water supply and transport networks) that convey natural resources (directly or in the form of transformed resources) to people in cities, often from afar. In this context, urban sustainability depends upon complex and cross-scale interactions between the natural system,

the engineered infrastructure and the individuals and institutions that govern these infrastructures (Ramaswami et al., 2012). As cities have a strong relationship with, and rely on, their hinterland, they cannot act alone. However, they can exercise leadership, thereby triggering a process of change beyond the administrative limits of the city.

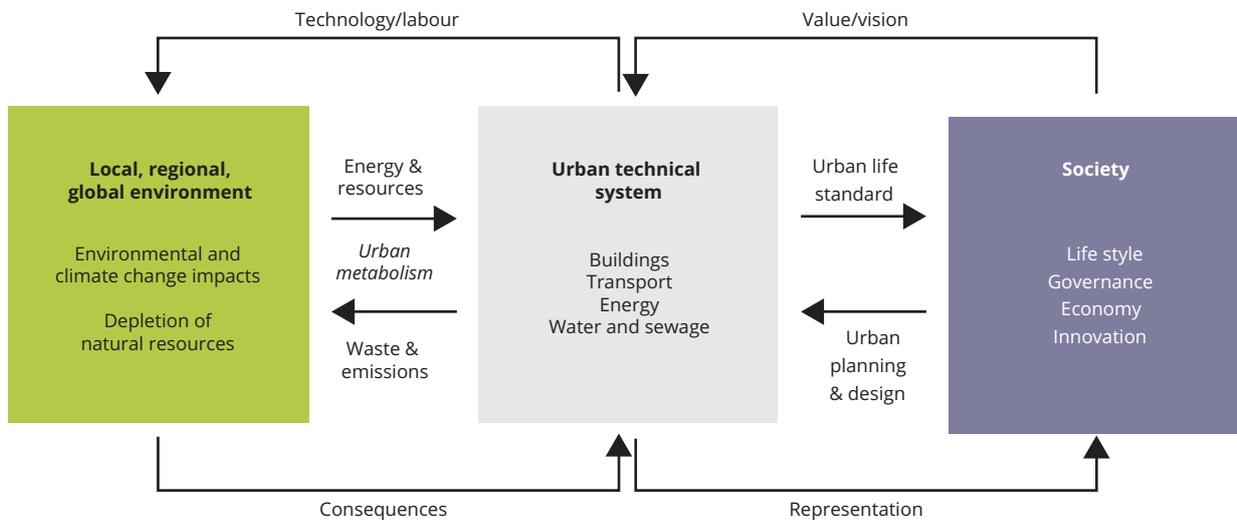
Finally, there is no conflict between policies to enhance the quality of urban life and those to achieve resource efficiency. Urban management, design and planning can preserve the health and well-being of all the city's inhabitants and users — such as commuters coming to work or to study, regular and occasional users of urban services (hospital, administration, culture, shopping, etc.), tourists, businesses — and at the same time improve resource efficiency. Generally, there is complementarity between the goals. For example, developing public transport makes daily life easier for the city's residents and at the same reduces fossil fuel consumption. A compact city does not mean no green spaces but better designed and more conveniently located green spaces.

1.3 Resource efficiency as a step towards urban sustainability

To achieve resource-efficient cities, the challenge is to simultaneously transform the interdependent components of the urban system (see Figure 1.1):

- Society gives the city its character through its behaviour, lifestyles and values. Governance and the policy-making process determines the ability to implement efficient integrated urban planning and to design a vision for the future.
- The 'grey' infrastructure system (roads, metro, railways, buildings, utilities) determines the spatial extent of the city and the urban pattern (urban form, density, design). It shapes how people live, work and move about. The current expansion and 'engineering' of urban areas results in misuse of resources through soil sealing, fragmentation of natural systems, and encouraging increased mobility and the associated pollution and energy and material consumption, (OECD, 2012b).
- The 'green infrastructure' system, i.e. the green areas inside and around cities (green roof, green walls, urban parks, private gardens, etc.), brings social, ecological and economic benefits to the urban population, such as air filtration, temperature regulation, flood protection and recreational areas (EC, 2013a).

Figure 1.1 The urban system



Source: Adapted from Bai and Schandl, 2011.

Cities are sources of problems but, at the same time, they also have a huge potential for resource efficiency:

- They drive societal and sectoral changes. They are places where people live, work, trade, produce, move, enjoy social interaction, study and innovate.
- They provide people with goods and basic services based on utilities such as drinking water, public transport, power and waste management.
- Their planning mechanisms determine the level of resource use.
- They have the potential to develop a territorial approach and find synergies between activities on the same scale.

To ensure their long-term viability, cities need to uncouple social well-being and economic growth from their use of resources. They have a lot to gain from achieving resource efficiency, in particular controlling costs by reducing their material (e.g. maintenance) needs and energy consumption and offering a better quality of life to their residents.

Action to enable cities to manage resource flows better and close urban cycles depend on spatial (form, planning), temporal (long, medium or short term) and sectoral (water, waste, energy) factors, management

(innovation, technology) and territorial governance (coordination, cooperation, social innovation, administrative delineation).

The urban system relies on cross-scale interactions among the natural system, the trans-boundary engineered infrastructure (building, roads, railways, water supply, power supply, etc.) and the different actors (1). The urban metabolism needs to be optimised on all scales, from the lowest possible (building) through block, district, city and neighbourhood to region. Actions are led by different participants at the same time and on different scales. The main challenge is to avoid conflict between these actions and to take into consideration the entire system, the interactions between the component parts and the long-term impacts.

There is no unique solution. An effective route to sustainability needs to be based on a place-based approach and take into account the characteristics of the city (geography, economy, climate, natural capital, social capital, etc.). Each city needs to find its own individualised solution. As most people live, work and travel in urban areas, small changes in urban management and citizens or businesses' behaviour can have considerable consequences for the use of natural resources. The challenge is how to produce more in terms of value and how to improve citizens' quality of life with less input of natural resources?

(1) Urban actors: individual end-users such as households and businesses, policy-makers, civil government officials, NGO actors — such as citizens' group, scientists, journalists, special interest groups, coalitions -, infrastructure designers and managers, institutions that govern infrastructure etc.).

1.4 Three reports on resource-efficient cities

Local authorities need at the same time to enhance the well-being of society and to preserve natural assets for current and future generations. They have to make the right choices, both now and for the long term, and choose appropriate trade-offs. Although the transition to resource efficiency does not rely only on local factors but also depends on global trends and policy contexts, cities can undergo radical transformation in different domains — energy, housing, transport systems, waste management, green areas, public spaces. Preparing for such transformation now in a controlled manner will allow us to further develop cities properly, while reducing the levels and impact of our resource use.

The objective of these reports is to support policy development and decision-making. They are targeted at policy-makers, decision-makers and stakeholders involved in urban management at the local and city level as well as at the regional level. They analyse the following:

- Why do resource-efficient urban areas matter?
- What are the main challenges and what can be done to meet these challenges?
- What solutions can be implemented on different scales and across sectors?
- What are the drivers of change?
- How can cities be governed to achieve the transition to resource-efficient urban areas?
- How can we involve society in the decision-making process?

This report is part of the following series of three short reports (see Figure 1.1), based on an overview of recent literature and successful case studies, that addresses resource efficiency issues in urban areas.

1.4.1 What is a resource-efficient city?

The report presents the concept of urban metabolism, the circular model and the role of compactness in urban resource efficiency. Cities requires natural resources and energy to sustain the daily life and activities of the urban population. Nevertheless, there are opportunities to minimise input and output flows. As the urban form shapes the way people live, work and move in urban areas, compactness offers the potential to reduce urban flows. The most well-documented effects of compactness are the reduced need for land and energy for transport. Urban planning, based on a vision of the future, developed with local stakeholders and crossing administrative borders, is a key factor in increasing the density of urban areas, developing mixed land use, avoiding the unnecessary uptake of land and soil sealing, reducing car dependency and encouraging the use of public transport, walking and cycling.

1.4.2 Resource-efficient cities: good practice

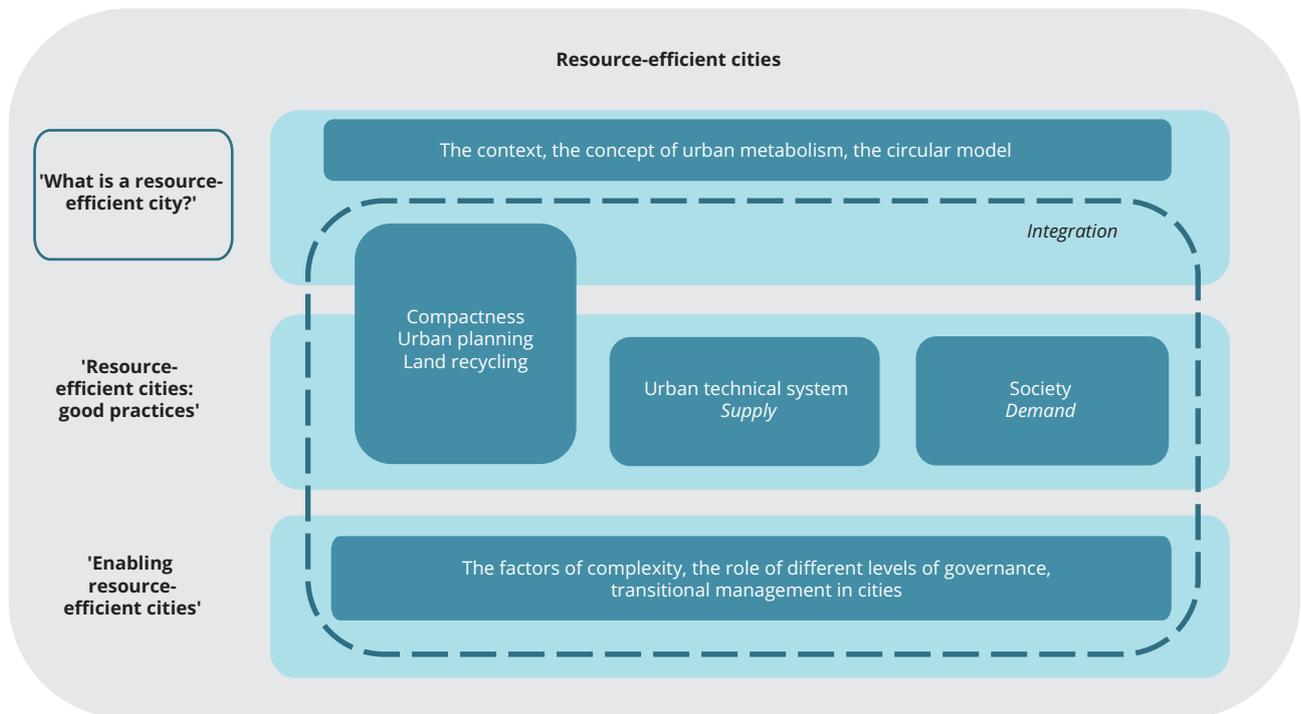
Cities are key players in minimising the use of resources and in developing the circular model. Generally, municipalities provide utilities and control public services for citizens and businesses that influence the majority of resource and energy use and the production of emissions and waste. Local authorities have the capacity to implement responses on multiple scales. The main challenge is to scale up actions from the most simple, one function, such as a building for housing, or one resource, such as water management, to integrated solutions in a large urban area (e.g. an ecodistrict) with many functions (e.g. housing, economic activities, green areas, renewable energy production, water harvesting). Another challenge is to move from the current centralised system, with mono-site and end-of-pipe utilities driven by municipalities or utility suppliers, to decentralised systems in which users are owners and producers. The report analyses both the supply and the demand issues. It is divided into two parts: the first is devoted to how to avoid, prevent and

Box 1.1 Urban areas, cities, urban environment

Urban areas are generally differentiated from other settlements by their population size and functional complexity. Most commonly, they are characterised by a particular human settlement pattern, a critical mass and density of people, a concentration of man-made structures and activities.

For ease of reading, the terms 'urban area', 'urban environment' and 'city' are used interchangeably throughout this report, and no specific distinction is made among the terms with regard to distinct morphologies or administrative boundaries.

Figure 1.2 The links between the three reports on resource-efficient cities



reduce the use of resources, and the second addresses reusing, cascading, recycling and harvesting.

1.4.3 Enabling resource-efficient cities

To achieve resource- and energy-efficient cities, local authorities have to overcome the limitations of policy instruments that are insufficient to deal with the complexity of urban challenges. They face not only strategic, technical and financial challenges but also institutional barriers created by the fragmentation of responsibilities and decision-making, the number and variety of actors (public, private, civil society, individuals) contributing to resource efficiency through their daily decisions and practices and operating at different levels, the challenge of addressing the urban system as a whole, and the characteristics of the city (geography, economy, climate, history, natural capital, social capital, etc.). Despite this complexity, some cities have adopted ambitious policy agendas with targets, managing the city in a far-sighted goal-oriented way, cooperating with surrounding municipalities and other levels of governance, and developing a transition management approach. This is a form of governance that facilitates societal change. It is based on a dialogue between private and public actors (users, citizens,

firms, universities, public authorities) that envisages a common future and identifies ways of achieving a resource-efficient society and, more generally, sustainability.

1.5 Scope of this report

Chapter 2 focuses on the global and European context. It analyses the megatrends, such as resource efficiency and urbanisation, and the policy context.

Chapter 3 presents the concept of urban metabolism and the main challenges and drivers. It examines the functioning of the urban system, in particular the interlinkages between the different drivers of urbanisation and the pressures and impacts.

Chapter 4 demonstrates how urban morphology (form, density, compactness) can change the input flows of the resources consumed by cities and the output flows emitted. It analyses the interdependence between the spatial dynamics of a city and its material resource flows. Urban planning is mentioned often as a tool to limit energy use and the city's spatial footprint but more rarely as a tool to reduce the city's use of material flows.

2 The context

Our societies and their economic systems are based on natural resources. They are fundamental not only for the economy but also for the services they provide for our health, well-being and quality of life. Throughout human history, the consumption of natural resources per capita has changed dramatically. In agrarian societies, resource consumption was essentially restricted to food, feed for animals and biomass for fuel (Girardet, 2010). Their consumption was lower than that of industrial societies, which was characterised by fossil fuel energy (coal, oil and gas) and other materials such as metal. But in a world of finite resources, non-renewable resources are, by definition, limited and some may be nearing the point of exhaustion (EEA, 2010a).

The demand for natural resources increases and threatens the security of supply because the demand for resources for the economy is growing, standards of living are rising and a middle-class is emerging in developing countries (Kharas, 2010). The sources of minerals, metals and energy, the stocks of fish, timber, water, fertile soils, clean air and biomass, and biodiversity are all under pressure. Access to resources is becoming a major economic concern, and the depletion and resultant scarcity of natural resources generates competition and increases prices.

The agglomeration effect in cities brings socio-economic benefits. The concentration of the population and activities increases opportunities for social interaction, culture, innovation, jobs, education, etc. It is also a resource-efficient model: the per-capita consumption of resources (in particular biomass, metals and industrial minerals) is lower in densely populated areas than in relatively sparsely populated areas (Krausmann et al., 2008). Increasing population density contributes to reducing commuting distances, air pollution, energy demand, land take and soil degradation, and fragmentation of habitats. It allows economies of scale for citizen-oriented services such as collective transport, power, water and sanitation services, waste management and district heating.

Cities are pre-eminent in facing resource challenges. They drive economic growth, consumption of materials and energy, production of waste, and emission of

greenhouse gases. City authorities manage utilities and lead urban planning. However, the transition towards resource-efficient urban management does not rely only on local factors — such as management of the urban system, urban planning, processes — it also depends on global and European trends and the policy context.

This chapter presents the main drivers that influence resource efficiency and fuel the transition to sustainable cities against the background context at global and European levels.

2.1 The urban age

By 2008, for the first time in history, more than half of the world's population was living in urban areas, and in future cities will absorb all population growth. The trend towards urbanisation will continue. By 2050, about 70% of the population is likely to be living in cities, compared with less than 30% in 1951 (UN, 2012a). Between 2011 and 2050, the world's urban population will increase from 7.0 billion (7 000 million) to 9.3 billion (UN, 2012b). In this global context, resource-efficient urban areas become crucial.

The development of megacities, with more than 10 million inhabitants, is the latest phenomenon of worldwide urbanisation processes associated with accelerating globalisation (Sassen, 2005). Some urban areas have achieved unprecedented size (in terms of both population and spatial area). Owing to their size, they can have a massive environmental impact and requirement for natural resources. In 1970, there were only two megacities (Tokyo and New York) in the world; by 2011, there were 23 megacities, and that number is expected to reach 37 by 2025 (UN, 2012b). Most new megacities are in developing countries.

Today, about 1 city dweller in 10 lives in a megacity; by 2025, it is expected that about 1 city dweller in 7–8 will live in a megacity (UN, 2012b). At the same time, the proportion of people living in cities of fewer than 1 million inhabitants is expected to decline in the future (UN, 2012a).

2.1.1 Europe: a network of small and medium-sized cities

The urban population in Europe

In Europe, already approximately three-quarters of the population lives in urban areas. The size of the urban population depends on the method used to quantify it. According to Eurostat's revised urban-rural typology, based on a 1-km² population grid, 68% of the EU-27 population was living in urban areas and 32% in rural areas (Eurostat et al., 2010). At the regional level, 42.5% of the EU-27's population lived in predominantly urban regions (2012) and a further 35.3% in intermediate regions (Eurostat et al., 2013). Although, in comparison with other regions of the world, the EU's population is growing at a relatively slow pace, the proportion is predicted increase to about 80% by 2020.

Few megacities in Europe

The largest urban areas, with more 10 million inhabitants, are London and Paris/Île-de-France and Istanbul. Then they are followed by Berlin, Madrid, the Milan agglomeration and the polycentric Manchester-Liverpool region, Athens and Rome. Twenty cities have a population of between one and two million inhabitants, and there are 36 cities with a population of between half a million and one million inhabitants (Eurostat et al., 2013).

The highest urban populations are found in almost all capital city regions, such as Lyon, the Rhine-Ruhr area in Germany, the entire Randstad area in the Netherlands, and in various port cities along the Atlantic (such as Bordeaux, Bilbao and Porto) and Mediterranean (including Barcelona, Marseille, Nice, Turin, Naples and Thessaloniki) coasts (Piorr et al., 2011).

Small and medium-sized cities predominate in Europe

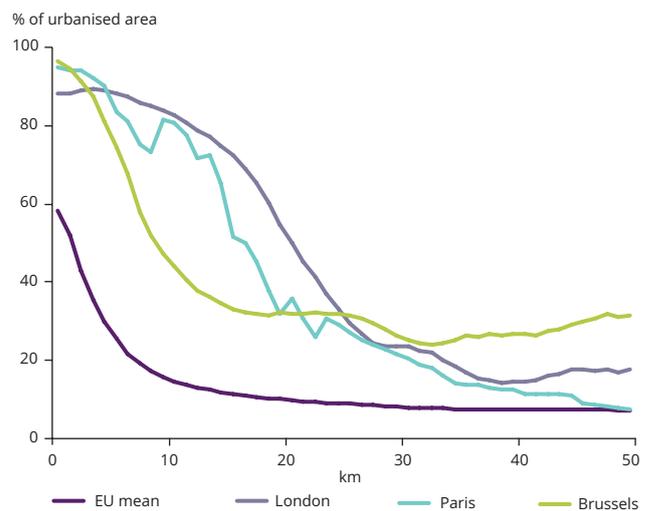
A large part of the urban population lives in small or medium-sized cities spread across Europe. One third of the European urban population lives in cities with fewer than 150 000 inhabitants (more than half of the total number of cities). Half of the population lives in cities with fewer than 500 000 inhabitants, representing less than 90% of the total number of cities (Eurostat et al., 2013). Some simulations show greater population increases in future for Europe's large and medium-sized agglomerations than for its smallest ones (Kabisch and Haase, 2011).

2.1.2 Cities with no clear limits

Cities, or more generally urban areas, are a social, ecological and economic system characterised by a particular settlement pattern, a critical mass and density of people, and man-made structures and activities. Most commonly, they are differentiated from other settlements by their population size and functional complexity (Fellmann et al., 1997).

The limit of city as an administrative area no longer reflects the physical layout or the socio-economic reality that is better described by the labour market basin, the commuting pattern and the large interconnected urban spatial structure of sub-centres that are economically and socially dependent on the major urban centre (EC, 2011c).

Figure 2.1 The urban profile in Europe



Source: Corilis (?), 2006 (2000 for Greek cities) based on Corine Land Cover v16.

Graph showing the urbanisation pattern from the city centre to a maximum distance of 50 km from the centre for the Urban Audit's selection of cities of over 50 000 inhabitants. Each line represents the proportion of urbanised area (%) in a 1-km buffer ring from the city centre (centroid of city boundaries, as defined by Urban Audit) for selected cities (London, Paris and Brussels) and the European mean value.

The percentage of built-up areas, in individual bands of 1-km width, is measured from the city centre out to a maximum distance of 50 km. Taking Brussels as an example, roughly 30% of the 20-km band is built up. On average, for 571 European urban areas over 50 000 inhabitants (Urban Audit's selection), 10% of the 20-km band is built up.

(?) <http://www.eea.europa.eu/data-and-maps/data/corilis-2000-2> (accessed 4 November 2015).

Cities are becoming bigger and fuzzier as a result of growing suburbanisation and increased commuting. The urban structure is increasing in complexity with the increasing development of mobility. Most of the largest cities are embedded in a large interconnected metropolitan area, with dynamic sub-centres emerging at the urban edge.

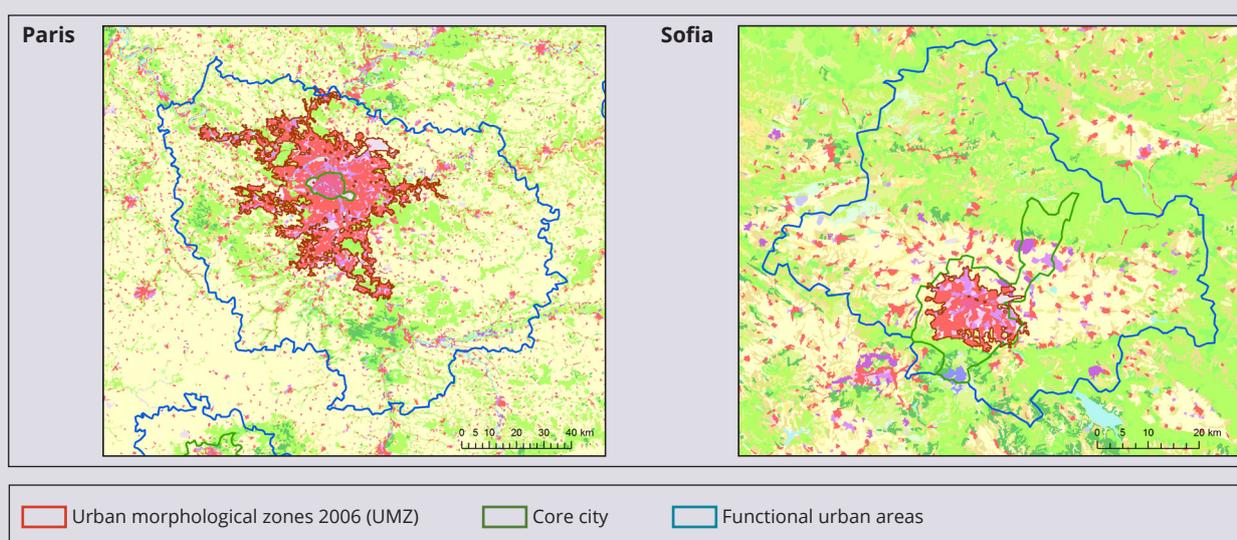
Typically, European cities are dense but they become less dense (i.e. lower population density, fewer buildings and less infrastructure) the further away one is from the city centre (see Figure 2.1). This transitional area is typically split among numbers of administrative areas that complicate the spatial integration of policies and the decision-making process.

Box 2.1 What is a city?

A city can be defined in different ways.

- *The administrative unit* generally corresponds to the historic city and does not reflect the limit of the built-up area or the borders of the real economic limits and the real behavioural patterns of people (EC, 2011c). The administrative boundaries are relatively stable entities compared with those based on economic, commuting or population density patterns. Owing to the different structures of local government, the definition of a city varies significantly from country to country.
- *The urban morphological zone* deals with the physical layout of an urban area (EEA, 2010b). It is the morphological approximation of the 'real' city. It describes the urban tissue of an area and the continuity of the artificial space.
- *The functional urban region*: the limits of the municipality are generally too small in spatial terms to be used in the comprehensive analysis of regional and city development trends (ESPON, 2006). The functional urban region is defined as 'a territorial unit resulting from the organisation of social and economic relations within that. Its boundaries do not reflect geographical particularities or historical events. It is thus a functional sub-division of territories.' (OECD, 2002: p. 11). It describes the travel-to-work catchment area and gives an image of the actual role played by a city in the region and beyond in terms of its functions. The functional urban region encompasses a system of surrounding towns and villages that are economically and socially linked with the core centre.
- The functional urban areas (formerly known as larger urban zones) developed by Urban Audit are an approximation of the functional urban region (Eurostat, 2004). They comprise the city and its surroundings in order to take account areas with a significant proportion of their residents commuting into the city.

Figure 2.2 Relationship between different types of delineations (Paris and Sofia)



Source: CLC2006; UMZ: UMZ 2006 (EEA); Core city and Functional Urban Area: Urban Audit (Eurostat 2010).

[http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/File:Defining_the_boundaries_of_the_larger_urban_zone_%E2%80%94_Barcelona_\(ES\)_and_Zagreb_\(HR\).PNG](http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/File:Defining_the_boundaries_of_the_larger_urban_zone_%E2%80%94_Barcelona_(ES)_and_Zagreb_(HR).PNG) (accessed 25 July 2014).

2.2 The increasing global demand for resources

During the 20th century, the world experienced a four-fold growth in population, a 23-fold increase in economic output and a 12-fold increase in use of fossil fuels (EC, 2011a). The extraction of construction materials grew by a factor of 34, ores and minerals by a factor of 27, fossil fuels by a factor of 12, and biomass by a factor of 3.6 (UNEP, 2011).

The global demand for resources is driven by the growing population and improvements in standard of living arising from increasing incomes. In Europe, population growth is a marginal factor; the key drivers are economic growth and the changing structure of economies that are based on a growing service sector and increasingly importing resources.

Box 2.2 What is a natural resource?

According to the European Commission's Thematic Strategy on the Sustainable Use of Natural Resources (EC, 2005a), 'European economies depend on natural resources, including raw materials such as minerals, biomass and biological resources; environmental media such as air, water and soil; flow resources such as wind, geothermal, tidal and solar energy; and space (land area)'.

As stated in the *Analysis associated with the roadmap to a resource efficient Europe* (EC, 2011a), the 'resources are all the resources that are inputs into our economy — metals, minerals, fuels, fish, timber, water, soil, clean air, biomass, biodiversity and land and sea'. In the Roadmap, the European Commission considers natural capital to include ecosystems, which provide a flow of goods and services essential for our well-being and economic prosperity, and biodiversity, which underpins many ecosystems and is vital to their resilience (EC, 2011a).

The Organisation for Economic Co-operation and Development (OECD) defines natural resources in relation to the economy as 'natural assets (raw materials) occurring in nature that can be used for economic production or consumption' (OECD, 2010).

The United Nations Environment Programme (UNEP) International Resource Panel uses a broader definition. A natural resource is 'anything that occurs in nature that can be used for producing something else' (UNEP, 2011). However, it distinguishes between material and immaterial resources.

- The use of immaterial resources has no effect on the qualities that make them useful, and it is not easy to give them an economic value. They include, for example, the heat of the sun or the song of a bird.
- The use of material resources is useful for certain applications. Their value is characterised by the qualities that make them useful. However, the state of material resources is transformed by their use and they are no longer available to be used for the same purpose.

Another distinction can be made between renewable and non-renewable resources.

- Non-renewable resources are formed over long geological periods and they cannot be replenished once they have been depleted. They include fossil fuels that provide energy, metal ores used to manufacture products, and industrial and construction minerals used to build houses and roads.
- Renewable resources can be replenished or reproduced easily. Some are continuously available such as sunlight, wind, the tides, etc. Others can be depleted by harvesting and use but can also be replenished over a short (e.g. agricultural crops) or a longer (e.g. water, forests) period.

Renewable resources can be lost as a result of destruction (e.g. soil sealing, habitat destruction), pollution or overconsumption beyond the resource's capacity for regeneration (e.g. some species of fish becoming overfished, when water abstraction exceeds the capacity for recharge, salt water intruding into coastal aquifers, overgrazing, etc.). Certain resources, such as minerals for construction, are potentially abundant on the planet but can be in short supply in the places where people need them.

2.2.1 The difference in consumption of resources between European countries

Material consumption is clearly positively correlated with well-being. The countries with the lowest score on the Human Development Index consumed less than 10 tonnes of materials per capita in 2008 (Dittrich et al., 2012). But, conversely, some countries achieve high levels of well-being at relatively low levels of material consumption, and a high level of material consumption does not necessarily lead to a high level of well-being ⁽³⁾.

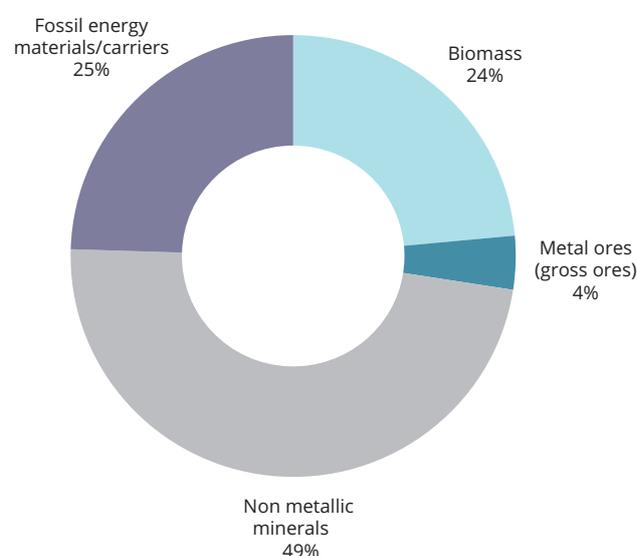
The level of material consumption per capita is assessed by direct material consumption (DMC), which is defined as the total amount of materials directly used in an economy. It is calculated as extraction plus imports minus exports. In the EU-27, the level of material consumption per capita was 14.6 tonnes in 2011 (this excludes water flows because they are so large). After reaching a peak in 2007, the use of material resources has declined owing to the economic downturn but less so than gross domestic product (GDP).

There are differences in the quantities and the composition of materials consumed among European countries (and therefore among cities), probably representing different consumption rates, living standards economic structures and stages of development. Measuring standard of living only by GDP per capita does not clearly indicate the level of material consumption. Five high-income countries (France, Italy, the Netherlands, Spain and the United Kingdom) (Eurostat, 2012) have lower material consumption, and some low-income countries are below Europe's average material consumption (Greece, Hungary, Latvia, Lithuania and Slovakia).

It is difficult to give a clear explanation for the level of material consumption per capita (DMC; see Figure 2.3). But it may be at least partly explained by population density: more densely populated countries, such as the Netherlands, the United Kingdom, Germany and Italy, tend to consume somewhat less than the EU-27 average (Eurostat, 2012).

Countries with a lot of construction activity have a high consumption of sand and gravel and other non-metallic minerals. Materials for construction (sand, gravel and other non-metallic minerals to construct houses, buildings, roads and bridges) account for around for half of domestic extraction.

Figure 2.3 Domestic material consumption (DMC) split by category in the EU-27, 2011



Source: Based on Eurostat data.

2.2.2 Hidden flows

All production processes start with the extraction of raw materials from nature. Some products are available in most countries, such as food products or minerals for construction. Other types of raw material, in particular fossil fuels and metal ores, are available in concentrated form in only a few countries.

The economy is growing faster than the use of materials in most European countries. This dematerialisation only becomes apparent because it results in the substitution of domestic production with imports. Most European countries ⁽⁴⁾ import more resources than they export, in particular finished or semi-manufactured products (Eurostat, 2001). That leads to a shift in the associated environmental burden in the rest of the world.

With the separation of production and consumption in the global supply chain, developed countries tend to reduce their domestic materials extraction through international trade and increasing their imports. Consumption in one country can have a negative impact in another country arising from the extraction of resources from the natural environment (e.g. mine tailings, oil spillages, pollution, erosion, loss of biodiversity). In addition, the amount of materials, hectares of land, litres of water or quantities of energy needed for production are hidden in each imported

⁽³⁾ This is measured by the Happy Life Years Index, which aims to quantify the quality of life in a country with the help of subjective measures of happiness.

⁽⁴⁾ Except Latvia and Sweden.

product. These hidden resource flows, as well as those related to material extraction, are not considered in current flow accounts because they do not enter the economy.

The raw materials needed to make imported products are not completely accounted for. The difference is particularly important for metals, which are often imported in a highly concentrated form or as pure metal and therefore enormous quantities of raw material extracted in the country of origin are left out of the equation.

At the European level, the consumption of materials fluctuates between 15 and 17 tonnes per capita per year. But the material 'foot print', which includes the 'hidden flows' of imports, is estimated at around 45 or 50 tonnes per capita per year (Eurostat, 2010). For Germany, in 2005, the amount of raw material inputs was about 2.4 times greater when these flows were included (Eurostat, 2010). Calculating raw material equivalents of international trade for 186 countries shows that countries' use of non-domestic resources is, on average, about three-fold greater than the physical quantity of goods traded (Wiedmann et al., 2013).

2.3 Major socio-economic changes

Society is always changing. Some factors such as changes in income, demography or the structure of households are key drivers that influence society's and the economy's demand for resources.

2.3.1 *The rise of consuming classes around the world*

The move to cities is increasing the incomes of millions of people around the world. According to OECD's projection, three billion new middle class consumers are expected by 2030 (Kharas, 2010). Each year up to 2030, at least 150 million people will enter the middle class (in terms of purchasing power parity). By 2025, a group of 600 cities will generate nearly 65% of the world's economic growth (Dobbs et al., 2012). The rise of the new consumers will be a driver for the world's economic growth, but at the same time it will exacerbate the demand for natural resources and food.

2.3.2 *Changes in household structure*

The change to more and smaller households is a major long-term societal trend in Europe. Average family and

household size has been declining since the 1960s, mainly because of the decline in the fertility rate over the past three decades, increasing divorce rates, which contribute to the increase in single-parent families, and the ageing population. The average household size in the EU-25 declined from 3.3 persons in 1960 to 2.4 in 2012. The average household size ⁽⁵⁾ in 2012 was between 2.9 persons in Romania and 1.9 in Denmark. In 2012, 32% of households in the EU-28 were single person.

The size of private households will influence the quantitative and qualitative nature of the demand for resources in the coming decades, in particular for housing. The decreasing size of households means that the growth in number of households is likely to continue to exceed population growth. In Europe, this increase in the number of households creates a need for more buildings, which is exacerbated by the general trend towards bigger dwellings.

2.3.3 *Changes in the demand for housing*

The structural and demographic changes within European society have had, and will continue to have, implications for housing and energy needs (EU, 2006), in particular in urban areas. The increase in the population will increase the overall day-to-day consumption. The rise in the total number of households will increase the demand for housing and thereby the demand for both land and materials for building new houses.

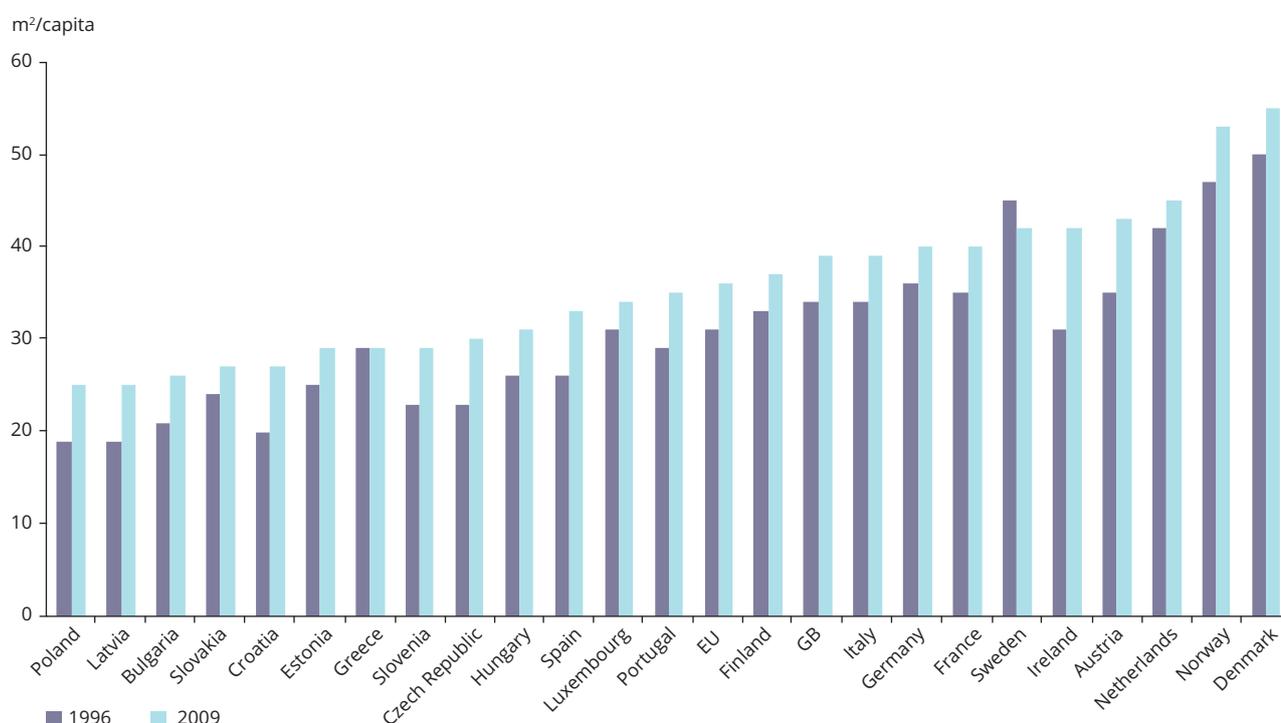
In addition, the decreasing household size means a decrease in material efficiency, as fewer people share the communal benefits of household services. Smaller households imply that more appliances and installations are required to provide the same level of service.

By 2060, around 30% of the population will be over the age of 65, and 12% over the age of 80 (EC, 2011d). The ageing population will be a significant driving force for the decrease in household size, the total number of households and the increase in the average size of homes, as people get older and stay on alone in their house, originally designed and bought to house a family.

The average living space per capita inside buildings has increased, although there are considerable differences between countries (see Figure 2.4). The demand for floor space depends on economic wealth, culture,

⁽⁵⁾ Eurostat: households by size (Eurostat). <http://appsso.eurostat.ec.europa.eu/nui/show.do> (accessed 4 November 2015); (Data for Ireland are not available.)

Figure 2.4 Average living space (m² per capita) in buildings (1996 and 2009) and population change (same period)



Source: ETC/SCP, 2013 — Calculation based on ENERDATA, 2012; population based on Eurostat, 2012.

climate, demand for single occupancy housing, etc. It is higher in northern and western EU countries than in central or eastern countries (see Table 2.1).

A decrease in population can also have an influence on space per capita in that fewer people inhabit the same number of dwellings. This is probably the case for countries such as Bulgaria (BG), Estonia (EE) Latvia (LV), Romania (RO) and, to a lesser extent, Hungary (HU), in which the population decreased during the period analysed.

2.4 The policy context

European policies — and also other international organisations (UNEP, World Bank, OECD) — are increasingly taking into consideration the use of resources and the related impact in the urban context. They have recognised the fact that cities have the opportunity to be more resource efficient by adopting appropriate strategies, planning and management. However, the major challenge is the coordination and integration of multilevel and multisectoral policies.

Table 2.1 Average residential floor space in Europe (m² per capita)

Area	Single family house	Apartment
Central and eastern Europe	26	20
Northern and western Europe	41	36
Southern Europe	50	31

Note: Southern Europe: Cyprus, Greece, Italy, Malta, Portugal, Spain.

Northern and western Europe: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland, United Kingdom.

Central and eastern Europe: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic, Slovenia.

Source: BPIE survey 2009 (BPIE, 2011).

2.4.1 EU strategy

The EU climate and energy package for 2020, known as the '20-20-20' targets⁽⁶⁾, sets headline targets for long-term policies. In this framework, the Europe 2020 Strategy aims to change unsustainable consumption patterns and surmount the economic crisis by concentrating efforts on achieving a smart, sustainable and inclusive economy (EC, 2010a). The major challenge is to create a low-carbon and resource-efficient economy while maintaining the structure and functions of ecosystems.

The flagship initiative 'Roadmap to a resource efficient Europe' (one of seven flagships of the Europe 2020 Strategy) sets up a long-term framework for policies to support a shift towards a resource-efficient and low-carbon economy. It addresses all aspects of resource efficiency: transition of energy, industrial, agricultural and transport systems; societal changes (behaviour of producers, investors, consumers); and technical changes. A range of coordinated roadmaps are consistent with the long-term objectives of the resource-efficient Europe initiative and are relevant for urban areas:

- The *Roadmap to a resource efficient Europe* (EC, 2011a) urges those managing the economy to 'create more with less, delivering greater value with less input, using resources in a sustainable way and minimising their impacts on the environment'. In its annex, it addresses specific practical urban issues: avoid land take and urban sprawl (in particular on fertile soil), remediate contaminated sites, reduce use of fossil fuels via better energy efficiency and use of renewable energy in buildings, build zero-energy buildings and increase the rate of renovation of existing buildings, and ensure sufficient interconnected green spaces as part of the green infrastructures.
- The *Roadmap for moving to a competitive low carbon economy* (EC, 2012a) gives a detailed analysis of cost-effective ways of reducing greenhouse gas emissions by 2050.
- The *Roadmap to a single European transport area, towards a competitive and resource efficient transport system* (also known as the White Paper on Transport) (EC, 2011e) sets out key goals for urban transport systems to be achieved by 2050, such as no more conventionally fuelled cars in cities (their use is to be halved by 2030), a reduction of 60% in greenhouse gas emissions from transport,

and a target of carbon dioxide-free city logistics in major urban centres by 2030.

The 2020 Biodiversity Strategy (EC, 2011f) is another cornerstone of the policies looking at better use of resources. Biodiversity underpins the delivery of many ecosystem services and makes the urban system less vulnerable to environmental shocks. The communication 'Green Infrastructure (GI) — enhancing Europe's natural capital' (EC, 2013a) promotes green infrastructure as a tool for providing ecological, economic and social benefits through natural solutions. Green infrastructure is present in both urban and rural settings. In cities it delivers health-related benefits such as clean air and better water quality. Green infrastructure solutions are generally a cost-effective alternative or complementary to 'grey' infrastructure.

Finally, the 7th Environment Action Programme, 'Living well, within the limits of our planet', is clearly focused on the transition to a resource-efficient and low-carbon economy (EU, 2013a) in which natural capital is protected and enhanced. Priority 2 of the programme, 'To turn the Union into a resource-efficient, green and competitive low-carbon economy', is devoted to resource efficiency, and priority 8, 'To enhance the sustainability of the Union's cities', focuses on urban areas.

2.4.2 Sectoral and thematic EU policies

A range of sectoral and thematic EU policies address resource efficiency and are particularly relevant in urban areas. The following list is not exhaustive, but it gives an overview of the main directives and communications having an impact on resource and energy efficiency in urban areas:

- **Waste:** The Thematic Strategy on Prevention and Recycling of Waste (EC, 2005b) resulted in a revised Waste Framework Directive in 2008 (EP, 2008) that includes a legally binding prioritisation of waste management activities, a new 50% recycling target for waste from households (to be fulfilled by 2020) and targets on the amount of biodegradable municipal waste that goes to landfill.
- **Water:** Over the last two decades, the EU Drinking Water Directive (EU, 1998) and Urban Waste Water Directive (EU, 1991) have been key drivers of infrastructure development and compliance with water quality criteria. Since 2000, the Water Framework Directive (EU, 2000) has established

⁽⁶⁾ The targets are: a 20% reduction in EU greenhouse gas emissions (compared with 1990 levels); increasing the proportion of EU energy coming from renewable resources to 20%; and a 20% improvement in the EU's energy efficiency.

a framework for water policies that is a driver for regulation of water utilities, indirectly via river basin management plans and programmes of measures. The implementation of cost recovery through water pricing is highly relevant for utilities. The communication 'Blueprint to safeguard Europe's water resources' (EC, 2012b) outlines action focused on better implementation of current water legislation and integration of water policy objectives into other policies.

- *Energy efficiency:* The Energy Efficiency Directive (EU, 2012a) establishes a common framework of measures to achieve the 20-20-20 headline targets. The EU Ecodesign Directive (EP, 2008) sets mandatory ecological requirements for energy-using and energy-related products (such as boilers, light bulbs, TVs and fridges). In 2009 a revision of the directive extended its scope to energy-related products such as windows, insulation materials and certain water-using products. The Renewable Energy Directive (EU, 2009a) established mandatory targets for the proportion of energy consumed by countries that comes from renewable sources to be achieved by 2020.
- *Buildings:* The Energy Performance of Buildings Directives (EC, 2002; EU, 2010; EU, 2012b) require all EU countries to strengthen their building regulations

and to introduce energy certification schemes for buildings. The objective of the communication 'Resource efficiency opportunities in the building sector' (EC, 2014a) is to reduce the environmental impact of buildings by improving their overall resource efficiency.

- *Transport:* The Action Plan on Urban Mobility⁽⁷⁾ (EC, 2009) and the communication 'Together towards competitive and resource-efficient urban mobility' (EU, 2013b) promote the development of sustainable urban mobility plans to address current and future transport needs in a sustainable way.

2.4.3 International policies

UNEP has published several documents with the aim of achieving resource efficiency in cities that highlight both the limits of the planet's resources and the potential for improving resource efficiency: 'Resource exploitation already exceeds the Earth's biological capacity, endangering the fundamental economic, social and environmental systems on which our development relies. However, significant potential exists for improved resource productivity through technological innovation and demand changes over the whole resource life cycle, from the extraction and use of raw materials to end of life disposal' (UNEP, 2013).

Box 2.3 Integrated Product Policy

The concept of Integrated Product Policy aims to minimise the environmental impact of products by looking at all phases of a product's life cycle. It calls for continuous improvement in product manufacturing and design and for promotion of their uptake by consumers.

Over the last 10 years, the EU has developed policies addressing the challenge of the growing use of resources and unsustainable production patterns. In 2005, the on the Sustainable Use of Natural Resources (EC, 2005a) aimed to reduce the environmental impacts associated with resource use. Subsequently, the Action Plan on Sustainable Consumption and Production and Sustainable Industrial Policies reinforced the life cycle approach (EC, 2008), as did the Ecodesign Directive (EU, 2009b).

In addition, EU policies stimulate innovation-friendly markets through the EU 'Lead markets' initiative. This initiative, devoted to demand-side innovation, focuses on six highly innovative and strategic markets: eHealth (ICT (information and communications technology) solutions for patients, medical services and payment institutions), protective textiles, sustainable construction, recycling, bio-based products, and renewable energies (EC, 2013b).

The objective of the 'Single market for green products'⁽⁸⁾ initiative is to make it easy for a company to market its product as green in several Member States. Two methods of measuring environmental performance throughout the life cycle, the product environmental footprint (PEF) and the organisation environmental footprint (OEF), have been established and are recommended. This initiative supports international efforts towards greater coordination in methodological development and data availability and sets out principles for communicating environmental performance (such as transparency, reliability, completeness, comparability and clarity).

⁽⁷⁾ The actions identified in the plan were implemented through EU programmes and initiatives from 2009 to 2012.

⁽⁸⁾ <http://ec.europa.eu/environment/eussd/smgp/index.htm> (accessed 6 June 2015).

The UNEP report also highlights 'the key role of cities in contributing to decoupling, as societal 'nodes' in which much of the current unsustainable use of natural resources is socially and institutionally embedded — but also as centres for knowledge, financial, social and institutional resources, where the greatest potential exists for sustainability-oriented innovations' (UNEP, 2013).

UNEP has created the International Resource Panel to support the framing of policies for sustainable resource management by providing independent, coherent and authoritative scientific assessments of the use of natural resources and its environmental impact over the full life cycle. Its assessments are solutions oriented, examining examples of innovation from both a technological and an institutional perspective.

The Rio+20 outcome document recognises that the inclusive and green economy is an important tool for achieving sustainable development and eradicating poverty. Resource efficiency is promoted through the green economy and the life cycle approach. The EU agreed to strive to achieve a land degradation neutral world in the context of sustainable development at the Rio+20 conference ⁽⁹⁾ (UN, 2012c).

2.4.4 Urban policies are gaining in importance

Urban areas are gaining more and more attention both at the European level and from international organisations (OECD, United Nations Habitat, UNEP). More and more Europeans live in urban areas that are the drivers of job creation and growth.

Cities play a key role in the implementation of the Europe 2020 Strategy and its seven flagship initiatives. They bring together the greatest proportion of the population and higher education and are at the forefront of implementing innovation strategies. Innovation outputs are particularly high in very large agglomerations. The three flagship projects — the 'Digital Agenda for Europe' (EC, 2010b) the 'Innovation Union' and 'Youth on the Move' (EC, 2010c) — address a series of urban challenges: exploiting the full potential of ICT for better health care, a cleaner environment and easier access to public services;

developing innovation partnerships for smarter and cleaner urban mobility; and reducing the number of young people leaving school early and supporting young people at risk, young entrepreneurs and self-employed young people.

The Thematic Strategy on the Urban Environment (EC, 2005c), the documents adopted during informal ministerial meetings, such as the Leipzig Charter (Informal Meeting of Urban Development Ministers, 2007), the Toledo Declaration (Informal Meeting of Urban Development Ministers, 2010) and the Riga Declaration ⁽¹⁰⁾, the communication on the key features of an EU urban agenda ((EC, 2014b), and the report *Cities of tomorrow — Challenges, visions, ways forward* (EC, 2011c) highlighted the importance of the integrated urban development and the mismatch between administrative and urban structures leading to fragmented urban management.

Cities are both part of the problem and part of the solution, as they concentrate the capacity for innovation and are the drivers of the economy. The promotion of green, compact and energy-efficient cities is a key contribution to green growth. Cities have an important role to play in implementing the agenda of the two flagship initiatives 'Roadmap to a resource efficient Europe' (EC, 2011a) and 'An integrated industrial policy for the globalisation era' (EC, 2010d).

Urban areas play an important role in implementing territorial cohesion for the programming period 2014–2020. Territorial cohesion aims to foster integrated urban policies and to enhance sustainable urban development across the EU. It highlights the promotion of low-carbon strategies, including the promotion of sustainable multi-modal urban mobility and measures relevant to mitigating and adapting to climate change. It underlines the preservation and protection of the environment and the promotion of resource efficiency (e.g. regeneration of brown sites, reducing air pollution, etc.) (EU, 2013c, 2013d).

The European Commission promotes and financially supports sustainable urban development (e.g. through projects such as ESPON ⁽¹¹⁾ and URBACT ⁽¹²⁾) to learn more about urban cities and to monitor their social, economic, environmental and territorial impacts.

⁽⁹⁾ Resolution A/RES/66/28, 11 September 2012, entitled 'The Future We Want'.

⁽¹⁰⁾ http://urban-intergroup.eu/wp-content/files_mf/ministerial_declaration_26052015.pdf (accessed 6 June 2015).

⁽¹¹⁾ <http://www.espon.eu/main> (accessed 6 June 2015).

⁽¹²⁾ <http://urbact.eu/> (accessed 6 June 2015).

3 Cities as a living organism

The majority of material consumption can be attributed to urban areas because of the concentration of population and the higher levels of income. These two factors drive economic growth, the consumption of materials and energy, the production of waste, and the emission of greenhouse gases. However, cities are also key players in achieving resource efficiency, and they have the capacity to implement measures on many different scales, even beyond the city borders, to foster resilience in urban society.

Cities have considerable potential for reducing input and output flows of resources by better urban management and governance. They can contribute to achieving decoupling by developing integrative and innovative approaches for more efficient management of resource flows, not only more efficient technology but also better spatial organisation, better urban planning, design and management and better governance, and changing citizens' change of behaviour.

Technological solutions alone are not enough to bring about decoupling. 'End-of-pipe' solutions, generally used to solve environmental urban problems, are no longer sufficient. There is a need for an integrated approach and better coordination among sectoral policies, levels and scales. Making sure that urban policies are coherent in this respect is a challenge, because they are often carried out independently by many participants with different aims and in different areas.

To assure their long-term viability, cities must disconnect social well-being and economic growth from their use of resources. The challenge is to develop an urban model using less material, less carbon and less nutrients. The ideal objective is to achieve urban resilience and to increase urban self-sufficiency in certain resources. Some cities are already developing innovative thematic programmes, such as those

oriented towards zero carbon or zero waste, which cut across sectors, levels, institutions and scales.

To achieve resource-efficient urban management and to help decision-makers, it is necessary to have a better understanding of urban flows and material stocks. There are methods for quantifying the material flows of cities, and different cities have already been fruitfully studied. This chapter presents urban flows in a simplified way. The aim is to raise awareness on urban flows and their impacts in urban players (policy-makers, urban managers and stakeholders). An understanding of the mechanisms that underpin urban flows is necessary to propose improvements.

3.1 Decoupling economic growth from resource use

According to the *Roadmap to a resource efficient Europe*, resource efficiency 'increases aggregate economic value through more productive use of resources over their life cycle. It requires using those resources in a sustainable way, within the planet's long-term boundaries. This includes minimising impacts of one resource's use on other resources, including the environment.' (EC, 2011a). In practice, this requires that stocks of all environmental assets are managed and used to achieve the maximum sustainable yields, that residual waste is close to zero and that ecosystems have been restored.

The general trend is towards a relative decoupling of economic growth from the use of material resources. Absolute decoupling takes place only under very limited circumstances (during recession or very low growth). It has rarely been observed. Despite the use of more resource-efficient technologies and the transition to service-based economies, European countries have not yet achieved relative decoupling.

Box 3.1 What do we mean by decoupling?

'Resource decoupling means reducing the rate of use of (primary) resources per unit of economic activity' (UNEP, 2011).

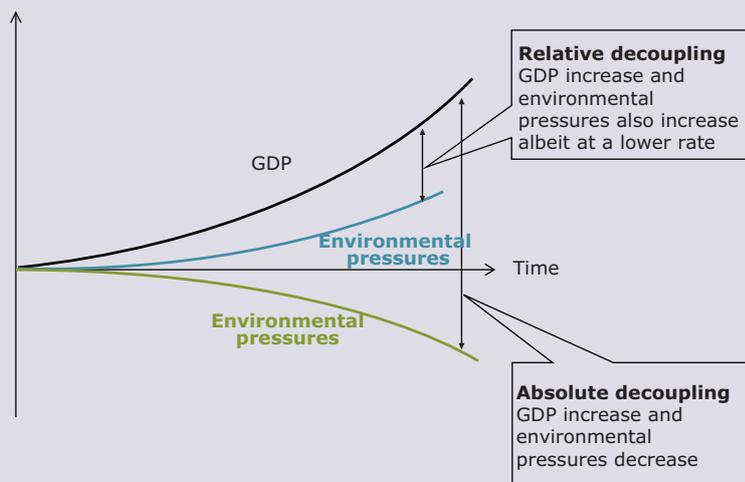
There are several modes of decoupling (EEA, 2013a):

- *Relative decoupling* is achieved when the growth rate of the (primary) resource use is lower than the growth rate of the related economic activity measured, for example, by GDP (see Figure 3.1).
- *Absolute decoupling* is achieved when the resource use either remains stable or decreases while economic activity increases.
- *Impact decoupling* is an enhanced form of absolute decoupling. Economic activities increase while environmental impacts ⁽¹³⁾ and resource use decrease in absolute terms.

Resource productivity measures the amount of economic value ⁽¹⁴⁾ generated per tonne of materials used. It is generally used as an indicator for measuring resource efficiency. However, increasing resource productivity does not necessarily indicate absolute or impact decoupling as they may be offset by increased economic activity.

Resource intensity is the inverse of resource productivity. It shows how much material is necessary to produce one unit of economic value.

Figure 3.1 Relative and absolute decoupling



Source: EEA, 2010a.

⁽¹³⁾ Environmental impacts such as pollution, emissions, soil degradation, soil sealing, destruction of biodiversity, etc.

⁽¹⁴⁾ There are different ways of measuring material productivity. In this report, material productivity is calculated as the volume of GDP at market prices (2005) per unit of domestic material consumption.

3.2 Urban metabolism

3.2.1 The concept

The best way to understand how cities can provide opportunities for decoupling is to understand how the flows of resources pass through them. The concept of urban metabolism emerged from industrial ecology (Baccini, 1997). It was developed by Abel Wolman, who was the first to draw the comparison between a city and an organism. Urban metabolism may be defined as 'the sum of total of technical and socio-economic processes that occur in cities resulting in growth, production of energy, and elimination of waste' (Kennedy et al., 2007).

Cities require massive flows, stocks and sinks of physical, chemical and biological resources through the goods and services they import or export to supply the urban population (Barles, 2010). In the same way as biological organisms and ecosystems, cities need input flows (such as energy, fuel, metal, wood, water, food, materials for building and infrastructure, space, etc.) to maintain their vital functions (Decker et al., 2000). Following their transformation and use, these 'metabolic inputs' are removed and discharged to the environment (atmosphere, water and soil) as 'metabolic outputs' in the form of air emissions, liquid and solid effluents and waste materials that can have environmental impacts both upstream and downstream.

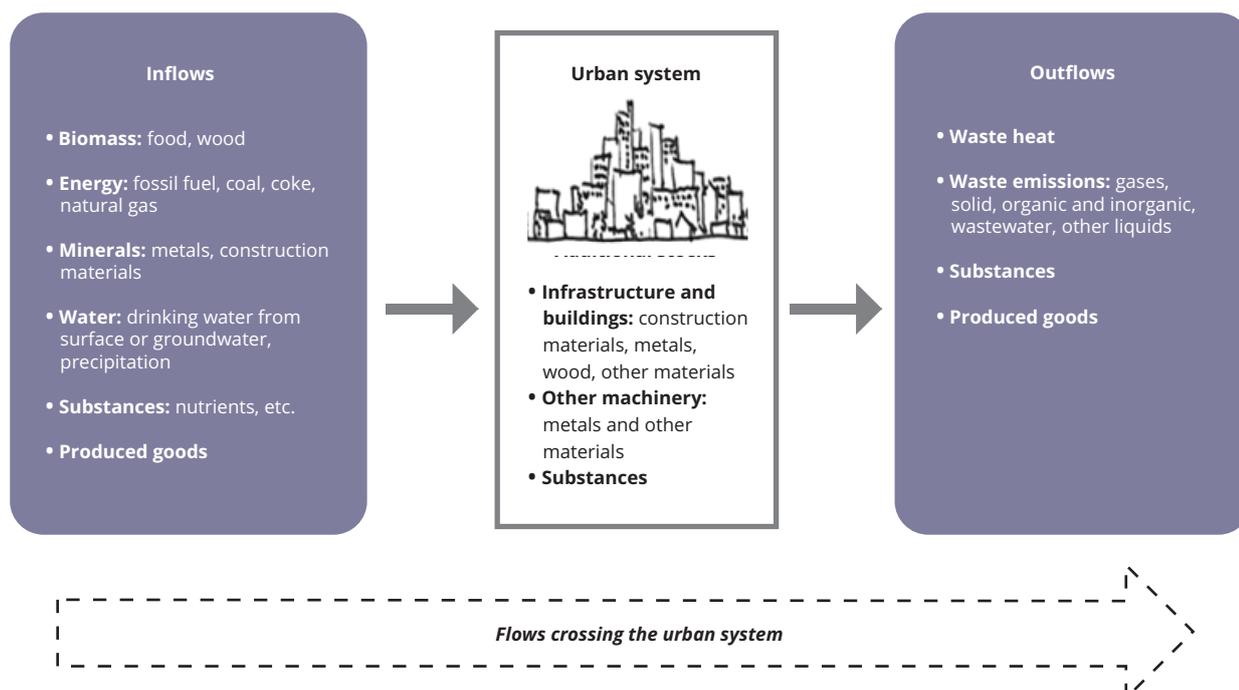
Flows are linked to four human activities that are thought to summarise human material needs: food, washing, residing and working, and transport and communication. The metabolism of cities can be analysed in terms of four fundamental flows or cycles (water, materials, energy and nutrients).

The concept of urban metabolism helps us to understand the ways in which societies use resources, energy, land and all other elements of the environmental system to maintain and reproduce themselves. The city is assimilated as an ecosystem that needs specific inputs and produces outputs. The relationship between the environment and the urban system is described by systematically recording all flows to and from the environment in physical terms. Urban metabolism has inspired new ways of thinking about how cities and urban areas can be made more sustainable (Rapoport, 2011).

3.2.2 An open system

The urban system is criss-crossed by a lot of material flows (see Figure 3.2). It is generally an open system that depends on its hinterland for both supply and disposal. Almost all resources come from outside urban areas, and often from afar. The resources are extracted from geological formations and harvested from forests, fields and water bodies. The notion of hinterland must

Figure 3.2 The linear urban metabolism



Source: Adapted from Kennedy and Hoornweg, 2012 — modified by the EEA.

be extended to the global scale for the supply of some resources (e.g. food, metal). Almost all emissions and final waste are disposed of, dissipated or assimilated in the immediate hinterland but in some cases also on the global scale. This linear nature of urban flows increases the vulnerability of cities.

The metabolism of cities is essentially linear, in contrast to natural systems, which are cyclical and efficient in their use of materials. Following the development of anthropogenic activities there is an intensification of the flows and also a linearisation: 'the materials do not return to their place of origin and, therefore, accumulate in a certain compartment of the biosphere. If the materials somehow return to their origin, they return in a different chemical form than the one they had at the time of their removal.' (Barles, 2010). These abundant linear flows contribute to environmental impacts such as resource depletion, climate change, proliferation of solid waste and loss of biodiversity.

3.2.3 The main factors

The amount and type of metabolic flows of individual cities are shaped by different factors such as planning, the economy, land use patterns and citizens' lifestyle

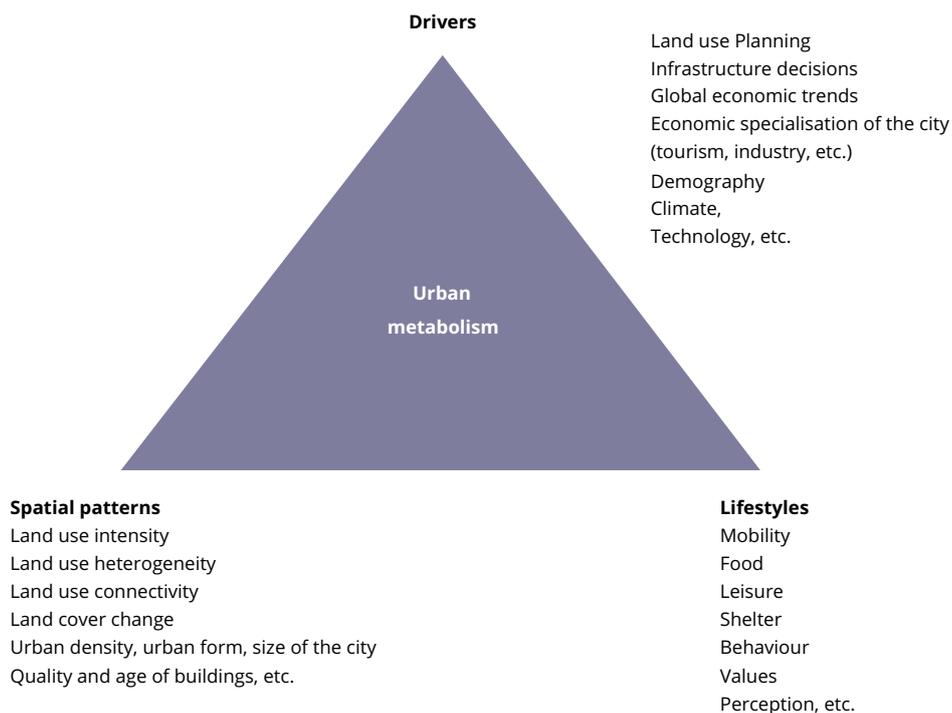
(Kennedy et al., 2007) (see Figure 3.3). The analysis of these factors provide a comprehensive framework to identify opportunities for efficiencies, improvements, and transformation (Barles, 2009).

3.2.4 Stocks shape the city in the long term

Urban metabolism is not only an analysis of flows but also of stocks, which can be defined as man-made fixed assets. Most of the input flows 'are converted into buildings and physical urban infrastructures or they are transported through cities by infrastructure.' (UNEP, 2013). The input largely outweighs the output, resulting in an accumulation of material stocks in urban areas (Bergbäck et al., 2001). For example, the stock of anthropogenic goods in the city of Vienna grows by approximately 1% to 3% per year (Obernosterer et al., 1998).

Stocks are composed of the so-called urban 'grey' infrastructure, which provides key services for urban daily life (e.g. utility services, housing, transport) and determines 'how resources in the form of water, nutrients, materials and energy pass through the system, and in what manner' (UNEP, 2013). Grey infrastructure shapes the physical layout of urban areas and determines the urban pattern (compactness,

Figure 3.3 The drivers of urban metabolism



Source: Minx et al., 2011.

Box 3.2 The flows of construction material in Paris and the Île-de-France

Paris and the Île-de-France are far from being self-sufficient with regard to construction materials. In 2003, regional extraction was only 1.5 tons per capita, whereas regional consumption was 2.6 tons per capita (Barles, 2009). The rest was imported from other regions.

On the outskirts of the region, where the built density is lower, a new inhabitant needs 600 tonnes of construction material, whereas a new inhabitant in denser areas, Paris city and its closest peripheral areas ⁽¹⁵⁾, needs 80 tonnes of construction material.

The type of urbanisation — city centre versus peri-urban areas — is probably not the only explanation for this difference. However, a single family home requires more infrastructure and public works than the construction of an apartment building and therefore consumes more construction materials than an apartment dwelling. Reducing this consumption of construction materials requires controlling urban expansion and therefore strong urban planning policies.

Source: Barles, 2008 and 2009.

sprawl, urban form, urban design, connectivity of streets, mobility patterns, density, urban landscape) and how city residents live, move and work (e.g. housing, connectivity, mobility, accessibility). It has a considerable influence on land use, energy consumption, greenhouse gas emissions and air pollution.

Stocks are continuously renewed. Old products are removed from the stock, and new products are brought and become part of the stock (Rosado, 2012). The stored materials are utilised until they become part of the waste flows, generally after a considerable time lag between input and output. As a result, stocks are growing, and the growth in stocks implies more waste too. The composition of stocks and their dynamism determines their recycling potential.

Stocks govern not only the amount and the quality of materials and energy flows necessary for their construction but also the inputs required to maintain their functionality and to use them throughout their life cycle (e.g. materials for renovating roads or for refurbishing obsolete buildings, energy required for heating and cooling, energy required for commuting) (SUME, 2010). Resource flows are affected by quantitative changes in the stocks (e.g. related to an increase in the demand for space at the population or individual level) and by qualitative changes in the composition of the stocks (e.g. improvements in the design of the built environment, insulation) or their spatial distribution (e.g. densification, sprawl).

Stocks have a long lifespan. Therefore, they have long-term consequences. Decisions made in the past in relation to 'grey' infrastructures can have a negative impact for long time and can lock cities into an unsustainable urban pattern for decades (EC, 2011a).

3.2.5 Methods for analysing flows

There are a variety of methods for analysing the materials used in urban areas. Their main objective is to increase the resource efficiency of urban areas by helping decision-makers analyse material flows and stocks within a given system and their impact on near and distant hinterlands. The main difficulty with all these powerful methods is the availability of data.

The following methods ⁽¹⁶⁾ are the most common (Goldstein et al., 2013).

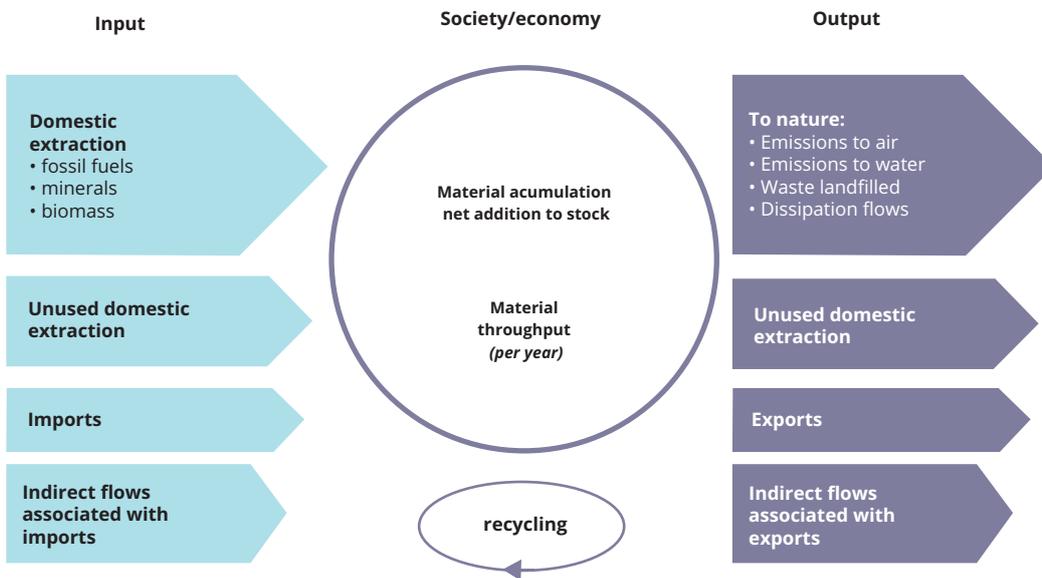
Material flows analysis (MFA)

MFA is the earliest method and has largely been used at the national scale (Eurostat, 2001) although more recently at the regional and urban scale (Charles University Environment Center, 2008). At the national level, MFA considers four main outputs: flows to nature, unused domestic extraction, exports, and indirect flows associated with exports (see Figure 3.4). In Europe, different studies at the urban scale, most often at the metropolitan scale, are generally based on an adaptation of the methodological guide published by Eurostat (2001).

⁽¹⁵⁾ Paris and the area named Petite Couronne.

⁽¹⁶⁾ There are other methods such as mass balance or emergy. Many studies quantifying urban metabolism in European cities have been conducted using different methods (see Annex 1).

Figure 3.4 A general scheme for economy-wide material flows analysis, excluding water and air flows



Source: Eurostat, 2001.

MFA is based on the principle of mass conservation changes:

$$\text{Mass of input flows} = \text{Mass of output flows} + \text{stocks}.$$

It is a way of assessing the material flows crossing cities (e.g. nutrient balances) and stocks (Barles, 2010). The systematic analysis, based on a comprehensive list of metabolic flows (e.g. food, water, fuels, electricity, construction materials), is easy to communicate but difficult to implement and interpret. Establishing links among metabolic flows, environmental sources and sinks and ecosystem functioning is a complex process.

The lack of data on material flows at the urban level and the lack of a unified methodology allowing consolidation and comparison of results are the major limits of MFA. Furthermore, the measuring only the input and output mass fails to address the varying potential for environmental damage of different substances (e.g. hazardous materials stored in building stocks) and their impact on ecosystem services (e.g. resilience).

Another problem is one related to the urban scale. As wastewater treatment plants, sanitary landfills and waste incineration are generally located outside the city, these flows are considered to be exports. The

balance quantifies only the city's direct consumption while ignoring the embedded upstream processes that provide the city with resources and omitting the impact of downstream processes (Kennedy et al., 2012). Some derived methods move beyond mass by including the environmental loading concept using 'emergy' (embodied energy⁽¹⁷⁾) (Odum and Peterson, 1996) or the ecological footprint method.

Life cycle analysis or life cycle assessment

Life cycle analysis is used to provide cradle-to-grave accounting of the direct, indirect and supply chain effects of resource transformation and use. This method integrates the inventory part of MFA to capture the indirect and direct supply chain impact of cities beyond their borders. It is an internationally standardised methodology (ISO 14040:2006)⁽¹⁸⁾ that is widely used to quantify the environmental pressures related to goods and services, the environmental benefits, the trade-offs and the potential improvements.

Standardised approaches are key to extending applicability and to enabling temporal and geographical comparisons (Kennedy et al., 2011). To facilitate this standardisation, the European Commission's Joint Research Centre (JRC) has published *the International reference life cycle data system (ILCD)*

⁽¹⁷⁾ Emergy accounting draws attention to the dependence of cities on ecological processes that themselves are possible only because of solar energy. Emergy is a measure of the energy flow from nature and humans to generate products and ecological services.

⁽¹⁸⁾ <http://www.iso.org> (accessed 6 November 2015).

handbook (JRC, 2012a), which provides guidance on data requirements, methods and assessments for performing high-quality and consistent life cycle analysis ⁽¹⁹⁾.

Economic input-output life cycle assessment

This method evaluates the resource inputs and emissions outputs associated with economic activity in every sector of the economy (Chester et al., 2013). These approaches have also been combined to reduce data and resource constraints in modelling while capturing the entire supply chain. The method requires significant amounts of nationally specific data and utilises economic (capital) metrics as a proxy for many materials and processes that are often difficult to integrate with material flows or mass/energy balance (Pincelt et al., 2012).

3.3 The scale issue

The linear urban metabolism is a source of vulnerability. It makes urban areas dependant on their hinterland for the supply of resources and waste

disposal. With the expansion in global trade, cities are less dependent on their hinterland for sustenance. To satisfy their demands, cities are increasingly importing goods, food, energy, water and building materials from afar. At the same time, waste produced in urban areas is increasingly being exported to distant regions and pollution extends beyond the city boundaries. Cities have an impact not only in their own territory but also in places in other parts of Europe and the world.

This situation generates dependency and unsustainability. The origins of food and energy and the destinations of wastes are invisible to urban dwellers. They do not perceive the problem until it is translated into local impacts, such as higher food or energy prices or frequent flooding (Allen, 2009).

In addition, cities are embedded within larger scale engineered infrastructures (e.g. electric power, water supply and transport networks) that convey natural resources over large distances for use by people in cities. 'The sustainability of city systems therefore depends upon complex, cross-scale interactions between the natural system, the transboundary

Box 3.3 A case study: the material flows analysis of Lisbon

The recent MFA of Lisbon metropolitan area (Rosado et al., 2014) provides information on consumption, changes in stocks and outputs to the environment. The study comprises the nine municipalities of Lisbon district, those north of the Tagus river ⁽²⁰⁾ and those south of the Tagus river ⁽²¹⁾. Nearly three million inhabitants live in the area. The MFA balance was calculated for the period 2003–2009 (on an annual basis).

In 2005, the metabolism of the metropolitan area of Lisbon showed that domestic material consumption, representing the input flows, was around 38 million tonne, about 10.4 tonnes per capita per year.

- *Stocks*: The amount of materials added to stock is around 18 million tonnes. Non-metallic minerals (sand, cement, clay, stone) represent the main fraction of materials in the overall input flows (around 51%). As these materials have a long lifespan, they will accumulate significantly in the long term (Rosado, 2012).
- *Non-renewable resources* represent 80% of total material consumption. 65% of the non-renewable fraction is non-metallic minerals (mainly construction materials).
- *Biomass* ⁽²²⁾ is the second most relevant material input. Food, comprising agricultural and animal biomass, represents 67% of biomass consumption.

The study highlights the fact that approximately one million tonnes of durable goods currently produced are potentially available for recovery every year, but only 600 000 tonnes were recovered. That means that approximately 400 000 tonnes of materials could still potentially be recovered in the region.

Values for different metropolitan areas are of the same order of magnitude, but it is difficult to interpret in detail comparisons with the results for other cities. Some differences may be explained by the characteristics of the economy.

⁽¹⁹⁾ More information on the European Platform on Life Cycle Assessment is available at: <http://eplca.jrc.ec.europa.eu> (accessed 6 November 2015).

⁽²⁰⁾ Amadora, Cascais, Lisbon, Loures, Mafra, Odivelas, Oeiras, Sintra and Vila Franca de Xira.

⁽²¹⁾ Alcochete, Almada, Barreiro, Moita, Montijo, Palmela, Sesimbra, Setúbal and Seixal.

⁽²²⁾ Agricultural biomass, animal biomass, textile biomass, oils and fats, sugars, wood and fuels, paper and board.

engineered infrastructures, and the multiple social actors and institutions that govern these infrastructures' (Ramaswami et al., 2012). For example, energy used for electric power generation or the water supply comes from outside the jurisdictional boundary of the cities (and sometime outside the country) using these infrastructure services.

3.4 Ecosystems as model

Urban metabolism relates to the model of natural ecosystems that conserve mass through biogeochemical cycling and are generally self-sufficient in energy or supported by sustainable energy inputs (Newman, 1999). Ecosystems have a circular zero-waste

Box 3.4 Available data on urban metabolism in Europe

Policy-makers need to understand the metabolism of cities to properly assess their current situation and to predict the potential consequences of their policy decisions. One of the major challenges is finding appropriate information to allow operational implementation and interpretation of the flows analysis.

There are considerable differences between European cities concerning the scope and quality of available information. Some Member States have very complete databases, whereas in other countries data collection is less systematic and more fragmented (EC, 2011c). City-specific data that are consistent and comparable across Europe are difficult to obtain for certain domains.

Even if the existing information on European cities has been increasing and improving in quality over the past decade, there is still no comprehensive European database integrating all the different aspects of urban metabolism, with the exception of certain case studies developed in research projects. The major limitations are the definitions of an urban area and the existing time series and sometimes methodologies (measured versus estimated or modelled). However, some information sources provide a basis for a pragmatic approach to the metabolism of European cities.

Integrated data sources

- *Urban Audit*: Information on a selected number of European cities. It includes transport, energy, environment and demographics.
- *European Green City Index* (Economist Intelligence Unit, Siemens): Data collected on 30 cities covering different domains (energy, environment, socio-economic information).

Thematic data

- *AirBase*: Public air quality database that contains information on air quality monitoring for more than 30 participating countries. Every year countries report air quality measurement data for a set of pollutants at a representative selection of stations. Reporting follows the requirements of Council Decision 97/101/EC, a reciprocal exchange of information on ambient air quality.
- *Corine Land Cover*: Land cover data with full European coverage.
- *High-resolution layers soil sealing*: This high-resolution imperviousness dataset provides a spatial distribution of all artificially sealed areas, including the level of sealing of the soil per unit area.
- *Urban Atlas*: High-resolution land cover data on Urban Audit cities.
- *NOISE*: Data on people exposed to noise from different sources. Every country has to report every 5 years in accordance with the requirements of the Environmental Noise Directive (2002).
- *WISE*: Water Information System for Europe. It comprises a wide range of data collected by EU institutions.
- *Covenant of Mayors*: An estimation of carbon dioxide emissions by sector in cities.
- *Quality of life in cities*: A perception survey conducted in 79 European cities.
- *Other sources*: some research projects or stakeholders' initiatives collect data such as 'Informed Cities' (indicators for city planners).

metabolism: they do not generate waste because the waste of one organism is the food of another.

Urban metabolic processes are still far removed from natural metabolism. As the circulation of flows is inefficient and incomplete, in most cases the circle is not closed. Inflows and outflows are largely unrelated. Raw materials are extracted outside urban areas, transformed into goods and products and ultimately end up as waste, sewage and emissions beyond the city boundaries. In this linear urban model, the amount of outflows is dependent on the amount of inflows.

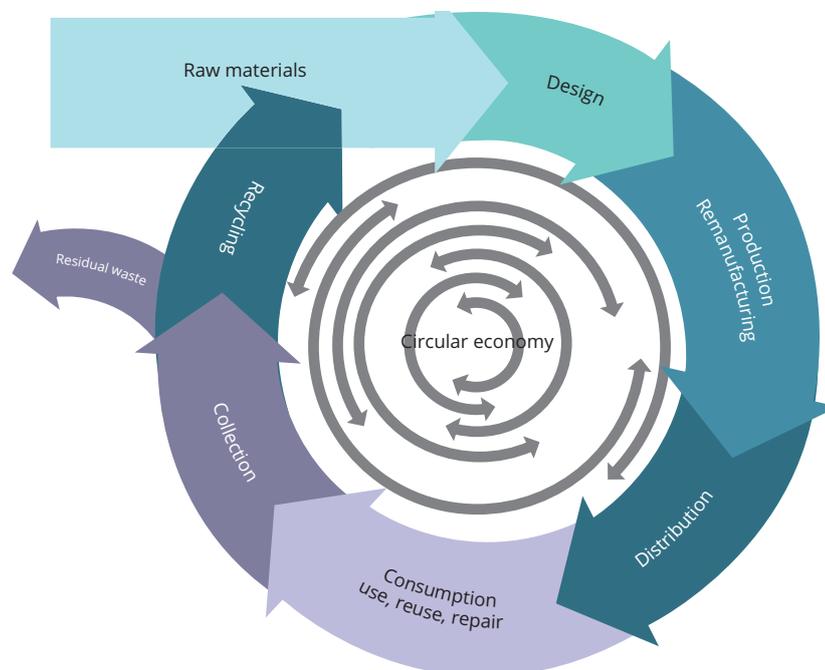
In a resource-limited world, cities must not only become more resource efficient and reduce their carbon emissions but they also need to close the loop of urban cycles by applying innovative technologies and forms of organisation, harvesting urban resources, and developing links with their surroundings and integrated urban planning (Agudelo-Vera et al., 2012). The 'end-of-pipe' solutions, generally used to solve environmental problems in a linear model, are no longer adequate.

3.4.1 The circular approach

Many industrial processes, in which wastes and by-products become inputs for new processes, have already been transformed from linear systems to closed-loop systems (see Figure 3.5). The same rationale can be applied at the city territory level as part of good urban management. The territory's material and energy flows can be optimised by integrating all urban activities (industry, utilities, commercial, housing, urban and peri-urban agriculture), by involving all the actors (including investors and city residents) and by working with municipalities beyond the city limits.

For a firm, recycling and reusing is a way of optimising the production process by reducing waste, costs and inputs of raw materials. As the prices of raw materials increase, reusing waste and by-products is increasingly becoming a significant commercial opportunity. Companies can either reuse or recycle their residues (steam, by-products, exhaust gases, wastewater, waste, etc.) themselves or transfer them to local authorities (EnergyCities, 2013a). The analysis of flows highlights potential synergies between different players.

Figure 3.5 The circular economy



Source: Adapted from EC, 2014c.

The efficiency of ecosystems in recycling resources is a model for industry. The industrial symbiosis in the district of Kalundborg ⁽²³⁾ in Denmark is the best-known example of industrial reuse and recycling. The district contains a cluster of industrial facilities that exchange by-products and energy that otherwise would be wasted. For example, the excess stream from an electrical generating facility is used as heat source for a chemical manufacturer. This approach is not only a way of reducing the use of raw material and energy but also good business. Each exchange of material and energy contributes to reducing costs.

The circular approach reframes urban environmental planning and management not simply as the efficient management of linear inputs and outputs but as a strategy for 'closing the loop'. Urban metabolism can be changed both through policies — urban design and urban planning, the technology and patterns used in transport systems, environmental urban management (water, waste, energy) — and through regulation. This kind of approach, based on the circular model, with a marked reduction in the use of energy and resources, has already been taken in both high-profile urban sustainability projects and on a small scale (PUCA, 2008). For example, the urban district of Hammarby Sjöstad (City of Stockholm, 2007) in Stockholm is closing material loops through the development of integrated urban systems.

3.4.2 Changing the model

Cities have great potential to reduce urban metabolic flows. Utility suppliers provide services (e.g. waste management, water management, social housing, public transport) that determine the quantity and quality of urban flows. Integrated urban planning and provision of utilities can change the way people live, move and work in the city (EEA, 2013b) and encourage citizens to adopt more sustainable behaviours (e.g. greater use of public transport). As drivers of the economy and places of innovation and creativity, cities can develop smart solutions, not only technological but also organisational, social and economic. As they are close to the city's residents, local authorities can play an active role in educating the general public and organisations, raising awareness of resource efficiency and promoting good practice (e.g. how to avoid food waste, how to minimise other waste)

The challenge for cities is to change the model 'Take-Make-Use-Waste' to a circular model 'Take-Make-Use-Remake'. Most of the waste

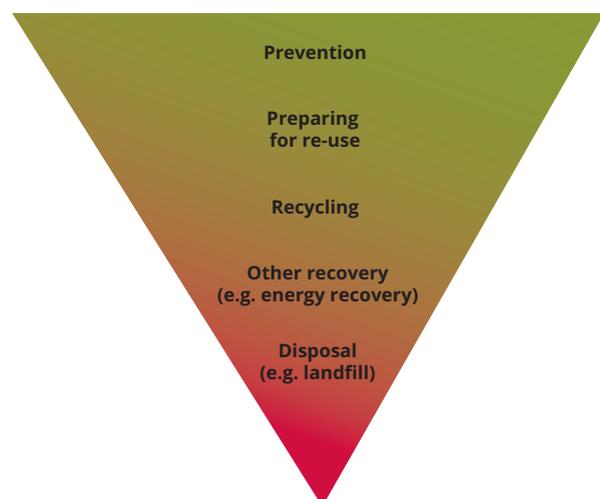
produced by the urban system can be treated, recycled or reused for energy production. It can contribute to the circular economy by creating loops of materials and energy sources close to the end users, by returning organic matter to the earth as compost for local food production, by sorting and recycling materials contained in different types of waste and finally by using non-recyclable waste as a source of energy.

Strategies for reducing resource consumption can be focused on the following steps (see Figure 3.6):

- reducing the demand for resources by developing better urban planning, stimulating behaviour change and encouraging new production processes;
- minimising inputs and outputs by using different approaches such as waste prevention, reusing, recycling, cascading (direct reuse of outputs but at a lower quality) and recovering (energy recovery, extraction of useful materials from wastewater, etc.);
- harvesting (using local and renewable sources such as rainwater, solar and wind energy, urban agriculture).

Waste minimisation strategies that address only end-of-life products and materials are not adequate to reduce the increasing amounts of waste associated with economic activities and material consumption. One of the challenges is to effectively address the environmental impacts materials can have throughout their life cycle (some of which occur abroad)

Figure 3.6 The waste management hierarchy



Source: Adapted from EU, 2008.

⁽²³⁾ Kalundborg symbiosis: <http://www.symbiosis.dk/en> (accessed 6 November 2015).

through efficient sustainable materials management (OECD, 2012b). The potential for reduction depends on the structure of urban areas and how these areas are managed (Beatley, 1999). The quantity and quality of resources used to sustain urban life are related to how urban areas have been built spatially and technologically (quality of housing, transport infrastructures, form of city). Urban metabolic inputs can also be reduced by adopting prevention policies in many domains and by changing citizen's lifestyle and behaviour (e.g. changing the culture of consumerism).

Cities as a source of resources

Bio-waste from biodegradable garden or park waste, food or kitchen waste (from households, restaurants, caterers or retail premises) and waste from food-processing plants can be treated by composting and anaerobic digestion. Composting is a form of recycling in which the compost is used on land for growing crops, whereas anaerobic digestion uses some of the energy potential of the organic waste. The demand for compost varies according to the need for soil improvement (e.g. carbon-depleted soils will have a greater need for compost). These wastes offer an untapped potential to achieve significant environmental and economic benefits.

Food waste is a major issue in developed countries. Over 100 million tonnes of food is wasted annually in Europe (Eurostat — estimation 2014) ⁽²⁴⁾. One-third of the food intended for human consumption is wasted globally (Esnouf et al., 2013). Food waste is generated throughout the whole value chain from farmers to consumers. The causes are many and include inefficient production methods, inadequate storage, poor product standards, lack of awareness, poor planning of shopping, large standard portion sizes, difficulty in anticipating the number of customers in restaurants, poor stock management and inadequate packaging.

Waste streams of manufactured products (e.g. appliances, electronic devices, mobile phones) and batteries ⁽²⁵⁾ are rich sources of valuable minerals and metals that have the potential to be recycled and become valuable secondary resources. Current products contain complicated combinations of minerals, metals and other materials — many of which are innately precious commodities. Gold, silver, copper, iridium, platinum, cobalt, nickel, rare earth elements, graphite and lithium are included in electronic waste that is growing because of planned obsolescence, falling prices or rapid technological innovation. For

example, one study shows that recycling cobalt and nickel for lithium-ion battery cathode material results in a 51% saving in natural resources (Dewulfa et al., 2010). To develop and organise a market for recycled metals requires sufficiently large scale (general regional, national or European) networks of cities, and for many materials proper recycling technologies still need to be developed.

Concrete, aggregates, bricks, tiles and asphalt are the main recyclable materials from construction and demolition waste, while soil recycling plays a large role in some countries. Materials used for building houses (concrete, bricks and tiles), are specifically targeted by recyclers, thereby creating a market for these materials. Road construction, recycled concrete aggregates and civil engineering applications, all of which use mainly aggregates, are the main recycling routes for construction and demolition waste. In the Netherlands, 93% of recycled construction and demolition waste is used in road base construction (ETC/SCP 2013). Crushed clean concrete can be used as inert aggregate material in new concrete. In the same way, gypsum products, such as plasterboard and blocks, can also be counted among the construction materials for which 'closed-loop' recycling is possible.

The functional economy

The move from a product-based economy to a functional economy involving greater use of services is also an opportunity to achieve environmental benefits. The functional economy optimises the use of goods and services. The economic objective is to achieve the greatest possible use for the longest possible time while consuming as few resources and as little energy as possible. Therefore, the functional economy is more sustainable and dematerialised than the current economy. Xerox's asset management programme, which focuses on selling photocopying services rather than photocopiers is the best-known example.

The leasing model is a new one, based on a new relationship between producers and consumers. As producers generally remain the owners of the products, they are motivated to make their products more resource efficient and to prolong the product's life, in order to optimise utilisation and recycling. Different services can be developed: product, product utility, product extension, electronic substitution and information-based product. However, there are considerable barriers to the extensive development and uptake of such services, and many of the more

⁽²⁴⁾ Europa — Food waste: http://ec.europa.eu/food/food/sustainability/index_en.htm (accessed 20 October 2014).

⁽²⁵⁾ <http://www.batteryrecycling.unicore.com/UBR/> (accessed 6 November 2015).

Box 3.5 Municipal waste In European countries

Improvements have already been made in the total recycling of materials such as glass, paper and cardboard, metals and plastic in municipal waste. The Waste Framework Directive ⁽²⁶⁾ in 2008 introduced a 50% recycling target for municipal solid waste ⁽²⁷⁾.

Total municipal waste generation in European Environment Agency (EEA) countries declined by 2% between 2004 and 2012, despite a 7% increase in real household expenditure. Per capita generation of municipal waste declined by 5% in the same period, falling from 503 to 478 kg per capita. Not everyone generates the same level of waste. In 2012, municipal waste totals varied considerably, ranging from 668 kg per capita in Denmark to 279 kg per capita in Estonia. The variations reflect differences in consumption patterns and economic wealth, but they also depend greatly on how municipal waste is collected and managed.

Europe has achieved substantial progress in diverting waste from landfill in recent years — both in absolute terms and as a proportion of total waste generated. Between 2004 and 2010, the EU-28, Iceland and Norway reduced the amount of total waste (excluding mineral, combustion, animal and vegetable wastes) deposited in landfill by 23% — from 205 billion tonnes to 157 billion tonnes.

The decrease in waste going to landfill is partly because of increased recycling and incineration of waste. For municipal waste, EEA countries achieved a recycling rate of 37% in 2012, compared with 28% in 2004. This improvement reflects an increase in the recycling of materials such as glass, paper and cardboard, metals and plastic, with only very modest improvements in the recycling of bio-waste ⁽²⁸⁾.

In 2008–2010 bio-waste ⁽²⁹⁾ accounted for 37% of the municipal waste in Europe (EU-27 excluding Cyprus, but including Norway and Switzerland). Many EEA member countries with a high proportion of bio-waste in their municipal waste still recycle only a limited amount of bio-waste, resulting in a relatively marginal effect of bio-waste recycling on total municipal waste recycling rates.

A stronger focus on bio-waste recycling is needed. In many countries, there is considerable room for improving the overall recycling rate of municipal waste by increasing bio-waste recycling.

Source: EEA, 2013c

successful service applications are not necessarily driven by environmental considerations.

Products can be shared through collaborative consumption; they can also have a 'second life' by being swapped or given away, and broken products can be repaired. Municipalities are key actors in supporting the development of these kind of solutions, which allow citizens to save both money and natural resources and include car-sharing, bike-sharing, tool-sharing and repair workshops.

Smart cities

There is no single definition of a smart city. Smart cities are mainly focused on technological, in particular ICT, solutions that increase efficiency by using fewer resources to generate the same services. However, as there is considerable concern over the danger of a rebound effect. Efficiency gains may be balanced out by a relaxation in behaviour patterns or the maximum number of installed appliances finally translating into increased use of resources. For example, intelligent traffic systems may increase private motoring by

⁽²⁶⁾ Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance) (OJ L 312, 22.11.2008, p. 3–30).

⁽²⁷⁾ The definition of 'municipal waste' in different countries varies, reflecting diverse waste management practices. For the purposes of national yearly reporting of municipal waste to Eurostat, 'municipal waste' is defined as follows (Eurostat, 2012b): 'Municipal waste is mainly produced by households, though similar wastes from sources such as commerce, offices and public institutions are included. The amount of municipal waste generated consists of waste collected by or on behalf of municipal authorities and disposed of through the waste management system.'

⁽²⁸⁾ Bio-waste includes food and garden waste but not wood, paper and cardboard, or textile waste.

⁽²⁹⁾ Bio-waste is defined in the Waste Framework Directive as 'biodegradable garden and park waste, food and kitchen waste from households, restaurants, catering and retail premises and comparable waste from food processing plants' (EU, 2008). Bio-waste recycling of municipal solid waste includes the amounts reported to Eurostat as composted or digested: the EU classifies biological treatment (including composting and anaerobic digestion) as recycling when the compost (or digestate) is used on land or for the production of growing media (EU, 2011).

making driving in the city more convenient. Therefore, such solutions might work better in combination with an integrated and holistic transport plan, taking into consideration all means of transport (EP, 2014).

Green infrastructure

Green infrastructure is 'a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas' (EC, 2013a). Through the development of green infrastructure in and around cities, municipalities can avoid building infrastructure when nature can often provide cheaper and more resource-efficient solutions. For example, instead of building dykes to protect against flooding, expansion flood areas can be implemented. Green areas in cities can also contribute to decreasing the temperature in built-up areas during heat waves, thus decreasing the need for energy for air conditioning.

Other methods

Some cities, such as Venlo in the Netherlands, are developing the Cradle to Cradle approach, in which biological and technical cycles are closed without damaging effects on the environment (Braungart

et al., 2002). This method is applied not only to manufactured products but also to the spatial organisation of buildings. The implementation of this approach is complex owing to the large quantities of nutrients produced in urban areas that are not easily incorporated into a closed-loop system (Reay et al., 2011).

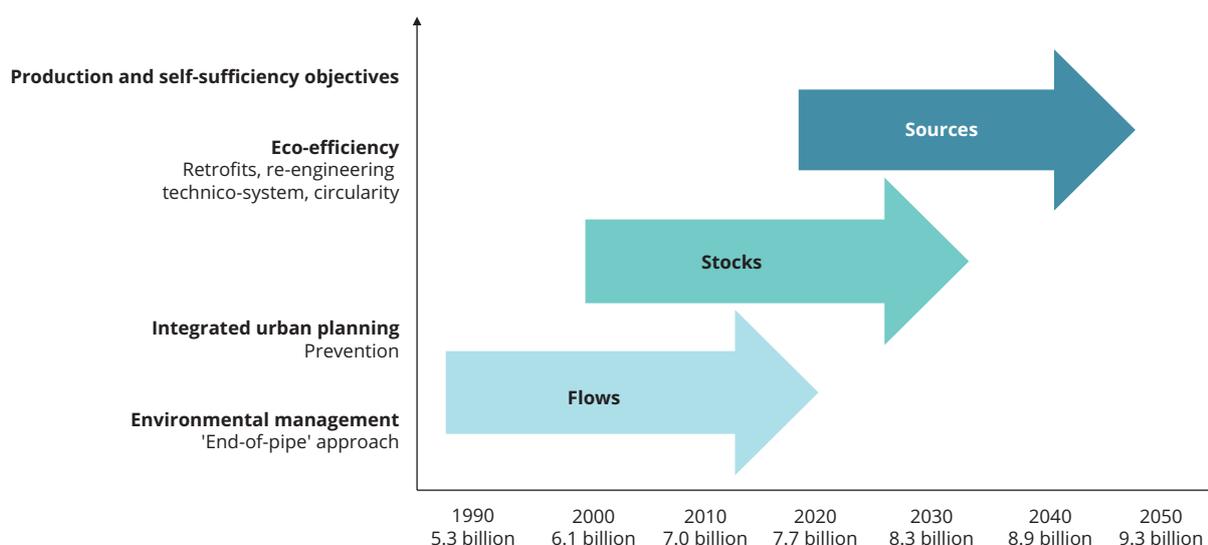
3.4.3 Emerging concepts

We need to take the next step. Cities can not only be more resource efficient but also develop ambitious goals and become net productive systems. Rather than focusing only on reducing their impact on the environment, they can also become resource generators. This is a far more ambitious goal than the simple development of an eco-district. Cities have the potential to produce more resources than they consume and process more waste than they produce (Brugmann, 2010). New concepts are emerging such as the concept of self-reliance (or 'productive cities' ⁽³⁰⁾) or the concept of 'regenerative cities' (Girardet, 2010).

Productive cities

Cities can be seen as places where resources can be harvested (e.g. food) and energy produced. The concept of local self-reliance is gaining in importance,

Figure 3.7 The evolution of action to achieve urban resource efficiency



Source: Adapted from Jeb Brugmann (session at the ICLEI World Congress, 2012), modified by the EEA.

⁽³⁰⁾ ICLEI World Congress 2012, session on 17 June 2012 led by Jeb Brugmann, which introduced the concept of the productive city.

in particular for energy and water (e.g. in Australia following a serious water crisis). A self-reliant community strives to produce all or most of its basic needs locally. Local policies and planning have to be tailored and oriented to meet the needs of the community. All the potential offered by the city territory and the hinterland need to be considered (Grewal and Grewal, 2013).

Decentralised renewable energy production at city and region levels can be provided by wind power, biomass, solar rooftop installations and biogas. Besides the more commonly used renewable energy sources such as solar energy or geothermal energy, there are many other sources of energy that should be explored at the local scale. For example, the city of Paris launched a call for contributions that was open to all citizens to identify the potential for energy generation in its territory: these included heat generated by data centres, the coolness of quarries, rainwater, pedestrians' kinetic energy, heat from bakery ovens or underground stations, and many others (EnergyCities, 2013b). All this information will be the foundations of local energy action plans. In addition, cities can play a key role in developing appropriate measures to encourage property developers to adopt best practice and to encourage their tenants to save on energy bills and to reduce greenhouse gas emissions.

Regenerative cities

Human society depends on the benefits provided by nature such as food, materials, clean water, clean air, climate regulation, flood prevention, pollination and recreation. These benefits are referred to as ecosystem services. They are increasingly critical for the health and well-being of city residents and for the viability of the local economy. Urban planning plays a major role in the preservation of local environmental assets that provide ecosystem services.

The concept of regenerative cities addresses the relationship between cities and the ecosystem beyond their boundaries on which they depend. 'The regenerative development of cities is a comprehensive approach that goes beyond established concepts of sustainable development. Cities need to proactively contribute to the replenishment of the run-down ecosystems — including farm, soils, forests and marine ecosystems — from which they draw resources for their survival' (Girardet, 2010). The renewal in the Ruhr region and Hamburg-Wilhelmsburg is an example of this kind of approach. A big regeneration programme began in 1989. The polluted and environmentally devastated region has since been cleaned up and greened. Hamburg has been transformed to offer improved living conditions of the highest possible standards by recycling and re-urbanising polluted land (Girardet, 2010).

4 Compactness for resource-efficient cities

4.1 Introduction

The guidance on achieving resource efficiency in cities is clearly defined: 'It is necessary to develop new products and services and find new ways to reduce inputs, minimise waste, improve management of resource stocks, change consumption patterns, optimise production processes, management and business methods, and improve logistics' (EC, 2011 b). How can a city realistically implement these new pathways?

The potential to reduce urban flows depends mainly on the urban form, the building stocks and consumption patterns. The urban form has a significant influence on resource use, not just because it determines the way that citizens move around and live but also because it defines the maintenance requirements, in particular the pace of deterioration of buildings and roads, and the method of provision and quality of services. Badly planned cities can be a permanent drain on resources.

A city cannot be easily transformed, but the 'grey infrastructure' may be effectively managed and retrofitted to enhance its performance. The main difficulty is avoiding conflict between policies that have to be developed at the appropriate spatial scales and taking into account cross-scale interactions between the natural system and the infrastructure and the individuals and institutions that govern it.

In addition, there are interactions between three kinds of actors. The demand for resources is determined by the behaviour of individual users (households, businesses), which depends on large-scale dynamic trends (income, technology, values, social standards, etc.) and on existing infrastructure (e.g. affordable and efficient collective transport, waste collection and recycling). Innovative and green solutions are developed by infrastructure designers, planners, architects and other operators, whereas the type of governance (urban/rural cooperation, top-down regulation, etc.) is developed by policy-makers and some non-governmental actors.

4.2 Land as a finite resource

Land use is determined by many factors, such as biophysical factors that enhance or constrain land use (climate, topography, soil, water, flooding, etc.), cultural and historical contexts, demographic and economic dynamics, the price of land, and policies and other institutional factors that influence land use and can change through regulation and changes in the demand for services and commodities. Land use is affected by sectoral and territorial policies at all levels. Current land use patterns are the expression of centuries of human intervention in the environment.

4.2.1 *Urban sprawl threatens services provided by land*

Land provides vital services

Land provides space for human activities and supports terrestrial ecosystems that provide vital services for urban society, such as biodiversity, production of food and fibres, space for water regulation and filtration, carbon sequestration, clean air and open spaces for recreational areas. Land use and management are one of the factors determining the capacity of ecosystems to provide these services and to develop adaptive strategies to address unknown future conditions including climate change, water scarcity or food insecurity.

Services provided by terrestrial ecosystems are considerably limited by soil sealing, one of the effects of urban sprawl, which is defined as 'unplanned incremental urban development, characterised by a low density mix of land uses on the urban fringe' (EEA, 2006a). As agriculture is generally the dominant land use in peri-urban areas, it use suffers from rapid changes. The uncontrolled expansion of built development and transport infrastructure around cities generates high rates of land take and soil sealing.

Soil sealing is the permanent covering of an area of land and its soil by completely or partly permeable artificial material (EC, 2012c), and it is a major threat jeopardising the sustainable use of soils (EEA, 2010c), in particular the highly fertile soils. It also leads to a

loss of ecosystem services owing to the disruption of natural cycles. Soil sealing generates harmful effects such as an increase in the heat island effect in urban areas and a decrease in the infiltration and acceleration of the run-off of water. In addition, urban sprawl contributes to numerous other pressures such as transport congestion, a decline in landscape quality, habitat degradation and social fragmentation.

Peri-urban areas are in an in-between situation, neither city nor countryside, and home to a range of functions from agricultural production to residential and recreational areas, energy production (wind turbines, biomass) (Piorr et al., 2011). The proximity of large urban populations enhances the value of nearby unsealed and multifunctional spaces in peri-urban areas.

Box 4.1 Land cover and land take in a nutshell

An inventory of land cover in Europe shows that artificial areas gained most between 2000 and 2006, growing by close to 3%. Thus, in 2006 about 4% of the European land area was classified as artificial. In this context, 'artificial' means land use for urban fabric, including green urban areas and sport and leisure facilities; industrial, commercial and infrastructure surfaces; and mines, dumping and construction sites.

The increased proportion in artificial areas is essentially the result of land take, a measure of how much land covered by agriculture, forests and semi-natural land, wetlands and water is converted to artificial land cover. In the period from 2000 to 2006, housing, services and recreation accounted for 43% of the average land take, followed by construction (21%) and industrial and commercial sites (16%) (based on data for 37 European countries) (EEA, 2013d). These averages mask regional differences. While the land provides space for human activities, land take also implies substituting the original (semi-)natural land cover to varying degrees with impervious surfaces. Thus, the connection with natural cycles is lost, and the services delivered by soils, including those important in the face of adaptation to and mitigation of climate change are curtailed.

General trends in annual land take⁽³¹⁾ in Europe showed a slowing down in the periods 1990–2000 and 2000–2006: from 1 078 km²/year to 914 km²/year (based on data for 28 countries). A higher resolution, new data source suggests that artificial surfaces have been underestimated. For example, the rate of change in impervious areas⁽³²⁾ indicates an increase of 1 252 km²/year between 2006⁽³³⁾ and 2009⁽³⁴⁾ for the same set of countries. However, the land take and imperviousness data are not directly comparable, as they are derived from data sets with different approaches to mapping and a different spatial resolution, and they refer to different time periods. Nevertheless, these data may indicate a slowing down of urban development on the outskirts of cities and in the countryside, leading to an increase in density in urban areas. This is an aggregated European trend that hides diverging patterns between different territorial units, including between countries; these patterns may thus reflect different approaches to spatial planning. European averages also obscure trends in sensitive zones: for example, in coastal areas the annual rate of urban development (0.66%) was higher than the average for all areas (0.52%) between 2000 and 2006 (EEA, 2013e).

Limiting land take is already an important land policy target at national or sub-national level⁽³⁵⁾. For example, the Federal Sustainable Development Strategy (2002) of the German federal government addresses land use and soil sealing. It has set the goal of reducing land consumption for new settlement and transport-related areas from about 115 ha/day in the year 2002 to 30 ha/day by 2020 (Umweltbundesamt, 2003; EEA, 2010b; Meinel and Schumacker, 2011). In the Netherlands, the notion of a compact city was included in the Fourth National Policy Document on Spatial Planning in 1988 and the more recent National Spatial Strategy in 2004, which sets out goals for 'concentration areas' around larger urban conurbations and for 'urban densification' in existing built-up areas (Nabielek, 2012).

In order to avoid increasing land take, incentives for 'land recycling' are worth pursuing; trends in this approach are described in the next chapter. Potentially negative land use impacts can also be mitigated: compact urban development and investment in 'green infrastructure' have positive effects on the delivery of ecosystem services (JRC, 2013). Green infrastructure is a way of working with nature to provide social, ecological and economic benefits (such as improved air quality, temperature regulation, noise reduction, flood protection and recreational areas) to the urban population (EC, 2013a).

⁽³¹⁾ Estimate based on the Corine Land Cover map.

⁽³²⁾ Estimate based on the Copernicus high-resolution imperviousness data set.

⁽³³⁾ Source: GMES (Global Monitoring for Environmental Security)/Copernicus precursor activities.

⁽³⁴⁾ Source: 7th Framework Programme Geoland2.

⁽³⁵⁾ *Land planning and soil evaluation instruments in EEA member and cooperating countries*, European Topic Centre for Spatial information and Analysis, <http://www.eea.europa.eu/themes/landuse/document-library> (accessed 10 November 2014).

Paradoxical shrinking cities

An analysis of 202 European cities shows that residential areas continued to increase, regardless of population growth or decline, between 2000 and 2006 (Artmann, 2013). The population can actually decline but the urban sprawl continues. This paradoxical phenomena can be explained by the following factors: the decrease in the size of households, which implies a decrease in the per capita efficiency of use of materials; the demand for more living space per capita (see Chapter 2); and the preference for detached houses with a garden. In addition, the emergence of metropolitan regions, integrating large parts of rural areas into the urban system, also contributes to increasing the urban land used per capita.

Shrinking cities, with a decreasing population have an abundance of land but no demand for it. Initially, decision-makers often allocate extra land for built-up areas to attract more investment. Consequently, cities continue to grow and land continues to be sealed but there is no demand for it. This situation continues until policy-makers realise that it would be more useful to invest in city-centre regeneration (Olofsdotter et al., 2013). For example, the International Building Exhibition on Urban Redevelopment in Saxony-Anhalt in Germany has shown that shrinking cities grow even if the population declines dramatically. The cities that were the largest in Saxony-Anhalt in 1990, Magdeburg and Halle, in 2007 have been superseded by a number of formerly small and medium-sized cities that have extended their urban areas ⁽²⁶⁾.

Competition for land

'The use of land is nearly always a trade-off between various social, economic and environmental needs (e.g. housing, transport infrastructure, energy production, agriculture, nature protection). Decisions on land use are long term commitments which are difficult or costly to reverse.' (EC, 2011f). Land-use is shaped by policy decisions concerning trade-offs between sectoral interests, including industry, transport, energy, mining, agriculture and forestry, as well as nature protection/ conservation and recreation activities (EEA, 2010c).

The EU does not have authority to regulate land use and land planning, but many European policies have a considerable impact on its territories (e.g. the Habitats Directive, the Common Agricultural Policy, resource efficiency policies, the Cohesion Policy). The *Roadmap to a resource efficient Europe* requires better integration of direct and indirect land use and its environmental impacts in decision-making at all levels (EC, 2011a).

The Roadmap calls for a multi-sectoral limitation in land take and soil sealing, asking in particular for the following:

- reducing land take for buildings (e.g. urban sprawl);
 - reserving fertile land for agriculture;
 - minimising the impact of the transport infrastructure on land fragmentation;
 - optimising land use to reconcile it with other uses;
 - optimising the energy infrastructure;
 - remediating contaminated sites.
- The requirements of housing, transport and economic activities are increasing the pressure on land resources in space and time, which creates competition. Integrated urban planning has to take into consideration all those trade-offs among sectoral, social and environmental requirements and potential synergies, as well as interactions within the surrounding territories. Many factors have to be taken into account, such as urbanisation and rural-urban relationships, regional competitiveness and cohesion, city shrinkage, fragmentation/connectivity, adaptation to and mitigation of climate change and, natural resource management, resource efficiency, energy production, and transport infrastructures.
- Conflicts often arise in the transitional areas between urban and rural areas (the so-called peri-urban areas), characterised by a mosaic of land use in which urban expansion destabilises rural economies and land markets (Piore et al., 2011). The proximity of urban areas enhances the value of unsealed land, and so-called greenfield sites are often seen as opportunities to build 'grey infrastructure' such as airports, business parks and high-value housing. In this transitional area, agricultural land and nature areas are under pressure from building, and it is necessary to have urban growth management strategies to ensure balanced and sustainable future development across the whole urban region (Fertner, 2012).

Planning in order to stop urban sprawl

Urban sprawl is one major cause of land take arising from the development of residential and non-residential areas and transport infrastructure (see Figure 4.1). Urban sprawl is characterised by the

⁽²⁶⁾ <http://www.iba-stadtumbau.de/index.php?iba2010-en> (accessed 6 November 2015).

development of low-density dispersed settlements that contribute to the loss of large areas of continuous open space, the fragmentation of valuable habitats, the destruction of productive agricultural land, soil sealing and the destruction of the natural functions of the soil (Schwick et al., 2012). Owing to the low density of the developments, there is an increase in traffic and the associated air pollution and noise.

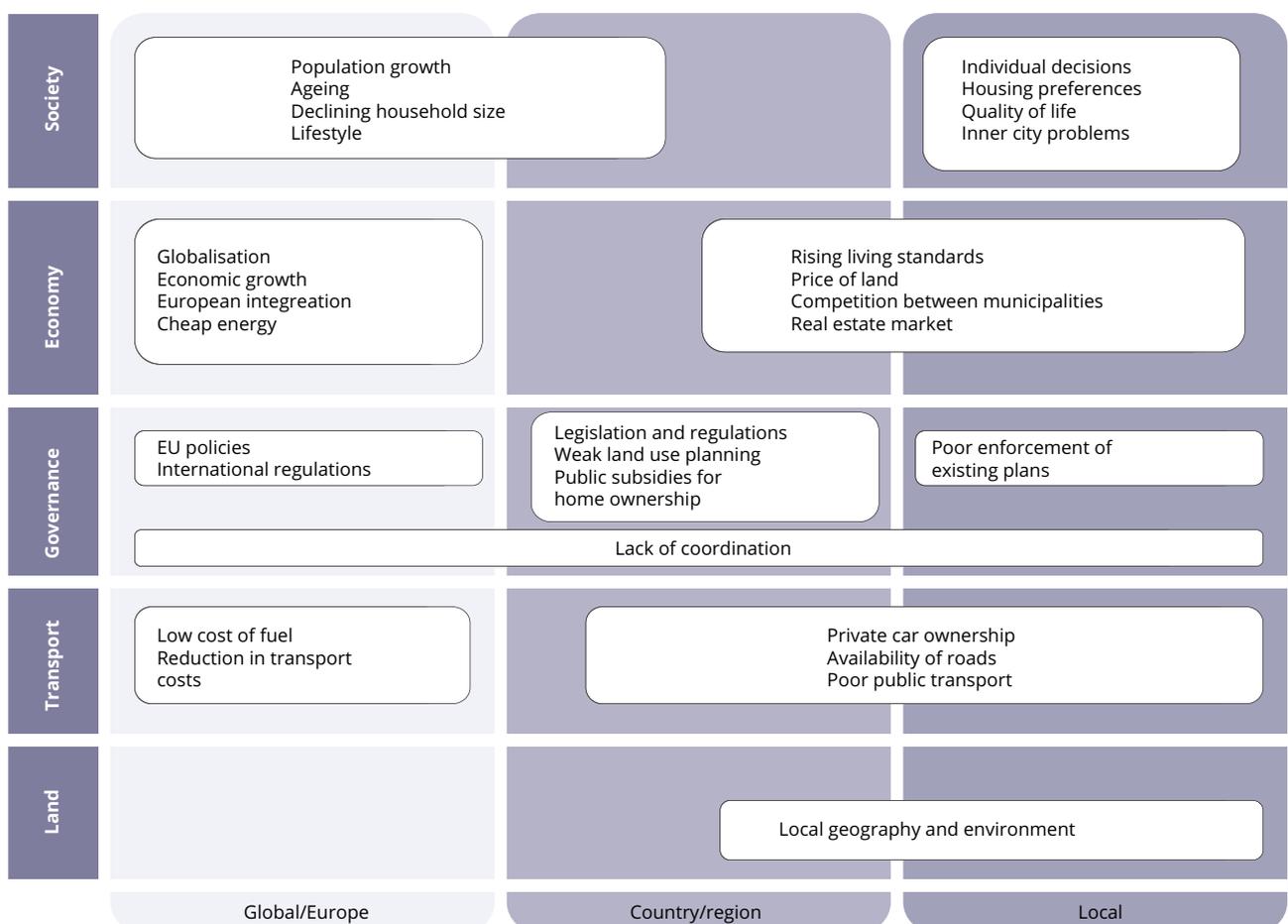
Public authorities determine the options for the land use through urban planning. Their ability to resist the pressure from market forces to generate urban sprawl depends on the strength of the administrative or governance-based planning instruments and the governmental level at which land use decisions are taken (Aalbers and Pauleit, 2013). To achieve efficient urban planning, local authorities need a strong legislation framework and a jurisdiction area adapted to the size of the urban agglomeration.

It also depends on public authorities' vision of the future and their ability to negotiate with all the

economic and political actors and civil society, which do not necessarily have the same interests (e.g families want quiet areas, investors want dynamic economic areas) (Olofsdotter et al., 2013). One major difficulty is the administrative borders of European cities, which generally include only the historic city and exclude its hinterland. The area delineated is therefore smaller than the 'real' city (i.e. the commuting area), in particular the 'resource-efficient' city, which needs to include its hinterland.

The importance of spatial planning (i.e. the allocation of land to different activities — economic, housing, recreational, education, etc.) is well established and widely implemented. In the absence of robust regulations, the urban zone will tend to extend at a lower density. Strict spatial planning regulations are a way of re-creating the dense core city, developing mixed land use, organising different activities in space, controlling the pressure on natural areas and limiting soil sealing. It is notable that soil is rarely considered as a resource in the governance of land in urbanised areas.

Figure 4.1 The main drivers of urban sprawl in Europe



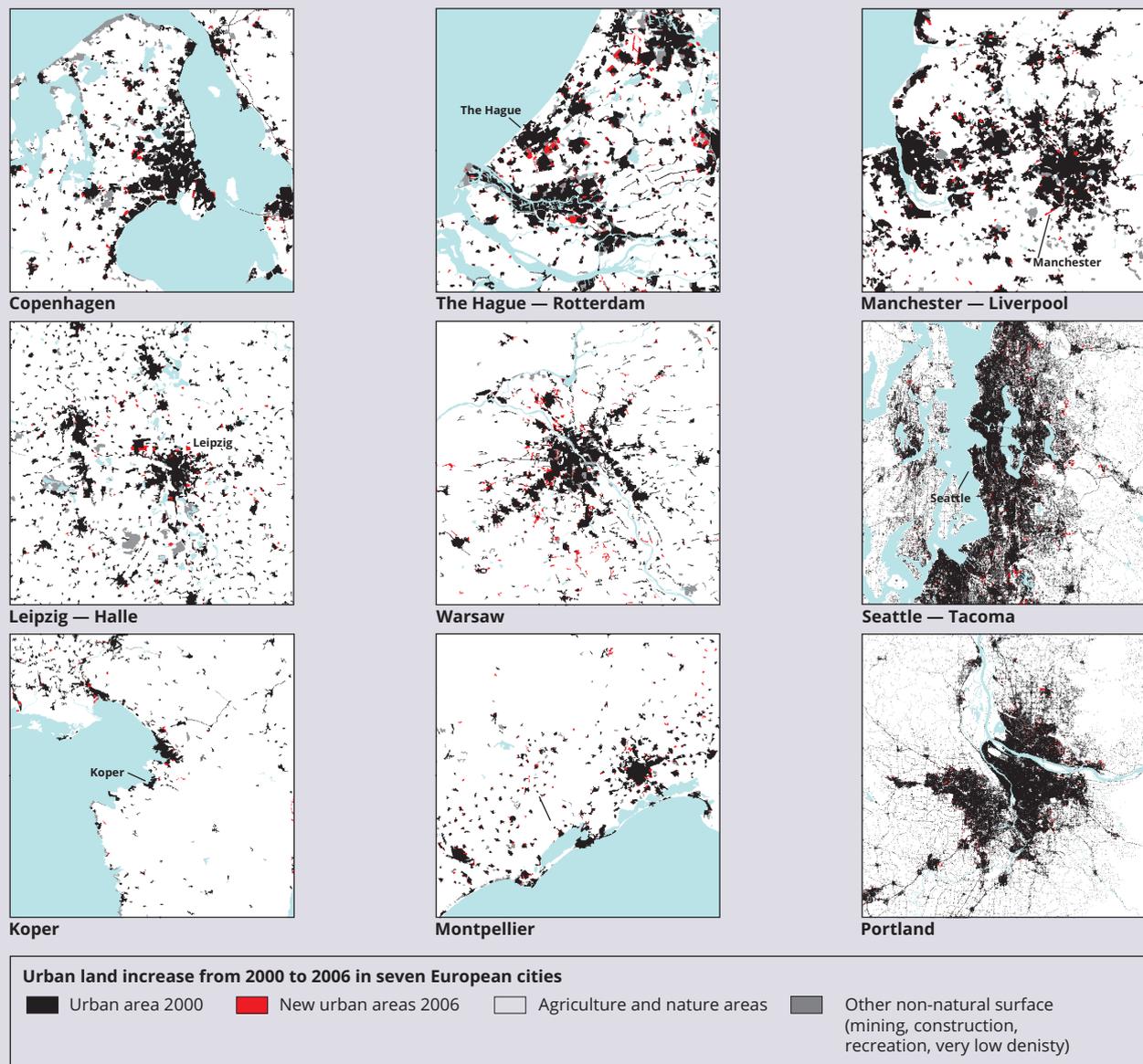
Source: EEA, 2010c.

Box 4.2 The impact of urban development on land use change in the city-region ⁽³⁷⁾

Case studies of land use change in nine cities ⁽³⁸⁾ (seven of which were European) show that the urban area increased between 2000/2001 and 2006 (Fertner, 2012) (see Figures 4.2–4.4.)

Urban form and urban change are different in each city: Hague–Rotterdam experienced a considerable increase in urban land in peripheral areas, whereas the increase was dispersed in Leipzig–Halle and concentrated in only few spots in the Warsaw region.

Figure 4.2 Urban land increase from 2000 to 2006 in seven European cities



Source: EEA, Corine Land Cover version 15 ⁽³⁹⁾.

⁽³⁷⁾ The data refer to the rural–urban region which was delineated in the Plurel project (Piorr et al., 2011: Plurel synthesis report, p. 25). It includes 'spatial clusters of three interrelated regional sub systems — the urban core, the peri-urban surroundings and the rural hinterland. Areas of recreational use, food supply and nature conservation located in predominantly rural areas are also part of the rural urban region.' (Plurel description of work 2009, p. 11). Rural–urban regions, as defined by the Plurel project, include both the 'functional urban area' (the daily commuting zone) and the surrounding rural hinterland. This definition has the advantage of being consistent across the whole of Europe.

⁽³⁸⁾ The original study includes nine cities of which seven are in Europe: Copenhagen (Denmark), Montpellier (France), Rotterdam–The Hague (the Netherlands), Warsaw (Poland), Koper (Slovenia), Manchester (United Kingdom), Seattle (United States) and Portland (United States).

⁽³⁹⁾ <http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-1> (accessed 10 November 2014).

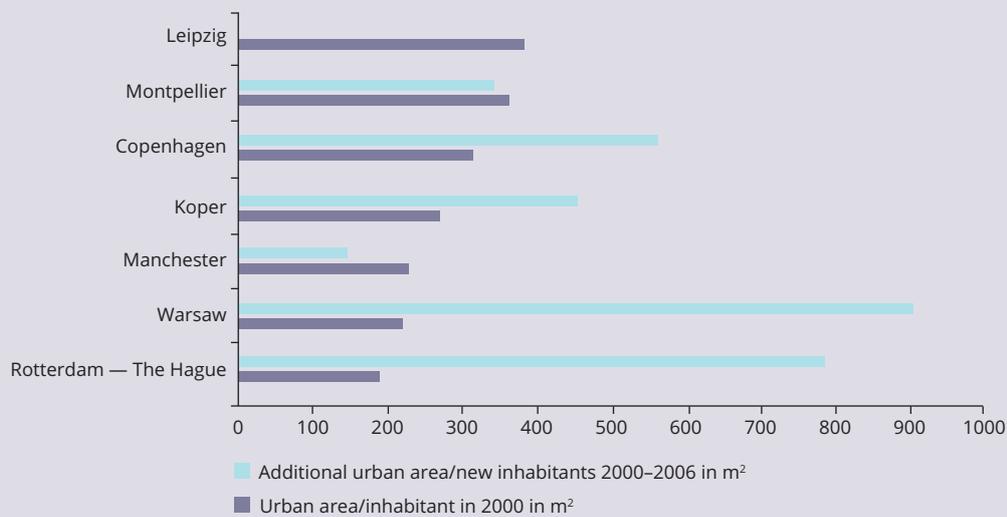
These examples show that there is no correlation between urban area growth and population growth. In Warsaw and Rotterdam–The Hague, there was strong urban growth despite only a small increase in population. In Leipzig–Halle, there was little growth in the urban area despite the population increasing during the period.

The consumption of urban land per new resident was very different in each case study. Manchester and Montpellier became denser. The other cities, including Leipzig, became less dense and each new inhabitant required more urban land in 2006 than in 2000.

Agriculture is the main land use lost due to urbanisation during the period. Consequently, it is the most threatened land use, probably because the agriculture areas is the most dominant in proximity to urban areas.

Source: Box adapted from Fertner, 2012.

Figure 4.3 Urban land use per inhabitant (m²) between 2000 and 2006



Note: No calculation for Leipzig in 2006 owing to shrinkage of its population.

Source: Eurostat, Corine Land Cover version 15; adapted from Fertner, 2012.

Figure 4.4 Annual land take for urban use (2000–2006) measured by lost land use (in percentage and hectares)



Source: Eurostat, Corine Land Cover version 15.

Box 4.3 Montpellier: planning in order to preserve agriculture areas

Montpellier, the capital of Languedoc-Roussillon in the south of France, has been experiencing rapid population growth since 1980. The quiet provincial town has been transformed into a major economic centre. Between 1999 and 2006, the rate of population growth in the Montpellier agglomeration was 1.5% per year (Insee — census data) ⁽⁴⁰⁾. This growth has resulted in widespread urban sprawl and changes in the regional landscape.

The area is characterised by remarkable natural areas of ecological value. The landscape comprises the coast and its ponds, the rivers and the hills in the garrigue. The area is exposed to serious natural risks, including frequent fires and flooding.

In 2006, concerned policy-makers adopted its 'Scheme for territorial cohesion' ⁽⁴¹⁾ for the agglomeration (bringing together 31 municipalities). This is an advanced strategy for better coordination of transport and land use planning, which has been extensively debated with citizens, stakeholders and the local governments of surrounding areas. Policy-makers clearly had the political will to develop this region through the sustainable integration of green open landscapes and urban developments, based on measures of quality of life and attractiveness, as well as the protection of agriculture and green spaces in the urban fringe. The Montpellier agglomeration coordinates planning procedures related to economic development, spatial planning and transport. All local plans and decisions on municipal housing and urban mobility, site developments and housing standards need to comply with the scheme.

The scheme requires a minimum housing density for new urban areas. A spatial framework for natural and agricultural areas, in which new development is robustly restricted, has been established. Apart from the scheme, an active policy to protect agricultural land in the urban fringe, in particular land use zoning and land price regulation, has been undertaken, and short product chains from farmer to consumer have been stimulated. A multifunctional land use plan, in which recreational and other social functions are integrated with agricultural production, has been used to protect and maintain open spaces in the urban fringe.

The mid-term review is positive: the area is becoming, denser and most of the agricultural areas have been preserved.

Source: Based on Montpellier Agglomération, 2012; Aalbers and Pauleit, 2013; Nilsson et al., 2014.

4.2.2 Reuse of land

In Europe the demand for housing and related services, industry, commerce and transport infrastructure drives land consumption on the outskirts of cities and in the countryside. However, land is a finite and non-renewable resource. The resulting imbalance between demand and supply must be 'governed' so that the land's potential to deliver goods and services is preserved. This has been recognised in the EU's *Roadmap to a resource efficient Europe* (EC, 2011a) and the EU Environment Action Programme to 2020, 'Living well, within the limits of our planet' (EU, 2013a).

Limiting land take is already an important target for land policy at national or sub-national level. In urbanised contexts, densification and 'land recycling' are both considered to be solutions. Land recycling refers to regeneration of land that has been developed

but is currently not in active use or available for re-development (so-called brownfield sites) (EC, 2012c). Between 1990 and 2000 2.5% of artificial surfaces were created on land already used or destined for development (excluding construction sites) (based on data for 24 countries; EEA, 2006b). Between 2000 and 2006 this fraction decreased to 2.0%, which was also the EEA-39 average over that period. However, these figures include infilling or densification of artificial land, rather than solely recycling land. In some countries, densification accounts for around half of the calculated figure (EEA, 2015).

Reusing land for regenerating the city

The clean-up requirements (remediation of soil, deconstruction of derelict buildings, groundwater protection) can have a high cost. However, this obstacle to regeneration can be offset by the potential of the area (e.g. the location of the area, the proximity of

⁽⁴⁰⁾ Insee: http://www.insee.fr/fr/themes/document.asp?ref_id=16187&page=synthese/syn1004/montpellier_agglo.htm#un (accessed 6 November 2015).

⁽⁴¹⁾ In French 'Schéma de Cohérence Territoriale' (SCOT).

public transport, the potential for greening). The reuse of brownfield land has become an important way of developing housing, modernising cities in industrialised countries and regenerating deprived areas. In many European cities, the reuse of former industrial and waterfront areas has become a key instrument in combatting urban sprawl and densifying urban areas.

Many cities in Europe have already led flagship projects to regenerate industrial brownfield sites (e.g. Cardiff, Cologne, Cork, Glasgow, Hamburg, Hanover, Le Havre, Liverpool, London, Lyon). The reuse of former industrial zones, in particular waterfronts, is a worldwide phenomenon (e.g. China, the United States). In general, it is driven by local authorities. The reuse

of brownfield sites can be an opportunity to rethink the urban planning of a metropolitan area, to stop urban sprawl by developing housing (including social housing) in the heart of the city, if the site is in the centre of the city, to improve urban design, to preserve industrial patrimony, to develop new green areas, and to provide opportunities for community initiatives. In general, it is a way of creating mixed use development (e.g. eco-districts) or areas with outstanding modern architecture that contributes to the city's identity and the reputation (e.g. Hamburg, Liverpool, Malmö). The revitalisation of brownfield sites is complex from the initial remediation (e.g. health problems), through the demolition and construction to the integration of the site into the structure of the city.

Box 4.4 Strong policy to limit sprawl in England

Centralised planning systems and the use of 'green belts' have helped to contain urban expansion in England and encouraged building on brownfield sites. In England, 77% of new homes built in 2008 were constructed on brownfield land, up from 57% in 1996. In the United Kingdom, new developments are restricted by the 1940s' urban containment policy and the use of green belts. The latter restrict development on a band of countryside surrounding a town or city. In addition, planning policy statements prioritise the redevelopment of brownfield sites. This policy seems to be a success. National data show that 77% of new homes built in 2008 were constructed on brownfield land, up from 57% in 1996.

Source: Baing, 2010; EC, 2013.

Box 4.5 Taking stock of longstanding regenerations

In the Liverpool Waterfront, Kings Dock was a contaminated site used as a car park for a number of years. The regeneration of the site, started in 2005, has brought economic (hotels, offices), environmental (wind turbines, buildings complying with BREAM⁽⁴²⁾, rainwater harvesting from roofs), historic (ancient buildings were restored), and social benefits (recreation and leisure).

The regeneration of Rheinauhafen in Cologne, a former goods trans-shipment location, has seen it progress from a derelict area to one highlighted in city planning. The mixed uses of the site offers tourism, commercial, industrial, housing and recreational facilities. The existing port buildings were refurbished, which retains the site's heritage, and modern buildings were added. The three cranehouses are now iconic modern buildings.

In the both cities, development were founded on high environmental standards and was important for the future of the both cities. These developments have shown the capability to attract outward investment.

Source: Maliene et al., 2012.

⁽⁴²⁾ BREAM: Building Research Establishment Environmental Assessment Method.

Box 4.6 From brownfield to greenfield: the Park Spoor Noord of Antwerp

The Park Spoor Noord ⁽⁴³⁾ project is a key example of the renewal policy of Antwerp, Belgium's second largest city and a prominent port. An abandoned railway (a 24-hectare site) was transformed into a green area in the heart of the city. The park opened in 2009.

This project fits into a city strategy based on seven 'inspiring images'. Eco-city is one of them. The objective is to develop open spaces and ecological infrastructure that is available for use by the city's inhabitants, and therefore must be easily accessible through footpaths and cycle tracks.

The transformation of this former railway area was seen as a way of maximising the use of abandoned land in the heart of the city, of providing much-needed open green spaces in a densely populated area, and of attracting new families. The Park Spoor Noord is now a green recreational space, which includes residential buildings. Around 30 000 people live within 800 metres of the park. The park has revitalised a deprived neighbourhood, and it now connects three areas that were previously cut off from each other by the railway site.

The success of the project is attributable to the local community. Strong participation during the open decision-making process has had a considerable influence: it was residents who decided to conserve the historic railway buildings that now fulfil public functions.

Source: Inforegio, in press, Park Spoor Noord: Urban park revitalises deprived city neighbourhood ⁽⁴⁴⁾.

Box 4.7 Hamburg's Hafencity ⁽⁴⁵⁾

This is a large inner city development project on the waterfront in old docks and abandoned industrial areas that will enlarge the city by 40% over a period of approximately 20 years. The main aims are to create a modern sustainable city district, to develop new mixed use, to remove car traffic in favour of pedestrians, cycle traffic, a subway and bus lanes, to densify the city and to avoid the spatial expansion of the city.

Following the transfer of some marine traffic to large container ships, some zones of the port are no longer used and have been designated as development land. Two zones located along the River Elbe, one of 155 hectares in the north and another of 45 hectares in the east have been allocated for redevelopment. The objective is to 'leap across the Elbe' to include districts that were initially islands in an inland river delta and previously used by industry.

The Hamburg Remediation Action Programme started over 30 years ago. Contaminated areas are identified and recorded in a register. Over the past 10 years, around 40 hectares of land have been recycled each year ⁽⁴⁶⁾.

The Hafencity is a major project that will increase Hamburg's density of population. An area of 155 hectares is being transformed into a lively mixed-use area including high-quality residential units, offices, recreational facilities, retail businesses and cultural facilities. The project envisages around 12 000 and 1 500 people living and working, respectively, in a district that also offers an urban park and an open boardwalk along the existing river channel.

Source: City of Hamburg, 2011.

⁽⁴³⁾ The project was part of a public-private partnership and was supported by the Objective 2 Programme of the European Regional Development Fund.

⁽⁴⁴⁾ http://ec.europa.eu/regional_policy/en/projects/belgium/urban-park-revitalises-deprived-city-neighbourhood (accessed 6 November 2015).

⁽⁴⁵⁾ <http://www.hafencity.com/en/home.html> (accessed 6 November 2015).

⁽⁴⁶⁾ European Capital Award — Application on sustainable land use: http://ec.europa.eu/environment/europeangreencapital/wp-content/uploads/2011/05/EGC-application_Hamburg_dec08_10.pdf

4.3 Urban forms and challenges

The urban form is resilient, as it is determined by physical elements, mainly buildings and their related open spaces, plots and the transport infrastructure (Rode et al, 2014). It can be analysed on different scales from city-region to individual building/lot scale. Urban form can be understood only historically, as the elements of which it is comprised undergo continuous transformation.

The diversity of urban forms can be traced to the complex functions that cities perform. Cities serve as centres of storage, trade and manufacture. They grew up around marketplaces. Throughout history, they have been founded at the intersections of transport routes, or points where goods must shift from one mode of transport to another, as at river and ocean ports.

4.3.1 Cycles of the urban fabric

The urban revolution happened independently in different places around the world and at different times. This city-making is a historical fact: the decline in the urbanism of the Greek and Roman cities, the revival of new towns in Europe in the Middle Ages, the rapid urbanisation of the 1960s in Europe. The urban form is not stable over space and time. Town-making and urban life are not a steady state of existence but surge and lapse in irregular cycles across continents.

Cities are an image of the dominant technology

Cities are built in the image of their cycle of production, distribution, exchange and consumption. The crystallisation of this cycle into a concrete urban form is what makes and remakes the built fabric of the city.

The 19th century had a major influence on contemporary cities in Europe. Industrialised cities grew very quickly as a result of migration. Some parts of cities were dedicated to production and manufacturing, others to the movement of goods and others to mass consumption (e.g. the department stores that emerged in 19th century Paris).

Over time, cities were actually made in the image of the predominant technology of their age. During the Industrial Revolution, cities were shaped by the emergence of factories, around which residential communities were built. In the age of the railways, cities were opened up to the surrounding countryside and nations were centralised around their capital cities through radial rail networks. In the age of steel, new technologies allowed cities to grow vertically, and in the age of mass production and the car, cities expanded horizontally with the creation of suburbs. Finally, the age

of information technology has allowed cities to become more competitive in making their service economies truly global, and the current Green Revolution is helping cities to build more with less.

Historically, there have been too many occasions when cities that were either left alone to withstand market and technological forces or relied on one predominant type of production, from mining to car manufacture, perished or failed. It is the role of urban planners to mitigate the negative external effects of market forces and steer cities towards sustainable future development.

The lock-in effect

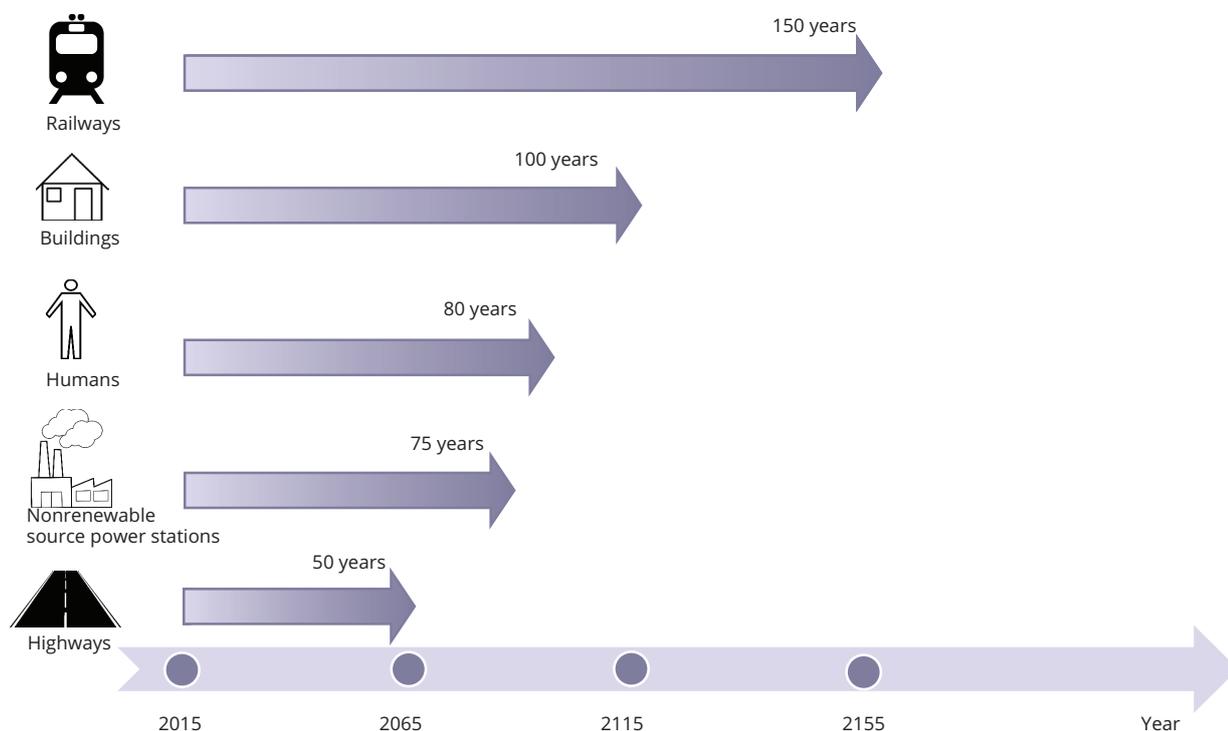
Spatial development has very strong 'lock-in' effects. As carbon emissions and energy consumption are closely connected to urban form, actions that influence land use and spatial development are among the most critical to achieving a low-carbon society. A crucial issue with 'grey infrastructure' is its long lifespan (see Figure 4.5). This locks cities into consumption and production patterns for decades because it is difficult (almost impossible in some cases) and costly to modify and retrofit existing infrastructure once it is built.

In Europe, cities were more compact and less dispersed in the mid-1950s than they are today. In the 1960s and 1970s, the growth of cities was mainly driven by the increasing urban population, the development of personal mobility and increasing car ownership, the extension of the road networks, the preference for new lifestyles in suburban environments, and the price of land (EEA, 2006b). During this period of rapid urban expansion, urban planners shaped cities for cars and extensive transport infrastructures were developed. People were living increasingly further from city centres. The road networks enabled them to separate the places where they live and work. As a result of this car-oriented period, some cities are now locked in to an unsustainable model.

The same phenomenon is currently happening in fast-growing macrocities of emerging countries, in particular in Asia. The level of urban development will have important 'lock-in effects' for China's future energy demands and greenhouse gas emissions. To support increased motoring, investments in its transport infrastructure over the next 5–10 years will lock it in to transport-related carbon dioxide emission patterns for the coming 20–30 years (World Bank, 2013; World Bank and Development Research Center of the State Council, the People's Republic of China, 2014).

A society can be 'locked in' into an unsustainable pattern by inefficient urban infrastructures for supplying heat, water and transport, a lack of urban planning or a large stock of low-energy-performance housing — but also

Figure 4.5 The lifespan of people, assets and infrastructure



Source: Adapted from UN et al., 2011.

by unsustainable social norms, consumption patterns and lifestyles (see Table 4.1).

Patterns of urban fabric

The relationships among urban forms, energy consumption and car dependency have been understood for some time (Kenworthy and Laube, 1999; Newman and Kenworthy, 2006). The urban form and spatial structure constrain cities' functioning (individual spatial behaviours, land use) and flows (travel, energy, water) and, retroactively, their functioning modifies both their morphology and their structure (Salat and Bourdic, 2012).

There is great variety in cities. The dense hearts of Paris or Hong Kong have a grid with an average distance

of 120 metres between intersections, while it is only 50 metres in Tokyo and Kyoto (Salat and Bourdic, 2012). Despite these variations, these cities have maintained a stable fractal structure for a long time.

The main problem for the contemporary city is the disconnection between scales. The fractal structure of historical cities has been ignored since the 1950s. Two scales have emerged: the metropolitan region traversed and structured by large transport infrastructures dedicated to speed and the neighbourhood. This 20th century model of urbanisation has led to the dehumanisation of cities, the loss of their urbanity and identity, and inefficient urban structures. It is as if a city with blurred limits is floating in a space that is too large (Salat et al., 2010).

Table 4.1 Sources of lock-in

Lock-in source	Examples
Technological	Dominant design, standard technology and components
Organisational	Routines, existing infrastructure
Industrial	Industry standards, technological inter-relatedness
Societal	Collective norms, individual values, representations, preferences
Institutional	Institutional territorial fragmentation, legal frameworks

Source: Adapted from Unruh, 2002.

Box 4.8 Differences in urban fabric

The structure of the urban fabric can differ and have several levels of complexity, efficiency and resilience (see Table 4.2). Streets are the most basic element of the urban spatial structure. They have a crucial role in shaping the quality of life and mobility patterns.

Table 4.2 The different structures of urban fabric

	Turin	Barcelona	Paris	Ginza, Tokyo	Pudong, Shanghai	Towers North, Beijing
Intersections per km ²	152	103	133	211	17	14
Distance between intersections (m)	80	130	150	43	280	400

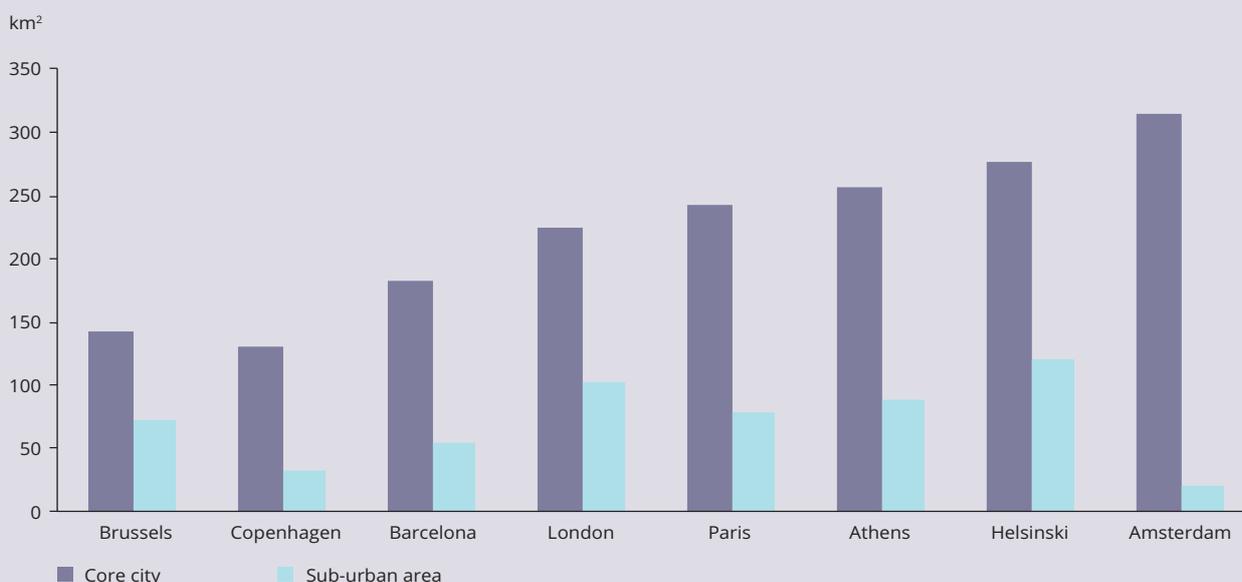
Source: Salat and Bourdic, 2012.

Streets provide spaces for mobility, including public transport and non-motorised transport (walking and cycling), commerce and social interaction. They also accommodate pipes (water supply, storm drainage system and sewerage), power lines, communication technologies (such as fibre optic cables) and management of city services (waste collection). When the amount of space allocated to streets is insufficient, the provision of basic services is significantly hindered. This is typically the case in slums, where the provision of basic services is hampered by the lack of streets.

Intersection density is a fundamental element of walkability and cyclability. Sufficient street intersections are needed to encourage mobility that is not dependant on cars. Street connectivity is a way of shortening distances, reducing travel times and encouraging walking and cycling. Direct shortcuts for pedestrians and cyclists are easily created in a grid plan with frequent intersections. Conversely, travel by cars can be encouraged by offering more direct routes for drivers. A high density of intersections helps to develop an efficient and easily accessible urban transport network.

According to the UN-Habitat report, *Streets as public spaces and drivers of urban prosperity* (UN-Habitat, 2013), on intersection density in large cities, in Europe, apart from Helsinki (120.6 intersections per km²), the suburban areas of the cities studied have unconnected street networks with fewer than 100 intersections per km² (see Figure 4.6). Despite the low density of streets in suburban areas, they are often underutilised because of the low population density, the small number of people served and the lack of connections to the street networks. 'Empty' streets do not make the most of the natural and financial resources used to build and maintain them.

Figure 4.6 Intersection density (per km²)



Source: UN-Habitat, 2013.

4.3.2 Spatial and temporal scales

The city and its hinterland

The core city cannot be seen in isolation. Depending on the issue being addressed, the scales of analysis go beyond the administrative jurisdiction: the landscape scale for natural assets and green infrastructure, the regional scale for networks such as energy or transport, the river basin or catchment scale for water supply, and the metropolitan scale for urban form, urban pattern and utilities such as the waste management system.

In order to implement their resource efficiency policies more efficiently, local authorities have to cooperate with surrounding local authorities on issues such as public transport, planning, flood protection, water supply and energy supply. Owing to urban expansion, the governance of land use is fragmented among many local governments, with considerable differences in the fiscal capacity of local governments that results in the filtering of funding for low-cost housing and exacerbates spatial and social segregation. In addition, cities and towns compete to attract residents and businesses. This competition generates low-density

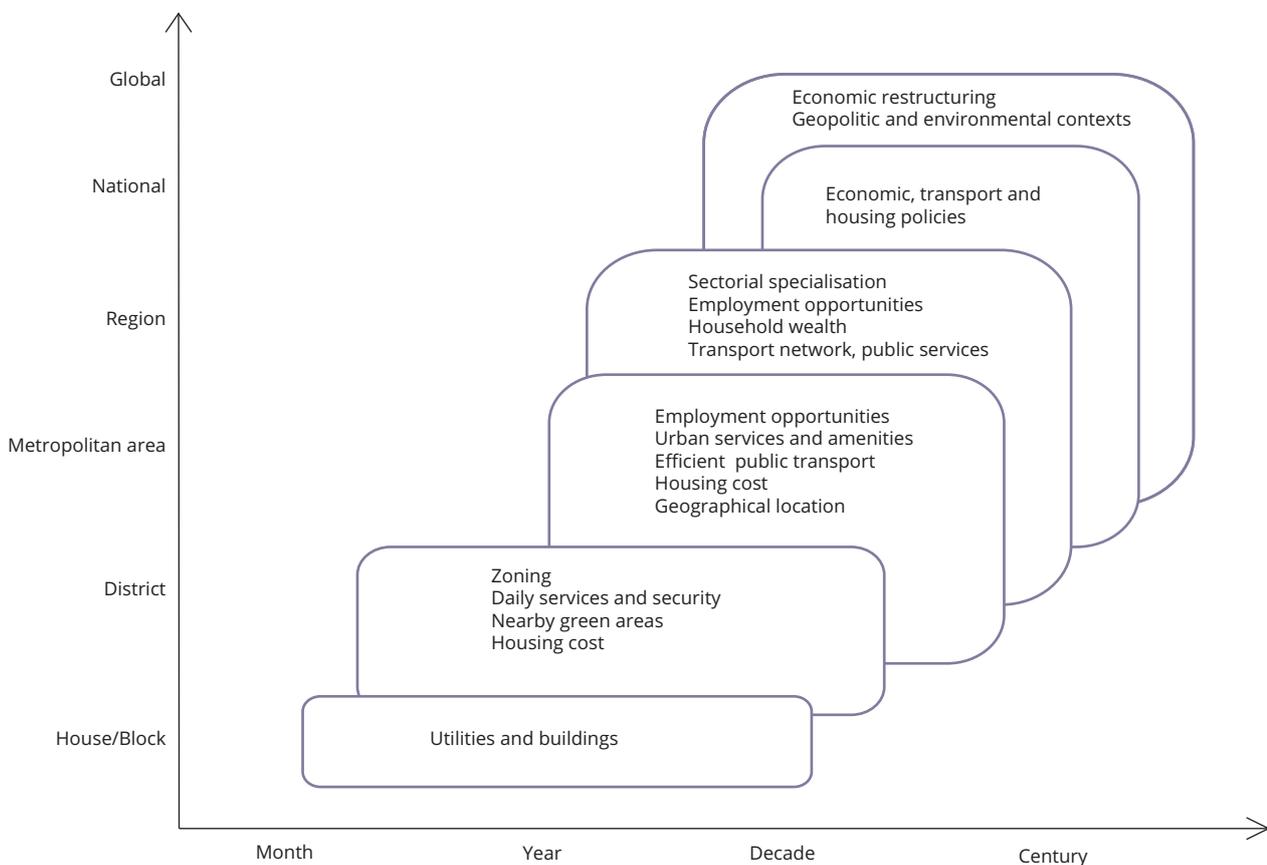
expansion, mainly into the surrounding agricultural areas and along major roadways. This low-intensity land use (people and jobs) and dispersion of built-up areas (construction or transport infrastructure) is the major physical characteristic of urban sprawl (Schwick et al., 2012).

Changes in time and space

The demand for land is influenced by several drivers, mainly demography, economic dynamics and lifestyle. The increasing number of smaller households, the demand for greater floor space and the preference for detached houses all lead to a growing demand for land.

Land use results from interactions between activities taking place across different spatial and temporal scales (see Figure 4.7). It is the result of a combination of decisions by individuals and public bodies. For example, decisions on where to live are determined not only by the characteristics of the garden or the house but also by other considerations such as the quality of the neighbourhood, the standard of services, the price, commuting time, noise levels, and the availability of

Figure 4.7 Changes in time and space influencing household location decisions



Source: Adapted from Pickett et al., 2011.

public transport and natural amenities. Other agents (e.g. firms, landowners) can be influenced by other factors. Without robust urban planning and regulation, the accumulation of individual decisions over time can generate cross-scale effects such as spatial segregation or urban sprawl on the metropolitan scale (Pickett et al., 2011).

Structural elements

Achieving resource efficiency depends on taking into account cross-scale and temporal interactions guide policy. A hierarchy has been established (Suzuki et al., 2010). The longer lasting elements are the first priority because they are structural elements that can be changed only slowly, at great cost and at risk of having an impact on other sectors and far beyond the city limits. Natural assets, urban forms, land use patterns, heritage elements and stocks (existing parts of the urban fabric such as buildings and infrastructure) are typically long-lasting elements (see Figure 4.8). They are key elements for integration.

The demand for resources depends on the type of economy and citizens' lifestyles. Even if each city is individual (in terms of culture, history, locality, and industrial, tourism or tertiary activities), they all have common characteristics that shape demand (global market, demand for energy, standard of household consumption, values) and cities can hardly act on all these drivers in the short term. However, cities can easily be more resource efficient in their management of utilities and by developing strong urban planning in the short term. The elements that last a shorter time

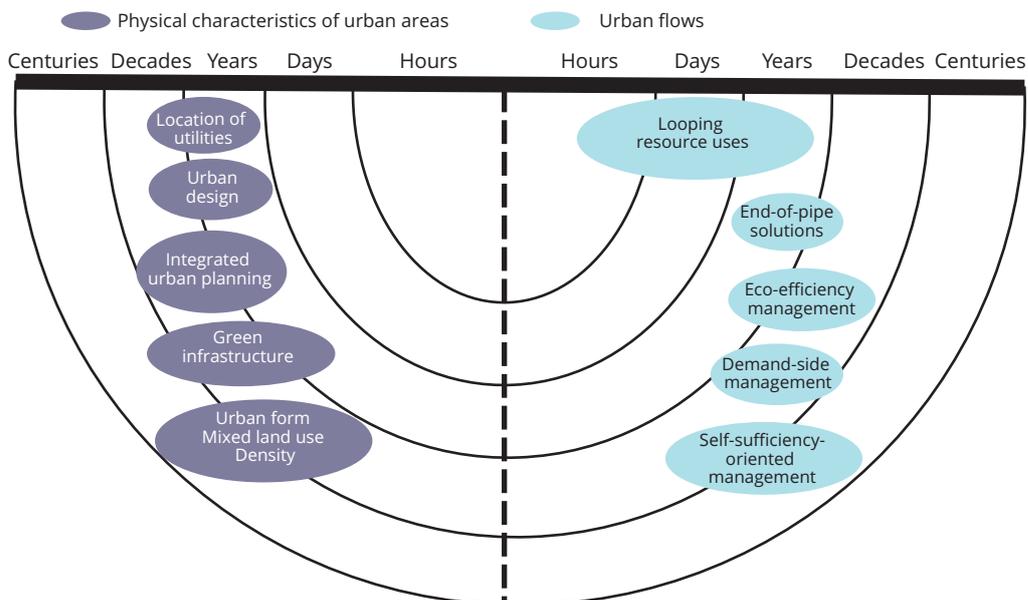
are easier to change by appropriate management, and in general they are at the local scale (house, block and district).

4.4 From traditional to modern urban form

As an organism, a city is changing all the time as a result of accumulated individual and public actions governed by culture, society and economic forces. A city is characterised by the permanent transformation of built structures, streets, green areas (gardens, parks, trees), public transport and public spaces. The form of cities has historically been shaped, and is always being transformed, by multiple factors, in particular mobility and economic prosperity. Throughout history, cities have always flourished and declined. They are unstable systems that tend to grow in favourable circumstances and to stagnate and contract in period of crisis.

The characteristics of cities shape changes in urban social inter-relations. The European city has been modelled by the values, moral concepts, principles and culture of its stakeholders over time. It is a place where civil society has been able to evolve, to develop cultural and social interactions and to expand its economic activities. These elements expand beyond the familiar definitions of the European city, which usually reduce it exclusively to its shape, its historical centre, its compact layout or its density. The European city is more than its form and its historical cityscape. Its extensions and peripheral areas are all part of the European city.

Figure 4.8 Sequential investment for a better return



Source: Adapted from Suzuki et al., 2010.

Table 4.3 Patterns of urban neighbourhood development

Pattern	Land use mix	Density range
Rural pattern	Low	Very low
Village pattern	Medium	Very low
Auto-oriented pattern	Low	Very low –low
Landscape-oriented pattern	Medium	Low–medium
Pedestrian-oriented pattern	High	Medium–high
Pedestrian and green infrastructure pattern	High	Medium

Source: Isocarp, personal communication from EEA author, 2014.

Land use and land cover change over space and time. These changes produce urban patterns (see Table 4.3). The European city is a place of constant transformation, of its building stocks, public infrastructure, privately owned trade, commerce and service facilities, and economic structures. Through this constant transformation, the European city reveals its inner strength. Whatever the shapes and forms, the pattern of the European city can still be distinguished.

4.5 The concept of urban compactness

The relationship between the urban form at the large scale and energy consumption has been studied in depth. A high-density urban fabric is the most energy-efficient structure, in particular when the high-density growth is along linear transport infrastructures (Steadman, 1979). There is a strong correlation between urban density and gasoline consumption (Newman and Kenworthy, 1989; Newman and Kenworthy, 2011).

The urban form and spatial structure are strongly related to resource use. They 'constrain cities' functioning (individual spatial behaviours, land use) and cities' flows (travel, energy, water) and, retroactively, their functioning modifies both their morphology and their structure.' (Salat and Bourdic, 2012). The enormous physical expansion of our cities in the last century, and the resulting problems, particularly regarding transport infrastructure and land consumption, led to the renaissance of the compact city as an ideal urban form in ideal urban planning (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 demand for resource compared with less dense, less compact cities (Beatley, 2003, p. 250).

Several arguments support the idea of compactness extending beyond the issue of resource use. This

includes, more generally, a reduction in transaction costs, enabling, for example, social interaction and integration or support for the creative economy (UN, 2010). However, there are also many critiques of the idea that the compact urban form really makes a difference (see, for example, Gordon and Richardson, 1997). Furthermore, compact cities have a number of potential adverse environmental, social and economic effects (Padt et al., 2012). In terms of resource efficiency, there are mainly three criticisms:

- other factors can be much more significant for resource use (e.g. social background for travel behaviour, lifestyle);
- the reduced potential for on-site activities increases the need of transport and greater infrastructures (e.g. farming on site, waste treatment on site, local water run-off, recreation on site);
- there are also some negative effects on energy consumption (e.g. increase in energy consumption as a result of urban heat island effects; inefficient energy use as a result of traffic congestion).

4.5.1 Understanding compactness

The arrangement of land use directly affects energy consumption primarily in the transport and secondly in the space heating/cooling sectors (Owens, 1986). However, the effects of the compact city can be evaluated very differently depending on the scale considered.

There are several assumptions about compact cities related to resource efficiency that can be discussed:

- compact cities save land because they stop urban sprawl;
- compact cities save energy used in transport because commuting distances are shorter;

- more efficient modes of transport are favoured in compact cities, because in dense areas there are more potential users of public transport than in low-density areas, and therefore it is more cost-effective;
- compact cities use less energy for heating/cooling, because in dense urban structures terraced houses or multi-storey buildings are more common than detached houses, which are less energy efficient;
- compact cities use less resources for the construction and maintenance of infrastructure (per person) because there are more users.

There is no general or unique definition of a compact city (see Figure 4.9). Three main issues make it difficult to draw up a clear-cut definition:

- *Compactness is a matter of scale:* Built-up structures can be compact at all levels (block, neighbourhood, district or city level). Compactness on one of these levels does not equal compactness on the other levels. Resource efficiency must be addressed at the level appropriate to the resource — e.g. district heating needs a compact neighbourhood to be feasible, while commuting transport issues are very much related to the compactness of the whole city.
- *The compact city is more than just a dense city:* Dense utilisation of urban land is not the only key issue. In a compact city it is important to secure public spaces, to develop an efficient public transport system (dense, frequent, affordable) and mixed land use at local scale (OECD, 2012a). Key characteristics reflecting the complexity of the

concept have to be considered when planning for a compact city.

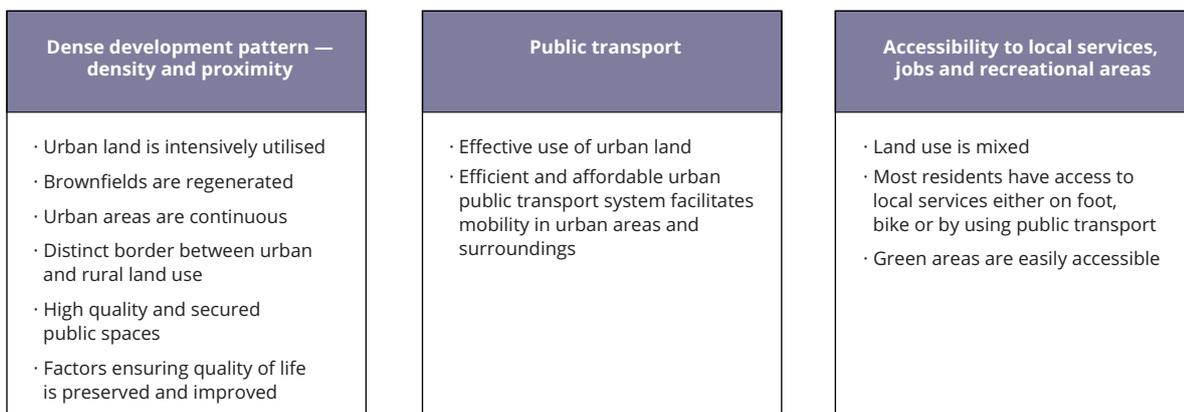
- *Compact cities have different urban forms:* Cities do not have to form a perfect circle (like a city in the Middle Ages) to be compact, as long as the built-up structures are still compact and connected to the other parts of the city. The urban form is adapted to the local geographical context and is also determined by existing buildings and infrastructure. A compact city can be monocentric or polycentric.

Compact city development is not only an issue of resource efficiency. It can have a considerable impact on the quality of life of the residents and the economic development of the city and its neighbourhoods. Despite the lack of a simple, empirically applicable definition of a compact city, cities can still aim to achieve it and adapt the concept to their own context and needs.

4.5.2 Urban sprawl versus compactness

Traditionally, European cities have developed in a compact pattern by growing around a dense historical centre; however, with urban sprawl, their density decreases towards the edge of the urban area. Owing to high residential and employment densities, mixed land use and the relatively small size of parcels of land, compact cities facilitate social and economic interactions, access to services (education, health, commercial, cultural), development of utilities (sewerage, multimodality), accessibility (local/regional, high degrees of street connectivity including pavements and cycle lanes), and adequate

Figure 4.9 The key characteristics of a compact city



Source: Adapted from OECD, 2012a.

Table 4.4 Comparison of urban densities and transit modes in international cities ⁽⁴⁷⁾

Group of cities	Urban density (persons/ha)	Journey to work by transport (% workers)	Journey to work by walking and cycling (% workers)
American cities	14.2	9	5
Australian cities	12.3	15	5
Canadian cities	28.3	20	6
European cities	49.9	39	18
Asian cities	157.4	49	19

Source: Kenworthy and Laube, 1999.

government fiscal capacity to finance urban facilities and infrastructure (Newman, 2005).

The compact city is characterised by balanced development, strong planning and controlled growth. Achieving compactness is crucial to developing efficient and affordable public transport networks. High density means large numbers of potential users of public transport and thus lower costs.

The well-known study by Kenworthy and Laube (1999) shows big differences in urban compactness between cities on a worldwide scale (see Table 4.4). Although these results are not recent, they demonstrate the existence of different urban models and the efficiency of the European urban model.

High densities are more resource and energy efficient but, at the same time, high concentrations of population means a high degree of soil sealing and a low open space to built-up area ratio. Therefore, the challenge is to develop compact cities that are liveable cities with sufficient green areas and other amenities. Urban planning and urban design at the appropriate scale (metropolitan or functional area) are key policies in the development of liveable compact cities (Newman, 2005).

A compact city cannot be thought of only in terms of the physical layout of the city. It refers more to the functional urban area, which is composed of the urban core, generally the historic city, and its hinterland — the neighbourhoods socially and economically linked to the city. This scale encompasses the labour market and the commuting pattern, which generally extends beyond the city's limits. There is no specific size for a compact city. Large urban metropolitan areas can be compact. A compact city can be either a monocentric or a polycentric urban structure (Metrex, 2010).

Compactness brings a series of benefits. The need for artificial land (in particular for infrastructure) is reduced. Car dependency and traffic congestion decrease. As a result, air quality improves and noise levels are reduced, and thereby public health improves. The sense of community among residents becomes stronger. Accessibility is more equitable for all citizens (National Research Council, 2009), and the cost of public transport is lower. In urban sprawl areas transport is dominated by privately owned motor vehicles. However in compact cities, when integrated urban planning measures are taken at the appropriate scale, significant energy savings can be made on account of reduced commuting and congestion.

⁽⁴⁷⁾ The study focused on metropolitan regions with medium to large populations.

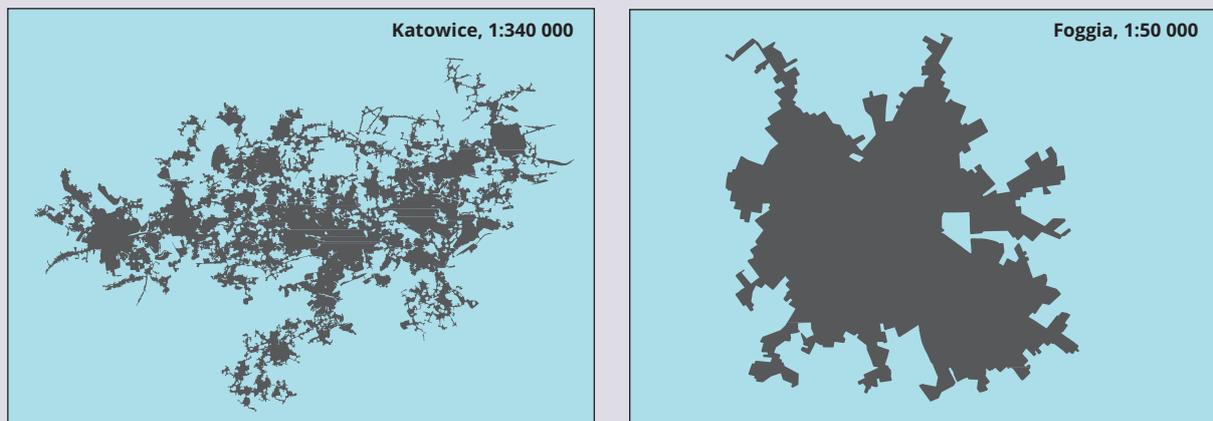
Box 4.9 Factors contributing to compactness

European cities are compact compared with American cities, and they are considered to be a more sustainable model. However, the complexity of the spatial organisation of cities cannot be translated into simple indices that establish a threshold between compact and dispersed cities. Often comparisons are based on extremes, omitting the complexity of the full range of situations. Analysing the compactness of European cities means looking at the entire continuum between the most dispersed and the most compact cities.

Urban morphology can be defined by different factors: compactness, size, population density, and the mix of land uses. These factors are directly or indirectly affected by urban planning and policy-making that shape the urban area, for instance through restrictions on certain types of urbanisation or the re-emergence of inner-city deprived areas.

The compactness index shows how far a city is from a circular form with the same area (see Figure 4.10). The circular form is the one with the lowest perimeter to area ratio. The compactness index ranges from 0 (for highly irregular and dispersed forms) to 1 (for highly compact and close to circular forms).

Figure 4.10 From 0 to 1, the extreme values of the compactness index



From 0 to 1, the extreme values of the compactness index	
<p>Urban Morphological Zones</p>	<p>Compactness index:</p> <ul style="list-style-type: none"> • Katowice: 0.83 • Foggia: 0.27

Source: Compiled from data in Urban Atlas, 2006 (calculation done by the European Topic Centre on Spatial Information and Analysis (ETC/SIA)).

The index ranges from 0 (more irregular and less compact city) to 1. Foggia and Katowice are the most extreme cases for the cities available in Urban Atlas.

Black: Built-up areas. Red: approximation of the urban form by 1-km grid square.

Density

Density is a measure of the intensity of land use. Density can be measured in a variety of ways (people per hectare, jobs per hectare, floor space ratio) and in gross or net terms. In general, the higher the density, the more people, jobs or built floor space there is per unit area. A minimum threshold density is necessary to support services (commercial, education, cultural) and public transport (frequency, proximity, cost). There is a significant increase in car use at densities below around 30 to 40 people and jobs per hectare (Newman and Kenworthy, 2006).

Employment density is as strategic as residential density. The location of jobs has a great impact on commuting distances and the means of transport used for commuting. There is a clear relationship between employment density and journeys to work by transport.

Box 4.9 Factors contributing to compactness (cont.)**Mixed land use**

Mixed land use means having a complementary and context appropriate combination of services, housing, offices and employment opportunities within the same area. People can therefore meet most of their daily needs nearby. The uses can be mixed vertically (between the floors of a building) or horizontally (commercial buildings located close by residential buildings) (see Figure 4.11). High land use diversity is considered desirable. It is a way of facilitating daily living and access to services, increasing the sense of community, reducing travel distances, combining more than one destination in each trip, and facilitating cycling and walking. It is also important to develop a mixed, diverse housing stock (a variety of housing types, tenures and prices) in order to prevent spatial segregation, encourage a mixed population and avoid having all the same demographic profiles in an area.

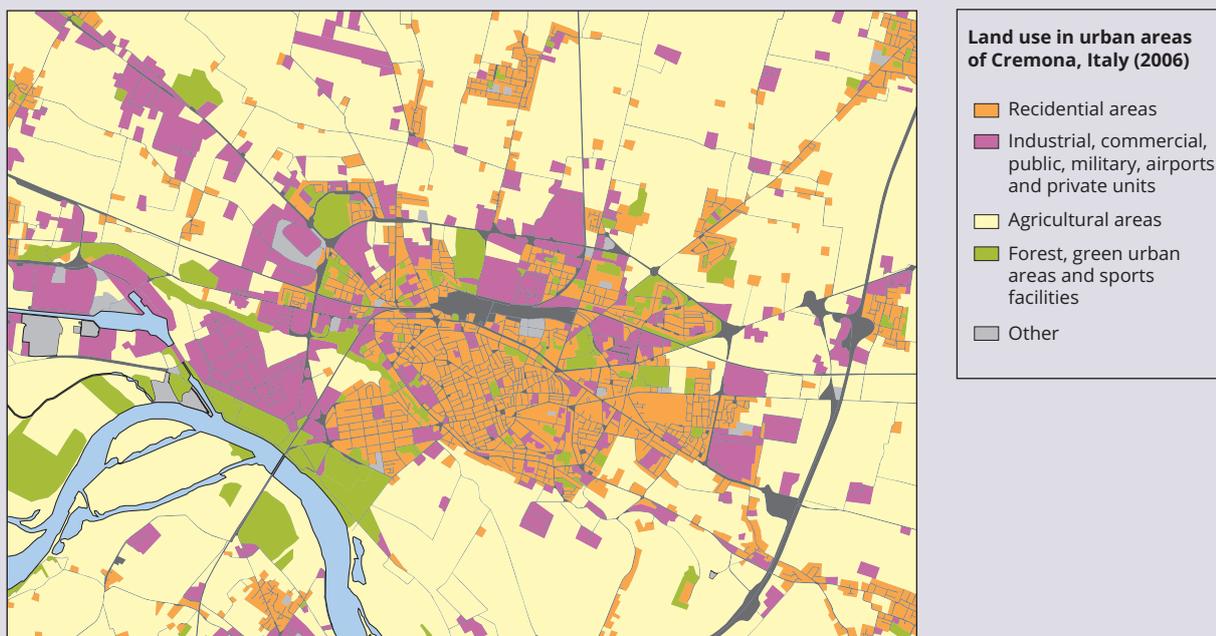
Ideally the land use mix should be evaluated at the block level. However, as Urban Atlas is derived from satellite images, it is not possible to identify mixed uses in a single block or parcel of land.

Urban design

Urban design means the arrangement of land uses, buildings and facilities with sufficient levels of density and diversity, together with attractive and visually interesting buildings, green areas and public amenities. A sense of place can be developed through a green neighbourhood (trees, parks and other green areas), a safe environment (pedestrian-friendly environment, cycle lanes), easy access to services (shops, schools, culture), good public transport (real-time information, frequent, low cost, well-distributed stops or stations). Generally, people walk further in high-density well-designed urban areas (Canepa, 2007).

Proximity

The distance to the city centre determines commuting distances and distances travelled within the city. It gives a notion of proximity.

Figure 4.11 Land use in Cremona (Italy)

Note: This city has the highest land use mix index (0.99).

Source: Urban Atlas, 2006.

Box 4.10 Are European cities compact?

Four groups of European cities have been identified by analysing different descriptors (compactness index, land use mix ranges, distance to city centre, land take per capita, soil sealing per capita) based on Urban Atlas (2006).

These groups reflect urban patterns from more irregular and dispersed cities to more compact ones:

- *Large irregular cities:* Lower land use mix and relatively small city centre compared with the metropolitan areas (Large Urban Zone).
- *Large irregular cities with intensive land use:* This group has similar properties to the previous group, but it has the highest degree of soil sealing.
- *Intermediate cities:* For most of the indexes this group represents a more compact city, although the soil sealing per capita is relatively high.
- *Compact cities:* Cities with the highest index of compactness, characterised by a large core city in relation to the metropolitan area (LUZ).

The analysis of these descriptors confirms the relationships between the compactness index and other descriptors of the city form. In general, southern cities have lower values (e.g. Barcelona, Rome, Athens). Cities in the United Kingdom also generally show a low degree of soil sealing. Generally, the sealed area per habitant is highest in the coastal cities of Portugal and in northern and central Europe.

Source: ETC/SIA, 2012.

4.5.3 Compactness and green infrastructure

In the European Commission communication *Green infrastructure — Enhancing Europe's natural capital*, green infrastructure is described as 'a tool for providing ecological, economic and social benefits through natural solutions. It helps us to understand the value of the benefits that nature provides to human society and to mobilise investments to sustain and enhance them. It also helps avoid relying on infrastructure that is expensive to build when nature can often provide cheaper, more durable solutions' (EC, 2013a).

Green infrastructure offers an alternative to standard and expensive 'grey' solutions that typically fulfil only single functions (e.g. transport infrastructures, networks for collecting stormwater), whereas nature provide multiple solutions that are cheaper, more robust and more resource efficient. For instance, a flood protection area can at the same time be an area for protecting biodiversity, a recreational area, a forest for timber production and an area with aesthetic value.

Green infrastructure inside and around urban areas

There is a wide variety of urban green infrastructure (see Table 4.5). Even in densely built-up cities where few spaces for creating green areas are available, there are many vertical opportunities such as green vegetated roofs, green terraces or green walls.

Brownfield regeneration is also another opportunity to improve the local environment and to incorporate urban wasteland into the green structures of cities. Wasteland is often the only large areas where wilderness can develop undisturbed over several years (Muller et al., 2010).

Green infrastructure inside and around cities provides environmental, economic and social benefits such as fresh air, drinking water, flood regulation, attenuation of surface run-off, thermal regulation, noise attenuation and recreational areas. Green infrastructure is crucial for strengthening the resilience of ecosystems and for sustaining the key ecosystem services that help in adapting to climate change.

Green infrastructure offers several services:

- *Provisioning services:* clean water, flood regulation, food, timber.
- *Regulating services:* carbon sequestration and storage, water infiltration, air purification, noise reduction, balancing peaks in storm water, reducing the effect of heat islands.
- *Cultural and social services:* recreation and tourism, a healthy environment, psycho-physical benefits, a perception of nature, aesthetic value, adding to the character of the urban landscape.

Table 4.5 Potential assets that make up green infrastructure grouped by scale

Local, neighbourhood and village scale	Town, city and district scale	City-region, regional and national scale
<ul style="list-style-type: none"> • Street trees, verges and hedges • Green roofs and walls • Pocket parks • Private gardens • Urban plazas • Town and village greens and commons • Local rights of way • Pedestrian and cycle routes • Cemeteries, burial grounds and churchyards • Institutional open spaces • Ponds and streams • Small woodlands • Play areas • Local nature reserves • School grounds • Sports pitches • Swales, ditches • Allotments • Vacant and derelict land 	<ul style="list-style-type: none"> • Business settings • City/district parks • Urban canals • Urban commons • Forest parks • Country parks • Continuous waterfront • Municipal plazas • Lakes • Major recreational spaces • Rivers and floodplains • Brownfield land • Community woodlands • (Former) mineral extraction sites • Agricultural land • Landfill 	<ul style="list-style-type: none"> • Regional parks • Rivers and floodplains • Shoreline • Strategic and long distance trails • Forests, woodlands and community forests • Reservoirs • Road and railway networks • Designated greenbelt and strategic gaps • Agricultural land • National Parks • National, regional or local landscape designations • Canals • Common lands • Open countryside

Source: Landscape Institute ⁽⁴⁸⁾.

Green infrastructure poses new challenges for urban planning. In the context of resource efficiency, ecosystem services should become key criteria for strategic decision-making. Planners have to preserve green spaces inside, around and between cities in order to guarantee ecosystem services and quality-of-life benefits. Based on the overview of potential benefits, multifunctional zones can be identified and management measures with targets defined for specific land uses. The development of green infrastructure inside and around cities is crucial to the concept of a compact city.

Preservation of biodiversity

'The unique physical and ecological conditions, the mixed and small-scale habitat mosaic, the mixing of native plant and animal species with a larger number of non-native species, and the various influence of people results in habitat types and plant and animal associations or communities in urban areas that are significantly different from the landscapes and land use.' (Muller et al., 2010). A city includes a variety of habitat mosaics, while at the same time the city itself is part of a larger landscape. In response to increasing competition, the green infrastructure will need to be managed in a 'smart' way within and around the city in order to preserve biodiversity.

⁽⁴⁸⁾ Landscape Institute, 2009. Green infrastructure: connected and multifunctional landscapes — position document.

Box 4.11 Demolition: an opportunity for urban biodiversity

Shrinkage is defined by demographic characteristics (depopulation, ageing and outmigration), land use change (dilution of the built-up and a decrease in density, demolition of buildings, creation of brownfields and wasteland) and economic decline (deindustrialisation). It is characterised by residential and non-residential vacancies, from large-scale brownfield sites to small-scale abandoned buildings or wasteland inside and around the city.

The spatial and environmental impacts of shrinkage are complex. Creation of new open land by demolition not only enhances residents' quality of life (e.g. an increase in recreation areas per capita, opportunities for new footpaths and cycle lanes) but also improves the ecological quality of urban green areas.

For example, east Leipzig's green infrastructure is characterised by small-scale green areas (pocket-sized parks) because of its fragmented urban structure. Demolition has increased the supply of green spaces per capita and therefore quality of life. Between 2002 and 2020, public urban green areas within 500 metres' walk will increase from 9 to 11 m² per resident. With regard to biodiversity, different indicators⁽⁴⁹⁾ show an improvement in the ecological quality of urban green areas, even with fragmented small patches. The contribution was greater in other parts of the city where the patches were larger.

Source: Müller et al., 2010⁽⁵⁰⁾.

Thermal regulation

The term urban heat island describes the higher temperature of air in the city compared with that in its rural surroundings. The intensity of heatwaves is influenced by the urban fabric and design. Buildings and sealing surfaces such as concrete, asphalt and stone store heat during the day and during the night it is released to the surrounding air. Surfaces with a higher degree of soil sealing have a higher temperature.

High temperatures during the night can have serious effects on people's health during heatwaves. They have impacts on well-being (psychological impacts, increased violence and social unrest); on water resources (pollution caused by a combination of low water flow and heat, water shortages, changes in patterns of vector-borne diseases); and on the economy and infrastructure (reduced productivity of workers in very hot conditions, increased hospital admissions and pressure on care services, increased failures in transport networks, increased demand for energy for air conditioning, failure of power supplies) (EEA, 2012).

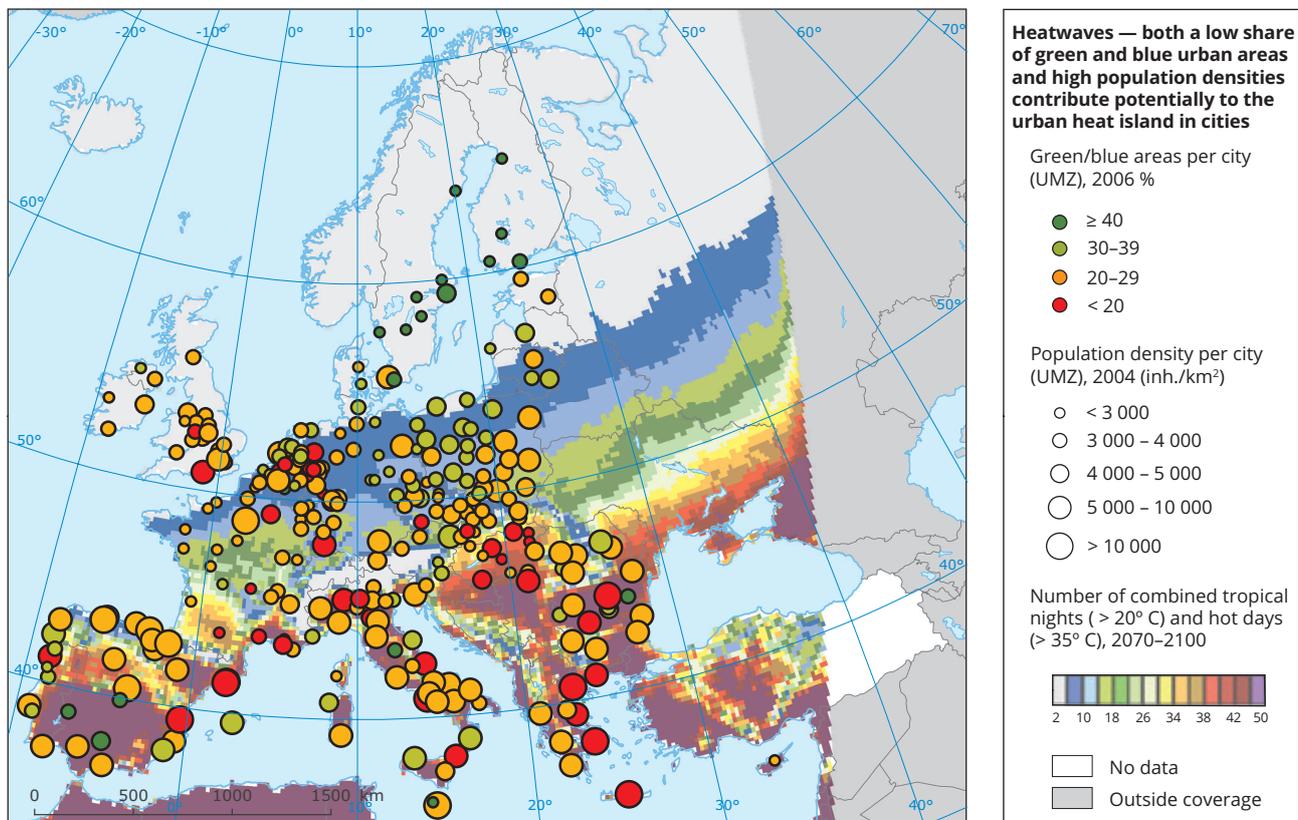
Green and blue areas help to regulate temperatures in the city. The proportion of green and blue areas and

their distribution determine cities' sensitivity to heat. Parks, urban green areas, green roofs, green facades and street trees can contribute to keeping buildings cool and therefore to saving energy rather than using air conditioning (EEA, 2012). In densely built-up areas, the major challenge for planners and urban designers is how and where to add vegetation in cities. One strategy is vertical integration. Many cities include green areas in their adaptation plan for managing temperature and other impacts of climate changes.

The EEA report *Urban adaptation to climate change in Europe* gives a European overview of the proportion of green and blue urban areas required to supply the necessary cooling effects for cities and their residents. Two indicators have been developed: the proportion of green urban area and the edge density between green and non-green space as a proxy for the distribution of green spaces. The resulting map (Figure 4.12) shows a large number of cities with a high urban heat island potential in the north-west, owing to their low proportions of green and blue urban areas, and in particular in the south-eastern part of Europe where, in addition, population densities are higher. In the western part of the Mediterranean area, the urban heat island potential seems to be quite variable.

⁽⁴⁹⁾ Mainly the larger patch index (LPI) of open land use and the edge density (ED), leaf area index (LAI), habitat suitability index (HIS) and Shannon diversity index (SHDI).

⁽⁵⁰⁾ Haase, D. and Schetke, S., 2010, 'Potential of biodiversity and recreation in shrinking cities: contextualisation and operationalisation, in: Müller, N., Werner, P. and Kelcey J. G. (eds), *Urban biodiversity and design*, John Wiley and Sons, Chichester, pp. 518–535.

Figure 4.12 The urban heat island potential of European cities

Source: EEA, 2012.

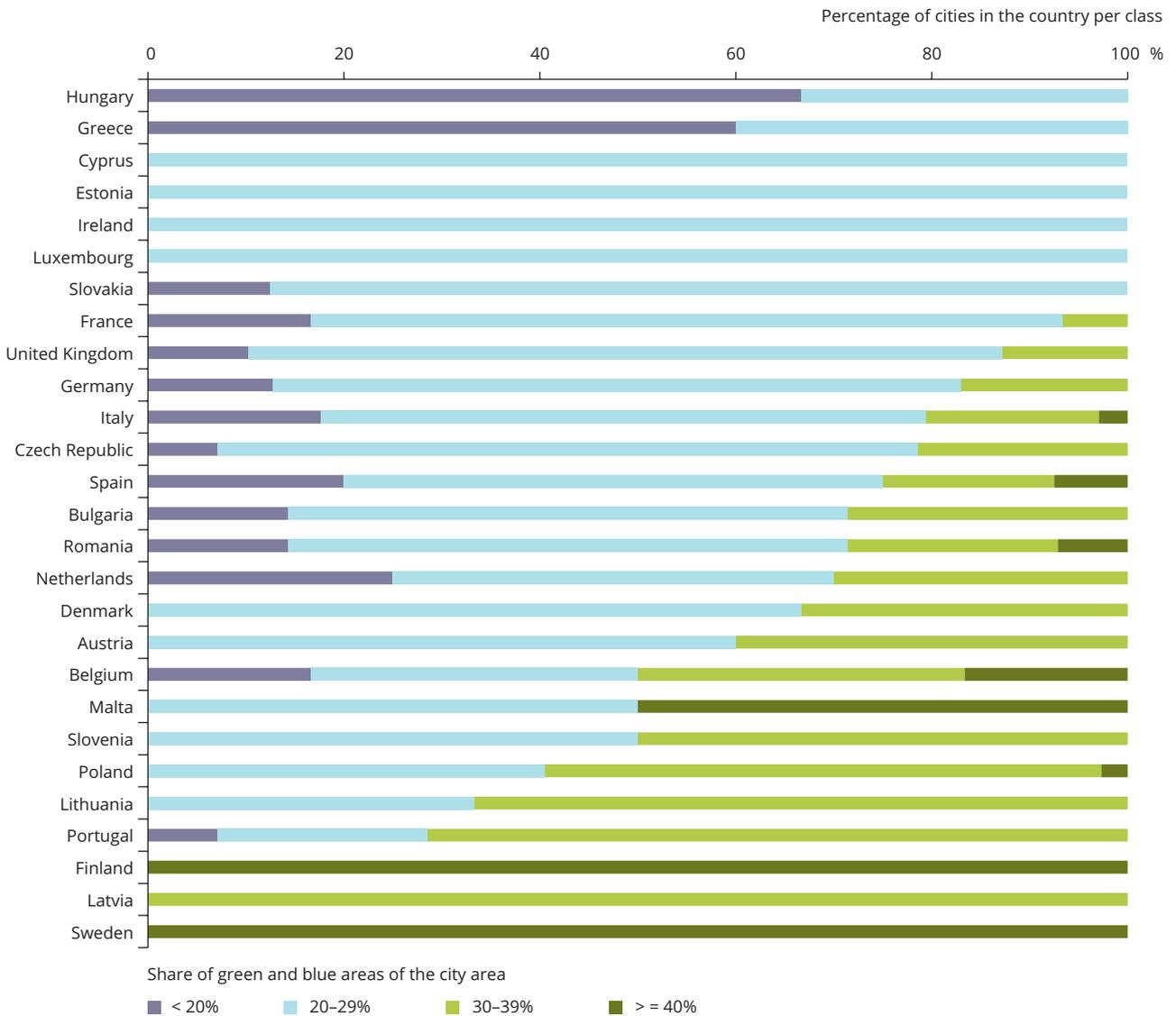
A large proportion of cities in eastern and southern Europe will experience relatively large increases in their heat load in future. If the heatwave intensity expands more to the north-west than expected from the results shown, it would be particularly high in Greece and Hungary, as well as Cyprus, Estonia, Ireland, Luxemburg and Slovakia.

Population density and the proportion of green/blue urban areas provide a reasonable initial estimate of urban heat island potential at the city level and can also serve as a European overview of potential hotspots (Figure 4.13).

A liveable compact city

Urban expansion is often perceived as a pathway to a better quality of life and other benefits arising from more green places to live. However, the preference for peri-urban areas as places to live leads to urban sprawl and deterioration and fragmentation of natural areas and loss of ecosystem services (EEA, 2006a). In contrast, compact cities with a high population density can also contribute to urban sprawl if the living conditions in the inner cities are unfavourable, e.g. noisy and polluted (Pflieger et al., 2009).

Figure 4.13 Percentage of green and blue urban areas — proportion of cities in each class by country



Source: EEA, 2012.

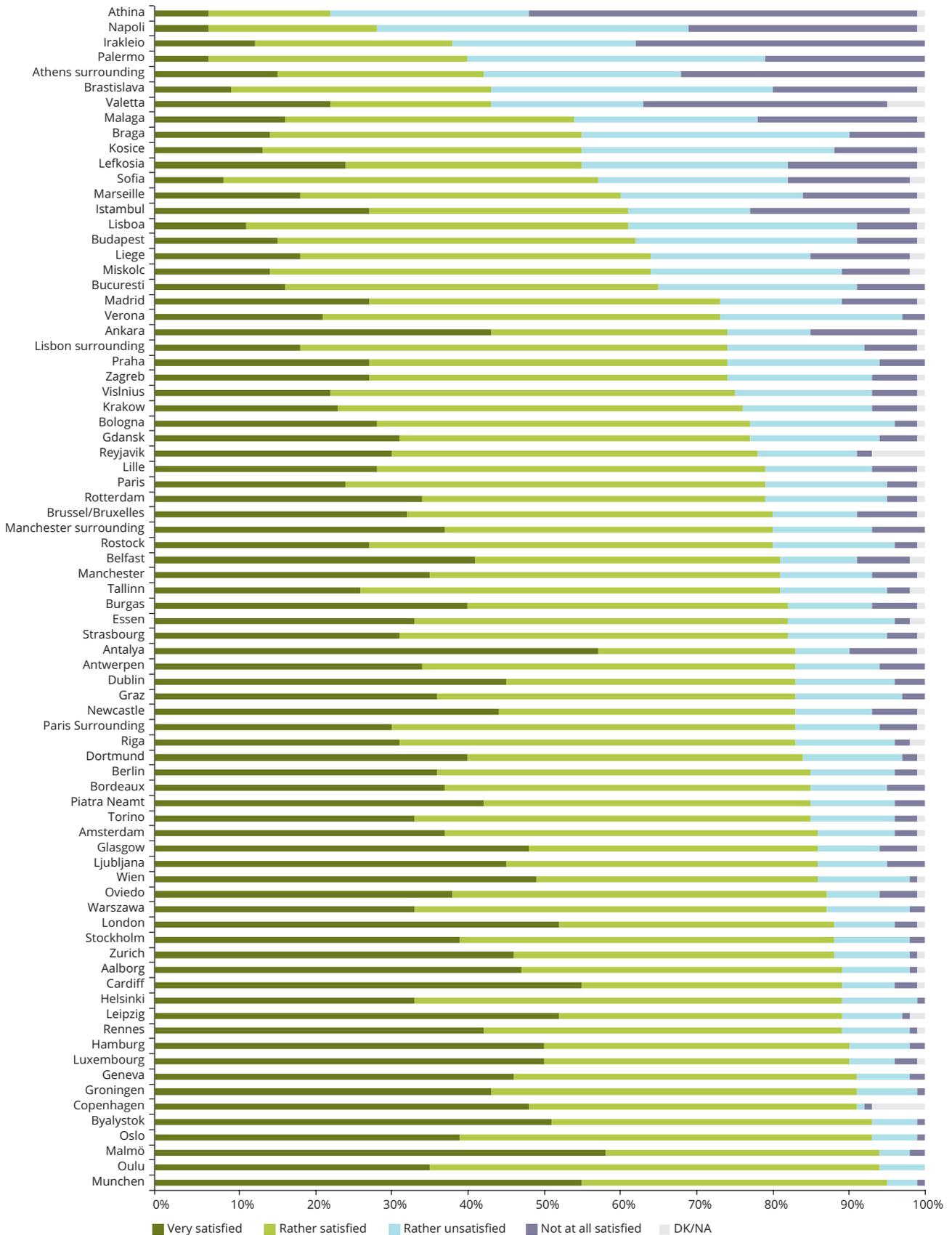
City residents need green open spaces of different sizes from nearby pocket gardens for daily use to large urban or peri-urban parks for a weekend use. This is crucial for their quality of life and health. The travelling time to open green areas needs to be taken into account in the planning process. Generally, people want nature nearby and easily accessed. They want to walk or cycle and will do so on a regular basis only if the urban park is really located in their vicinity. For example, Natural England's *Accessible natural greenspace guidance* proposes a tool to ensure sufficient green space (Natural England, 2010).

Between 2000 and 2006, green space provision per capita increased in both growing and shrinking cities in western and southern Europe, while it decreased in

eastern Europe (Kabisch and Haase, 2013). It is lower in cities with greater population densities (Fuller and Gaston, 2009). Proportional green space coverage in cities increased with increasing latitude. The lowest provision is in the south and east of Europe, increasing to the north and north-west (Fuller and Gaston, 2009).

A perception survey in 79 European cities (TNS Political & Social et al., 2013) shows that cleanliness, green spaces and public spaces, such as markets, squares and pedestrian zones, as well a feeling of safety, are the features that are most highly correlated with overall satisfaction with living in a city (Figure 4.14). Satisfaction with green spaces was generally high. In 61 cities the level of satisfaction was at least 70%, and it was greater than 80% in 45 cities. The highest levels of satisfaction

Figure 4.14 Satisfaction with green spaces



Source: TNS Political & Social et al., 2013.

Box 4.12 Green roofs reduce the demand for energy

Soil and plants forming green roofs act as an insulating cover for buildings. The study by Ascione et al. (2013) focused on the technical and economic feasibility of using green roofs to save energy in buildings: it compared the energy requirements of buildings with green roofs of different vegetation types, with traditional roofs, and with roofs with a highly reflective coating (cool roofs). This study was undertaken in different European cities (Tenerife, Seville and Rome for warm cities and Amsterdam, London and Oslo for cooler ones) to cover a wide range of weather conditions.

Results indicate that green roofs reduced buildings' demand for energy compared with traditional roofs, especially in summer. Savings were up to 11% in warmer cities, with lower values (up to 7%) in the cooler ones. However, it should be noted that in warm weather cool roof coatings performed better in general.

Source: Ascione et al., 2013.

with city green spaces were in Munich, Oulu and Malmö. A majority expressed dissatisfaction in seven cities and districts: Athens, Naples, Irakleio, Palermo, Athens surroundings, Bratislava and Valletta.

3.5.4 Compactness and land use

The most obvious effect of compact cities is the reduced need for urban land. The general trend in Europe, as in the rest of the world (Angel et al., 2011), is still an ongoing dispersion of urban land. Although the population is becoming concentrated in metropolitan areas, urban land in these areas is growing at proportionally higher rates (Figure 4.4.15). Between 1990 and 2006 Europe's population grew by 7%, while over the same period the urban area grew by 37% (Fertner, 2012). Land is less efficiently used than previously: we are consuming more and more land per capita.

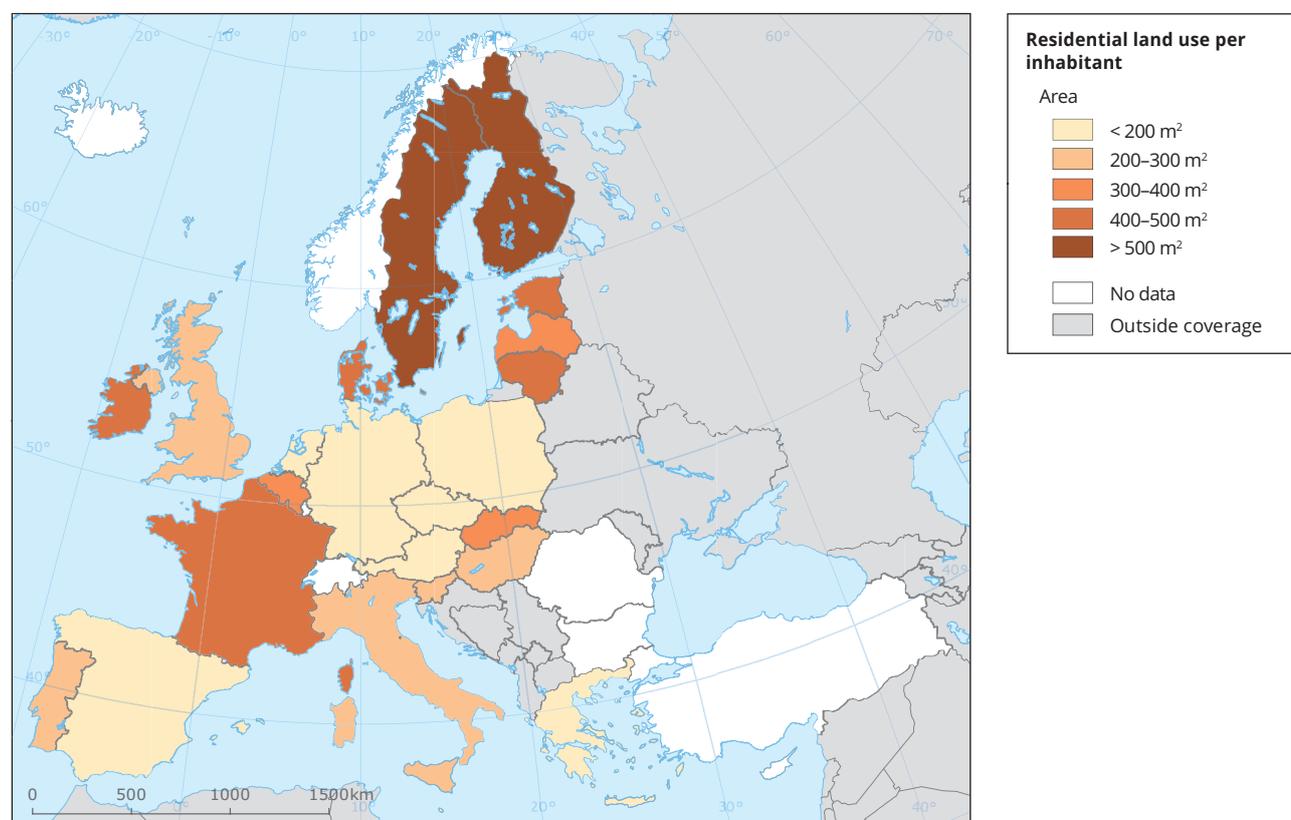
Consequently, an important issue is what kind of land gets urbanised. Cities are typically located in areas with the most fertile soils. Most of the land being converted to urban areas is agricultural land (EEA, 2006b). Urban growth therefore directly affects urban-rural relationships (e.g. the local provision of food or resources).

Higher densities of dwellings, jobs or other activities reduce the (relative) need for new urban land. The decoupling of land consumption from 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 greater recreational potential.

Saving land from urbanisation can be the result of geographical limitations (e.g. cities constrained in a valley or limited by available water) but also of policies on urban development. In the European context there are ambitions to manage spatial development at all policy levels, from the structural and territorial cohesion policies at the EU level to the national, regional and local levels. The first urban growth management policies go as far back as 1900, when the first green belts were designated in the United Kingdom (Ali, 2008), following the garden city movement, and initiatives were taken to preserve green areas around major European cities (Konijnendijk, 2010). Today some variety of growth management is part of the 'standard mode of operation' in spatial planning. There are, however, large national and regional differences across Europe regarding competences, administrative delineations, systems and public interests. However, the need to control urban sprawl is widely accepted. With the exception of a few cities, sprawl remains a challenge in Europe (EEA, 2006a).

Building density is related not only to land consumption but also to general energy consumption. Theoretical calculations show clearly, everything else being equal, that 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, so there are also implications for the urban scale. Regarding energy for transport and heating, Box 4.13 and Table 5.6 present some evidence.

Figure 4.15 Residential land (m²) per inhabitant in 2009 in Europe

Source: Eurostat/LUCAS.

Box 4.13 A life cycle energy analysis of residential development in the Greater Dublin Area

The study estimates total carbon dioxide equivalent (CO₂) emissions from residential developments in the Greater Dublin Area constructed between 1997 and 2006. The emissions are estimated using a life cycle assessment approach over a 100-year building lifespan and employing process, input-output and hybrid energy techniques. Life cycle stages include construction, operation, transport, maintenance and demolition.

Per capita CO₂ life cycle emissions in the Great Dublin Area were found to be approximately 50–55% greater in the exurbs and commuter towns than in the city centre. Of the five life cycle stages studied, operational energy requirements (predominantly space heating and hot water, but including power) contributed most significantly to emissions (68%), followed by transport (17%), construction (9%) and maintenance/renovation (6%).

Operating emissions from dwellings in the commuter towns and exurbs were almost twice those in the city centre as a result of both larger dwelling sizes and the predominance of detached and semi-detached dwellings (with large areas of exposed wall) in the former and the prevalence of smaller apartments in the latter. Car use was most pronounced in the zones furthest from the city centre where per capita emissions were almost twice those of residents in the city centre. Despite their smaller size, the per capita construction CO₂ emissions of apartments were approximately one-third greater than those of low-rise dwellings owing to the greater energy intensity of the structure. However, this difference was more than compensated for by the significantly lower operational emissions.

This study supports policies aimed at curbing CO₂ emissions from the domestic sector that focus primarily on reducing operational emissions from new and existing housing through design and construction improvements. However, it demonstrates that significant reductions in operational emissions are associated with high-density residential development with modest floor areas. Furthermore, it highlights the scope for reducing transport emissions through better spatial planning leading to reduced car travel.

Source: Duffy, 2009.

4.5.5 Compactness and mobility

Another main argument for compact cities is the reduction in energy used (especially fossil fuels) for transport. Compact cities can reduce the travelling distances by supporting mixed use development in neighbourhoods, thereby shortening distances between different activities. Furthermore, compact cities also allow a more sustainable modal split, favouring 'green' modes of transport. Highly attractive public transport systems such as metro lines work efficiently only in areas with a minimum density of attractions (households, jobs). So energy use is reduced through reducing the length of journeys and adopting more energy-efficient modes of transport.

Empirical studies show that there is a correlation between urban form and transport behaviour. The most famous study on this topic was by Newman and Kenworthy in 1989 and showed a relation between population density in cities and gasoline consumption per capita (Newman and Kenworthy, 1989). However, the study was criticised for methodological flaws. The main difficulty is comparing cities across different contexts and regulatory conditions (Minx et al., 2013). It is impossible to control people's real travelling preferences and, for example, a person who likes to cycle will choose to live in an area where this is possible. Another concern is whether or not the correct elements of the urban structure are represented in empirical studies. For example, available parking space is very crucial to the choice of transport mode, but it is seldom included in empirical studies. This can make quite a difference in both older and newer compact urban developments.

However, other studies focusing on single cases or cases within a similar context have come to conclusions similar to Newman and Kenworthy's. It has been found that per capita vehicle miles of travel (VMT), energy consumption (in British thermal units: BTU) and vehicle emissions are inversely related to population density in metropolitan areas in the United States (Clark, 2013). A study from the United Kingdom 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' (Stead, 2001). An in-depth study 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 (Naess, 2006). Another study showed that urban structural variables influence travel behaviour, even in a small town of around 30 000 inhabitants (Naess and Jensen, 2004). At the micro-scale and the neighbourhood scale, another

study showed that high population and employment densities are positively related to the use of public transport (Schwanen et al., 2002).

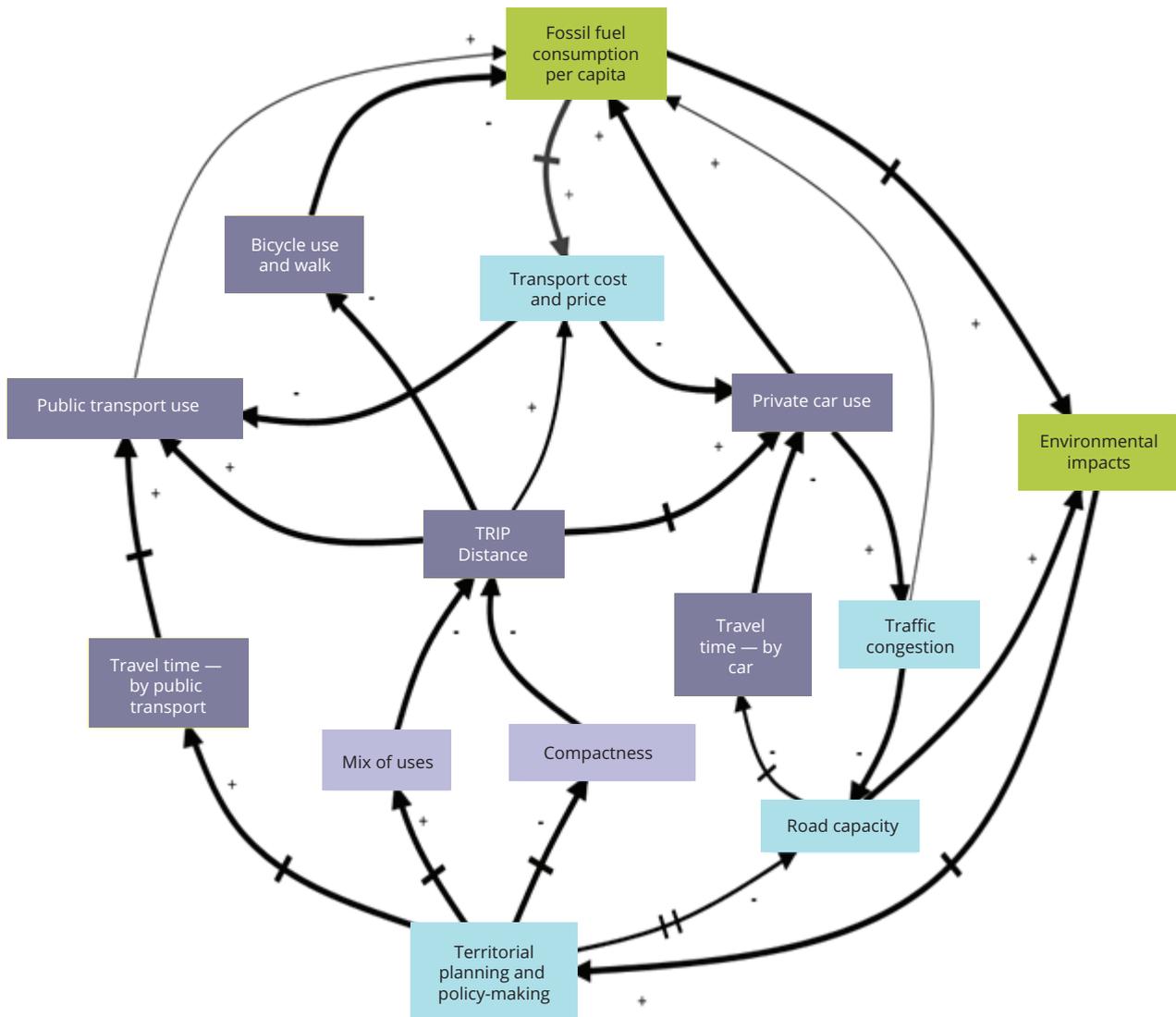
4.5.6 The causal loop of urban transport

Many inter-related variables can affect traffic in urban areas. Even when there is a strong correlation between factors such as population density and transport use, it is difficult to demonstrate definitively the causal relation between such factors. There is not a single factor that would explain, even partially, why transport is more efficient in one city than another or why some metropolitan areas have better air quality. Many factors are relevant to explain the broad range of situations: mixed land use, availability of a good public transport network, efficiency of vehicles, behaviour of citizens.

In general, concerning mobility and compactness, the following can be said (see also Figure 4.16):

- *Low densities* generate greater traffic, in particular road traffic, and demand for the development of transport infrastructure, although a large number of socio-economic (e.g. type of activities) factors influence travel patterns too. High densities discourage single-occupancy cars only if alternative modes of transport are available.
- *Cost of public transport*: High population densities tend to reduce the costs of public transport because of the economy of scale and the large number of people using public transport.
- *Compactness and urban size* determine the maximum distance for commuting from home to work (at least, for movements within the city). The trip distance for commuting decreases as compactness increases, and this relation is strengthened by mixed use developments. The further away from the central city someone lives or works, the greater the chances that they will drive to get around. Conversely, compactness and centrality increase the chance that residents will walk to work (Bento et al., 2003).
- *Mix of land use and planning*: Employment and residential areas need to be efficiently distributed at the functional or metropolitan level in order to improve the use of public transport, cycling and walking and limiting land used for parking. With a good balance of land uses (including residential, commercial, industrial, educational) the population is not forced to move far for daily work and life. Locating employment near a station increases the use of public transport for commuting, decreases

Figure 4.16 The effect of urban morphology on the energy consumed in commuting



Source: EEA/ETCSIA — author's compilation using Consideo iMODELER.

the use of cars and reduces parking requirements at centres of employment. Conversely, locating employment clusters near a rapid transit network increases the use of cars (Trans Link, 2010).

- *Trip distance* is a key factor influencing commuters' choice of mode of transport. For the shortest distances, commuters prefer to walk or cycle. When the distance increases, they prefer cycling and public transport (metro, bus or train). For longer distances, private cars or public transport (bus or train) are most often used. In Barcelona, 57% of the total journeys with their origin and destination in the city are made by walking or cycling, while travel to the metropolitan regions is

mainly by public transport (51%) or private vehicles (44%) (Autoritat del Transport Metropolità, 2012).

- *Travel time*: Generally, commuters estimate accessibility in terms of travel time rather than by distance. Commuters spend a certain amount of time on their daily movement, and this travel time is relatively stable (around 30 minutes). Therefore, when accessibility is facilitated, commuters can choose between travelling the same distance in less time and travelling a greater distance in the same time (Miralles-Guasch, 2008). From 1990 to 2000, the time spent on commuting trips decreased slightly from 22.5 to 21.9 minutes in the region of Barcelona (Giner, 2002). For car drivers,

average trip duration ranges from 25 minutes in France and Italy to nearly 35 minutes in Poland (JRC, 2012b). Travel time by car is mainly affected by road capacity. A reduction in road capacity acts as a disincentive to urban sprawl, and, conversely, a higher road capacity can generate a 'rebound effect' (Filcak et al., 2013).

- *Walking distance:* Accessibility is different for each mode of transport. For example, some destinations

are more accessible by car than by walking. Current planning practice recommends a 400- to 800-metre radius as the pedestrian catchment area for transit services (Canepa, 2007). For local stop transit services, a 400-metre pedestrian catchment area is often used, representing a 5-minute walk. For rapid transit, people accept that they will have to walk farther. An 800-metre pedestrian catchment area is generally used, representing a 10-minute walk.

Box 4.14 Causal loop ⁽⁵¹⁾ to simulate interactions in a complex environment

A causal loop diagram is a visual model to summarise the interactions between different variables that determine the dynamics in a system. The diagram consists of a set of variables connected by causal links describing the causes of change. Sentences are constructed by linking together key variables and indicating the causal relationships between factors and the effects that they have on each other. Variables must be able to increase or decrease over time.

A coherent story about a particular problem or issue can be created (Kim, 1992). The analysis of a model can show counter-intuitive cause-and-effect chains and non-linear developments that are a result of feedback loops. Potential risks and promising measures can be identified — which perhaps no expert would have come up with (Neumann, 2011).

Causal links characterise the effect of one variable over another by:

- *A polarity:* A positive causal link describes two variables that change in the same direction (for example, a decrease in 'private car use' leads to a decrease in 'traffic congestion'). On the contrary, a negative polarity describes a relation between variables that change in the opposite direction (for example, the increase in teleworking, teleconferencing and online shopping reduce the need for individual journeys and therefore there is a decrease in fossil fuel consumption per capita).
- *A delay* (an effect in the short, medium or long term): A different time span before the effect is perceived is attributed to each relation. For instance, an increase in 'road capacity' implies an increase in 'land uptake'. The effect of this enlargement in road capacity is perceived on the converted land in the short term. However, the effect on public transport can be longer.
- *A strength* (high, medium or low impact): The causal relation between two variables may have different degrees of impact. For example, increased access to public transport has a strong effect on the split between different modes of transport.

Analysing the diagram requires closed feedback loops to be identified, as they determine the patterns of behaviour:

- *A reinforcing feedback loop* is a closed cycle that propagates the variation maximising the effect through the cycle. An example is the positive effect of public participation in motivating management to tackle urban sprawl.
- *A balancing feedback loop* is a closed cycle in which the effect of a variation in any variable propagates through the loop and returns to the variable a change opposite to the initial one (Zhou, 2012). A balancing loop seeks a goal, it provides stability and reduces the effect of fluctuation, but it can also present resistance against needed changes (Kirkwood, 1998). The effect of traffic jams on discouraging the use of private vehicles is an example of a balancing feedback loop.

Source: ETC/SIA, 2014.

⁽⁵¹⁾ Causal loop diagrams were developed using the Consideo Modeler. This is a tool that can be used to visualise and analyse the cause-and-effect relationships that exist in any complex situation within business, politics or science. It can be used to facilitate planning, decision-making and communication. Based on references and expert judgement, the strength of connections is characterised using weighting values for 'weak' — 10 (thin line), 'middle' — 17 and 'strong' — 25 (thick line). Adding the type of connection (with positive or negative impact) and the time scale of influence (short term, medium term — one crossing line on the link — or long term — two crossing lines on the link) allows some immediate measures (based on the positive factors) and the risks (starting with the negative factors) to be identified.

- Fuel cost:* Higher fuel costs act as a barrier to urban sprawl. A study of different Mediterranean regions in Spain shows that an increase of 1% in the price of fuel generates a decrease of 0.733% in the proportion of newly built single-family houses (Ortuño-Padilla and Fernández-Aracil, 2013). The same study concluded that an increase of 1% in the price of fuel generates an increase of 1.8% in urban compact areas. In both cases, fuel price will influence fuel consumption by limiting it.

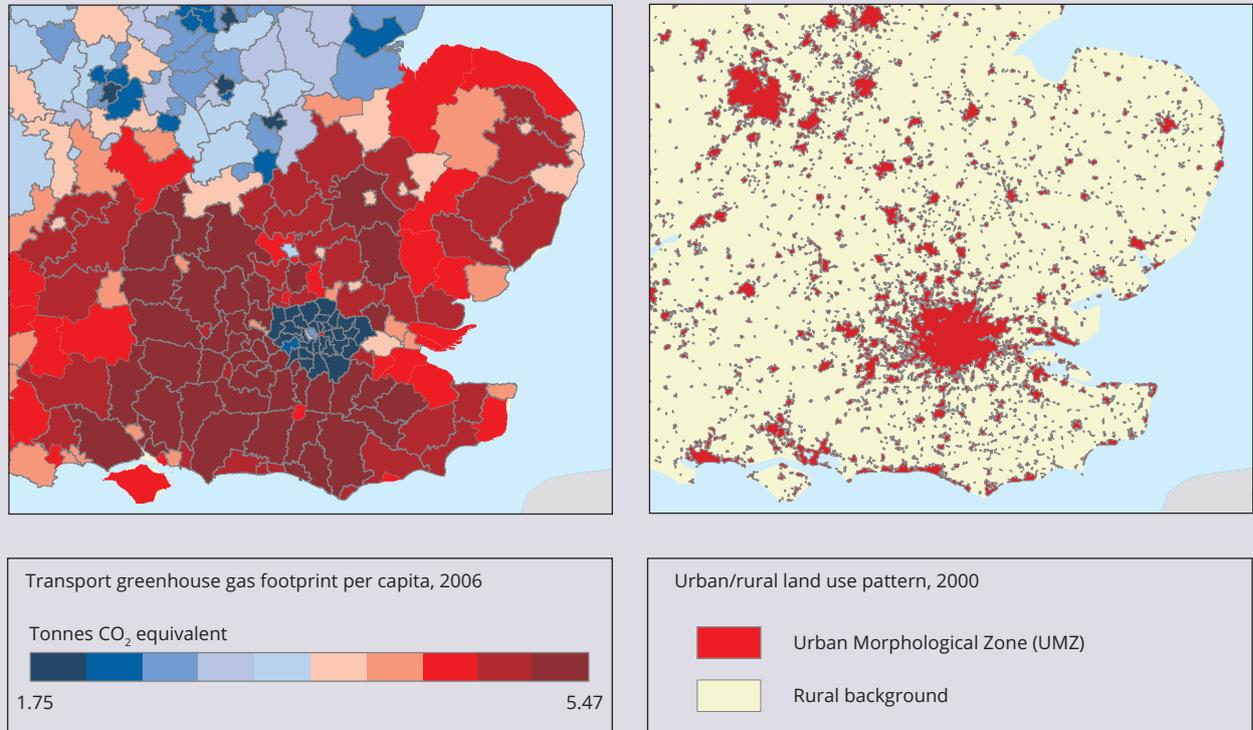
Table 4.6 Positive and negative effects of urban density on energy consumption

	Positive effects	Negative effects
Transport	<p>Increases the cost-effectiveness of public transport</p> <p>Encourages the use of public transport at the expense of using private cars</p> <p>Facilitates the use of non-motorised transport (walking and biking)</p> <p>Reduces the length of trips taken</p> <p>Reduces time spent using transport on a daily basis therefore also reducing stress</p>	<p>Without adequate measures and policies, risk of congestion in urban areas that reduces the fuel efficiency of vehicles and increases pollution and noise nuisance</p>
Infrastructure	<p>Reduces street length and the material and energy needed to construct streets and roads</p> <p>Reduces need for, and cost of maintenance</p> <p>Shortens the length of infrastructure facilities such as water supply and sewage lines, reducing the energy needed for pumping, and the maintenance needs</p>	
Vertical transport		<p>Increases the need for electricity for lift in high-rise buildings</p>
Ventilation	<p>Street grid orientated in the direction of the wind facilitates the movement of air, the decrease of temperature and the dispersion the pollutants emitted by vehicles</p>	<p>A concentration of large and bulky high-rise buildings blocks with very limited open spaces in between leads to lower permeability for urban air ventilation, in particular at the pedestrian level</p>
Thermal performance	<p>Compared to detached houses (frequent in low density urban areas) or high rise buildings, heat losses for multi-storey buildings are reduced given the smaller external surface</p> <p>Shading among buildings could reduce the solar exposure of buildings during the summer period resulting in a decrease in the demand for cooling</p>	
Urban heat islands	<p>Green areas and green roofs contribute to decrease the urban temperature</p> <p>Adequate street orientation may increase potential for shade and decrease the level of insolation received by building and impervious areas</p>	<p>Urbanization with high share of built-up land and impervious areas are factors increasing heat impacts and the need for air conditioning</p>
Energy systems	<p>District cooling and heating systems are more feasible and cost-efficient in high density urban areas</p>	
Natural lighting		<p>Potential for natural lighting is reduced in high-density areas resulting in an increasing need for electric lighting</p>
Use of solar energy	<p>The potential for solar energy can be increased by the adequate orientation of roofs</p>	<p>Roofs and exposed areas for the collection of solar energy are limited</p>

Source: Adapted from Hui, Sam, 2001.

Box 4.15 Differential greenhouse gas footprints for transport and housing

Figure 4.17 Greenhouse gas footprints per capita for transport and housing in United Kingdom local authorities



Sources: Stockholm Environment Institute, 2009; footprints Corine Land Cover, 2006; EEA, 2009..
Source: SEI, 2009; EEA, 2000e; EEA,2010d.

The main carbon-relevant differences between urban and rural areas in most developed countries can be traced back to two areas where cities have specific functions — transport and housing. Most city residents have shorter distances to travel to work, and urban housing is normally more efficient in terms of energy consumption. The population density in cities means shorter journeys to work and access services, greater use of walking, cycling or public transport, and living in apartments in multi-family blocks requiring less heating and less ground space per person. As a result, urban dwellers on average consume less energy and land for living per capita than rural residents. However, not all cities and their corresponding metropolitan areas have the same patterns. A good example is the high impact of transport around London in contrast to the pocket of low footprint in the city centre itself.

4.5.7 Compactness and water consumption

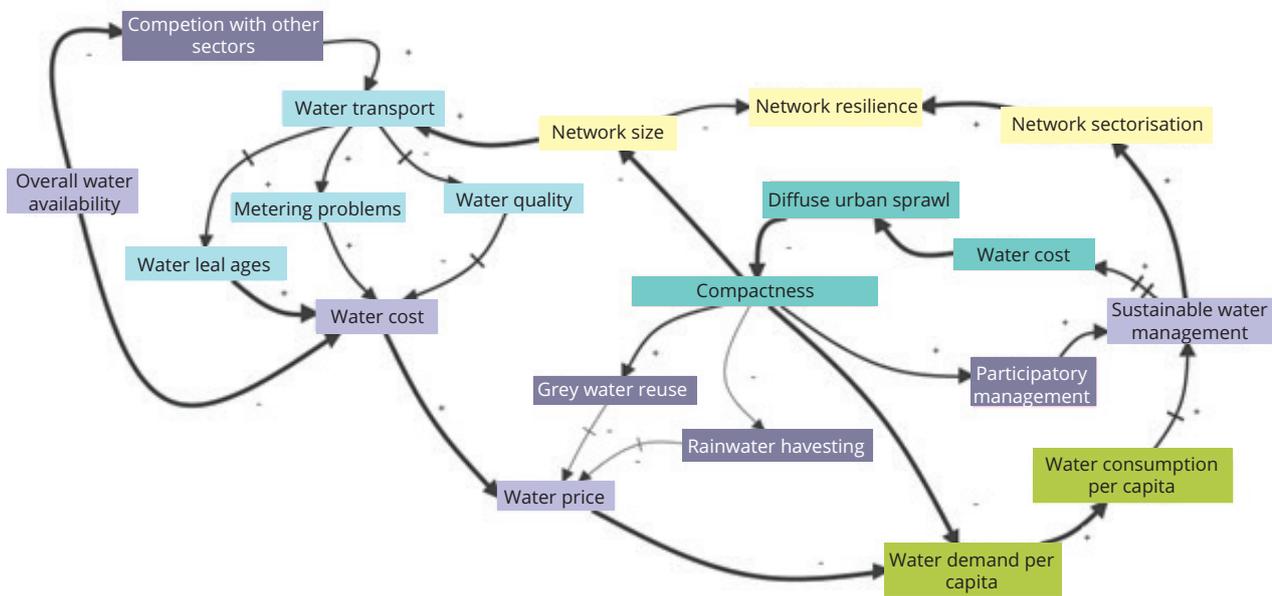
The water supply network is smaller in a compact city compared with that in a diffuse city (see Figure 4.18). Therefore, the transport of water requires less energy, less water is lost through leakages and management is easier. Reducing the size of the supply network decreases the cost of production, and therefore the final price of water (but lower prices could cause a 'rebound effect' and the risk of the demand for water increasing).

Generally, diffuse residential developments increase water demand and consumption (see Figure 4.19).

The type of housing in a compact city differs from that in diffuse urban areas, where private gardens and swimming pools demand much more water (Domene and Sauri, 2006). In addition, some water-saving measures, such as reusing grey water, can be much more easily implemented in building blocks than in individual homes in a diffuse residential area.

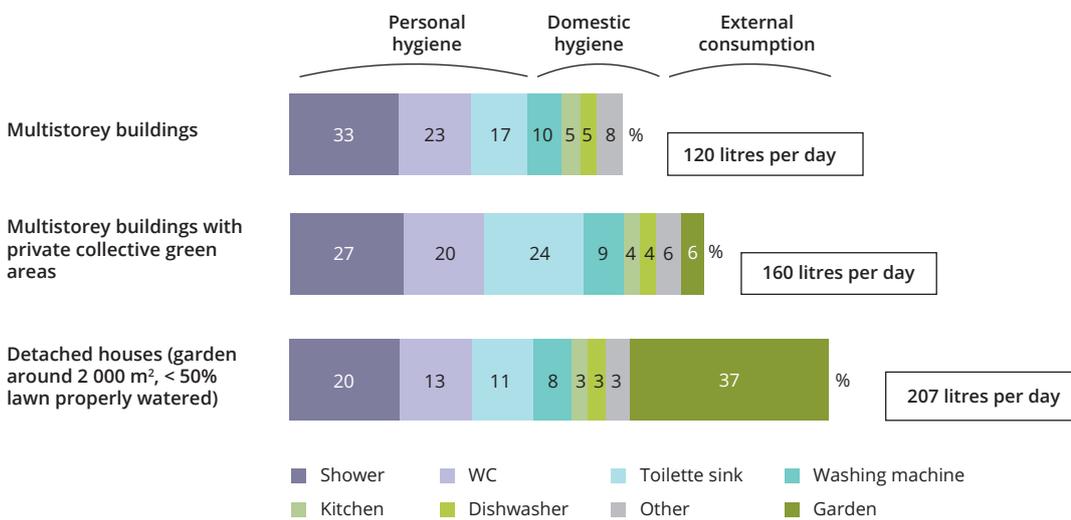
The cost of water is very effective in discouraging inefficient use of water. The factors relating to the efficiency of the water network (e.g. land planning, water leakages, metering) have weaker effects and act in the long run.

Figure 4.18 The consequences of urban compactness for the water system in terms of demand, transport, use and reuse



Source: EEA — ETC/SIA.

Figure 4.19 Distribution of water consumption by household type in the Barcelona metropolitan area



Source: Saurí and March, 2007.

4.5.8 Compactness and heating/cooling

Spatial structure and the urban form have a considerable influence on the heating and cooling of buildings. In climates where heating is required, the energy demand for heating increases by between 17% and 25% for site densities between 30% and 60%. For a given urban site, compact, multi-family apartment blocks provide the lowest carbon dioxide emissions per capita (Tereci et al., 2013).

Large-scale heating and cooling systems play an important role in some countries. Often combined with combined heat and power plants, these systems are feasible only at particular minimum densities because of the high infrastructure costs. Furthermore, because of the high energy losses in transit, the low-grade energy (i.e. heat) has to be produced close to the users. In addition, efficient district heating/cooling systems need a mixed user structure, which requires both low-grade energy (heat, hot water and steam) and electricity (OECD, 1995). This could be different types of industry, hospitals, hotels and residential areas, having not only different demands for the type of energy but also different patterns of daily use, helping to reduce peaks in demand in the system.

Regarding resource consumption, an important issue in district heating is the handling and conversion of energy. The introduction of combined heat and power is often linked to a switch from high-quality fuels to lower quality fuels, such as coal and biomass (OECD, 1995).

Another issue of heating/cooling and the urban form is the general layout and orientation of buildings, influencing their heating/cooling demand. It has been found that compact urban development on the neighbourhood/building scale saves energy for heating and cooling in single buildings, mainly through shading and insulation effects and resulting in changes in the microclimate (Futcher et al., 2013). Beyond local climate conditions, the types of buildings and way in which they are grouped are the most important spatial planning factors related to heating.

4.5.9 Compactness and infrastructure costs

Particular types of infrastructure need a minimum density of activities/users, for example high-level public transport or district heating systems. However, infrastructure investment and maintenance costs per person may also be cheaper in compact cities. This also applies to social infrastructure (schools) because they are more easily accessible and their catchment areas include more potential users. The hypothesis is that

urban infrastructure can be used more efficiently in compact cities, especially if different users (households, different kinds of service and manufacturing companies) are within the catchment area, avoiding a one-sided use of the infrastructure.

'A city four times denser consumes four times less land and sixteen times less network infrastructure.' (Salat and Bourdic, 2012). Empirical evidence is, however, difficult to establish, as there are many other factors influencing the costs of infrastructure

4.5.10 Compactness and waste generation

Waste collection services are one of the most visible responsibilities that local authorities face. The provision of these services is crucial to increasing recycling (i.e. increasing the separate collection of recyclable wastes) and to facilitating the better handling of waste. Providing waste collection depends on the context, in particular the urban pattern (urban tissue, type of buildings, density, width of the streets) and the infrastructural and socio-economic conditions in which the service is provided (Timlett and Williams, 2011).

The type of buildings served and the density of both residential and other municipal waste generators within a service or administrative area (principally commercial waste), together with the surrounding infrastructure, are important factors that help define both the types of service offered and the potential success of different services.

There are differences in providing waste services to multi-family housing, single-family housing and, where possible, specific commercial enterprises (e.g. food waste from the catering industry). Different types of building generate different types of waste (e.g. garden waste in particular is predominantly produced by houses rather than in apartments):

- *In multi-family dwellings*, the capacity for waste collection systems is determined by the capacity for storing the different materials in the building.
- *Single-family dwellings*, which are lower density housing than multi-family dwellings, generate slightly different (and often more) waste than multi-family dwellings. The primary additional waste type is garden waste. Home composting can be used to largely avoid this entering the waste management system.
- *Detached, semi-detached and terraced houses* in residential areas generally receive a kerbside recycling collection system. Local authorities

offer this service, as participation and capture of materials are higher in these schemes than in centralised or communal schemes for this type of resident, because it is more convenient for the householder (Williams, 2013). Such houses have space to store materials in different containers.

Some specific solutions adapted to the urban tissue have to be developed when there is little public space available for waste facilities, either owing to physical limitations (such as narrow streets in the historic part of a city) or for development reasons (regeneration of urban centres).

4.5.11 Trade-off

The spatial structure has some influence on resource use, as described above. However, for a number of resources, spatial structure and urban form play only a minor role. This includes in particular consumption and behaviour patterns related to lifestyle and economic wealth, such as use of consumer goods per person (including the resources used for their production) or the consumption of electricity by household appliances.

Some resources might be indirectly connected to the urban form but are not elaborated further in this text (e.g. production of food). Compact urban development as, for example in the form of urban growth management, might ease the development pressure on agriculture and foster local production of food. However, dense urban structures might also make it difficult to grow food on a small scale in the city because of spatial limitations and shading effects. Urban farming might compensate for that.

Integrated urban planning to achieve compactness has to be accompanied by housing and employment measures to guarantee a balanced mix of uses, and to avoid undesirable drawbacks such as the lack of urban green space, overcrowded neighbourhoods or expensive housing. Compact city development has a positive effect on reducing the energy used by transport. However, other factors should be considered, as they might be more significant for resource use (e.g. social background for travel behaviour) (Echenique et al., 2013).

There are a number of trade-offs regarding compact city development and resource use that are not fully explored and subject to concrete planning measures because of their local complexity, such as the potential increase in energy required for air conditioning in densely built-up areas because of the heat island effect, the high cost of infrastructure construction because of the dense and complex urban pattern (e.g. building a metro underground rather than on the surface), etc.

However, there is, with adequate planning, more complementarity than there is conflict between compact development at the city (transport) level and at the building (mainly heating) level (Næss, 2004; Næss, 2006). Despite the benefits in terms of resource use, there are trade-offs regarding social constraints with compact cities. This includes housing affordability (Clark, 2013) and also issues related to quality of life, such as traditional, local environmental qualities, that raise questions about our ability to develop compact cities without destroying valuable natural or cultural heritage (Næss, 1997). Strategies often applied to deal with those 'sustainability trade-offs' include urban renewal, limitations on car use, mixed land use and life cycle residential strategies (Padt, F., Westerink, J., 2012).

The urban form and spatial structure is strongly related to resource use, especially with regard to land use, energy for transport and energy for heating/cooling. However, urban density cannot be the only measure. If the idea of the compact city is to have any effect on resource efficiency (and limit its trade-offs) other elements have to be implemented, such as efficient public transport systems to offer an alternative mode of travel and reduce congestion.

Although the spatial structure of a city changes only very slowly, spatial planning has an important role to play in avoiding the risk of the lock-in effect in future. Buildings and the communication and transport infrastructure, as well as water and sanitation systems, have a long lifetime. Spatial planning therefore has an important role to play in ensuring that we are prepared for changes in energy use (Næss, 1997). Therefore, although we implement some behavioural measures (e.g. price incentives) that have an immediate effect, the physical structures have to be included from the start, even though (or because!) they cannot be changed quickly.

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