Co-financed by the European Regional Development Fund

SUPER – Sustainable Urbanisation and Land Use Practices in European Regions

Applied Research

Annex 4 – Sustainability assessment and scenarios

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This applied research activity is conducted within the framework of the ESPON 2020 Cooperation Programme.

The ESPON EGTC is the Single Beneficiary of the ESPON 2020 Cooperation Programme. The Single Operation within the programme is implemented by the ESPON EGTC and co-financed by the European Regional Development Fund, the EU Member States and the Partner States, Iceland, Liechtenstein, Norway and Switzerland.

Authors
David Evers (PBL Netherlands Environmental Assessment Agency), Ivana Katuric (URBANEX), Ries van der Wouden (PBL Netherlands Environmental Assessment Agency), Maarten van Schie (PBL Netherlands Environmental Assessment Agency), Frank van Rijn (PBL Netherlands Environmental Assessment Agency)

On the basis of contributions from
Lia van den Broek, Kersten Nabielek, Frank van Rijn, Ries van der Wouden, PBL - Netherlands Environmental Assessment Agency (Netherlands)
Volker Schmidt-Seiwert, Anna Hellings, Regine Binot, Lukas Kiel, supported by Jonathan Terschanski, BBSR - Federal Institute for Research on Building, Urban Affairs and Spatial Development (Germany)
Giancarlo Cotella, Umberto Janin Rivolin, Alys Solly, Erblin Berisha, Donato Casavola, Politecnico di Torino (Italy)
Ivana Katurić, Mario Gregar, Sven Simov, Katarina Pavlek, Ranko Lipovac, URBANEX (Croatia)
Joaquín Farinós-Dasí, Albert Llausàs, Carmen Zornoza-Gallego, University of Valencia (Spain)
Dorota Celinska-Janowicz, Adam Ploszaj, Katarzyna Wojnar, University of Warsaw, Centre for European Regional and Local Studies - EUROREG (Poland)
Mailin Gaupp-Berghausen, Erich Dallhammer, Bernd Schuh, Ursula Mollay, Roland Gaugitsch, Liudmila Slivinskaya, ÖIR GmbH - Austrian Institute for Regional Studies (Austria)
Tristan Claus, University of Ghent (Belgium)

Advisory Group
Project Support Team: Isabelle Loris, Flanders Department of Environment (Belgium), Tamara Slobodova, Ministry of Transport and Construction (Slovakia), Harald Noreik, Ministry of Local Government and Modernisation, (Norway), Frederick-Christoph Richters, Ministry of Energy and Spatial Planning (Luxembourg)
ESPON EGTC: Marjan van Herwijnen (project expert), György Alfoldy (financial expert)

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Contact: info@espon.eu

ISBN: 978-2-919795-39-0

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Version 06/11/2020

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Abbreviations

AESOP	Association of European Schools of Planning
ARTS	ESPON Assessment of Regional and Territorial Sensitivity
BBSR	Bundesinstitut für Bau-, Stadt- und Raumforschung (Federal Institute for Research on Building, Urban Affairs and Spatial Development)
CEMAT	Council of Europe Conference of Ministers Responsible for Spatial/Regional Planning
CLC	Corine Land Cover
COMPASS	ESPON Comparative Analysis of Territorial Governance and Spatial Planning Systems in Europe
EC	European Commission
ECP	ESPON Contact Point
ECTP	European Council of Town Planners
EEA	European Environmental Agency
ERDF	European Regional Development Fund
ESPON	European Territorial Observatory Network
ESPON EGTC	ESPON European Grouping of Territorial Cooperation
EU-LUPA	ESPON European Land Use Patterns
EU	European Union
GVA	Gross Value Added
ISOCARP	International Society of City and Regional Planners
ITI	Integrated Territorial Investments
JRC	EU Joint Research Centre
LCC	(Corine) Land Cover Change
LUE	Land Use Efficiency
MCA	Multi-Criteria Assessment
NUTS	Nomenclature of Territorial Units for Statistics
PBL	Netherlands Environmental Assessment Agency
POLITO	Politecnico di Torino
PCG	Project Coordination Group
SCBA	Societal Cost Benefit Analysis
SDG	Sustainable Development Goal
SPIMA	ESPON Spatial Dynamics and Strategic Planning in Metropolitan Areas
SUPER	ESPON Sustainable Urbanization and Land Use Practices in European Regions
TANGO	ESPON Territorial Approaches for New Governance
TIA	Territorial Impact Assessment

1 Sustainability assessment of modes of urbanization

1.1 Introduction

The phenomenon commonly referred to as ‘urban sprawl’ has existed for a long time. Already during the seventeenth and eighteenth centuries, elites of affluent cities like London and Amsterdam bought land at a comfortable distance from the city to build summer (and sometimes permanent) residences. The construction of railways in the nineteenth century accelerated this process, resulting in the first commuter suburbs (Couch et al. 2007: 11; Hall 2014). However, it would take at least another century before this became the dominant form of urbanization. Car ownership in combination with growing prosperity in the post-war period allowed the suburban ideal to be enjoyed by an increasingly greater number of people in the western world (Bruegmann 2005). Later, alerted by the massive report *The Costs of Sprawl* in the US (RERC 1974) and similar findings in Europe, politicians began to worry about the side effects of uncontrolled urbanization, and looked to spatial planning to manage urban growth.

Today, the policy discourse centres on the concept of sustainability. Especially in Europe, there is a palpable concern that current planning decisions and practices are negatively impacting future generations and undermining long-term economic prosperity, social cohesion and ecological vitality (Hennig et al. 2015; Jehling et al. 2018). Despite the plethora of studies on the impacts of various kinds of urban development over the past decades, few scholars have attempted to systematically compare the sustainability of different urbanization modes. One exception is Jabareen (2006) who proposed a methodology to measure the sustainability of four contemporary urban planning concepts (i.e. neo-traditionalist, compact city, urban containment and ecocity). In this document, we build on his approach by widening and simplifying the concepts considered (for analytical clarity) and, rather than only considering environmental sustainability, applying the multidimensional definition of sustainability outlined in the Inception Report (ESPON 2019).[1]

1.2 Three modes of urbanization

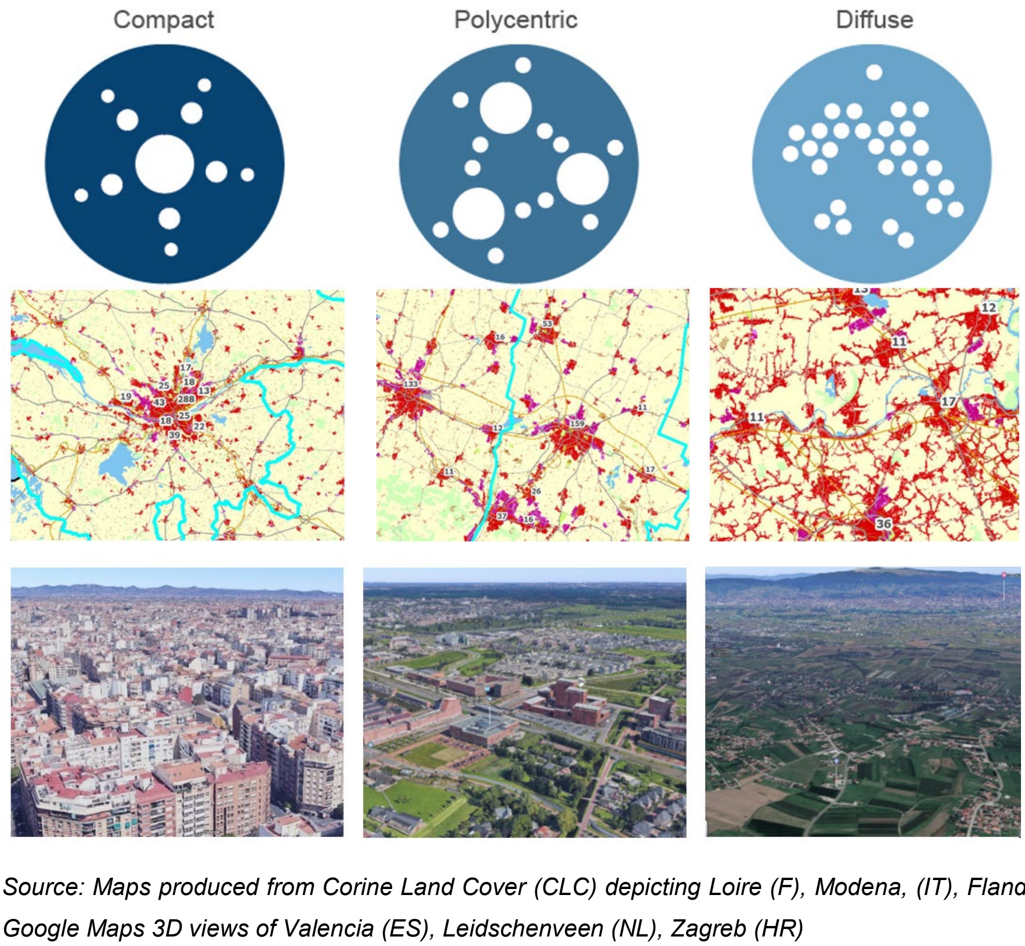
Sometimes a false dichotomy is invoked between interventionist urban-containment policies that severely restrict urban growth, preferably with ‘zero land take’, and an implicit choice for ‘urban sprawl’ by taking a laissez-faire approach to urban development. The reality is far more complex. In addition to the culturally embedded suburban ideal of owning a house with a garden and two-car garage (Jackson, 1985; Fishman 1987), modern spatial planning was confronted with changing demographics within the cities themselves such as a growing use of residential space by their inhabitants. A century ago, an average of 4.5 people lived in every house in Amsterdam, but by the end of the 20th Century this was less than 2 (Wintershoven 2000: 128-129). This made it difficult if not impossible to accommodate growing housing demand within the existing urban fabric. Because of these tendencies, new strategies were invented to direct urbanization to balance individual desires for space (including

[1] The categories of Jabareen proved insufficiently distinctive as regards urban morphology to be useful for our purposes. For example, the ecocity mainly non-spatial elements such as green roofs and solar panels and could conceivably fit all urbanization modes. Similarly, we found the overlap between compact city and urban containment to be too great to be useful as distinct categories; in this project we use these terms interchangeably.

businesses) and the public interest (preservation of valuable cropland, natural habitats, support for public services and infrastructure). This resulted in the production of a variety of urbanization models and planning neologisms such as self-sufficient growth centres or garden cities, satellite towns and green belts, or finger-shaped urban extensions. These strategies were later adapted as their side-effects became apparent. For example, new towns created in the 1970s and 1980s increased traffic congestion in the UK and Netherlands, prompting a move towards transit-oriented development in more recent years (Cervero 1998).

To escape the binary world of ‘zero land take’ versus ‘urban sprawl’, avoiding the normative meanings of these two terms, and doing justice to the real world of spatial planning, we discern three archetypical modes of urbanization: *compact urbanization* (i.e. high-density compact cities with land-take close to zero, often the result of urban containment strategies or geographical limitations), *polycentric urbanization* (i.e. clustered, medium-density urbanization usually resulting from spatial development policies like new towns, smart growth, TOD, some new urbanist designs, etc.) and *diffuse urbanization* (i.e. low-density scattered urban development like monofunctional car-oriented suburbs, ribbon development and exurban, often informal, construction). Other urbanization modes certainly exist, but we concentrate on these three for the sake of analytic clarity. For the same reason, even though we acknowledge that these modes are not mutually exclusive and can be combined in practice, we evaluate them separately.

Figure 1.1: compact, polycentric and diffuse urban form illustrated



Source: Maps produced from Corine Land Cover (CLC) depicting Loire (F), Modena, (IT), Flanders (BE); Photos: Google Maps 3D views of Valencia (ES), Leidschenveen (NL), Zagreb (HR)

The three modes of urbanization have variegated impacts on sustainability. Based upon an extensive literature review of North American[2] and European sources, we have estimated the various effects on sustainability (the economic, ecological and social dimensions of sustainability). The findings of the literature review are presented in full in the Table *Modes of urbanization and aspects of sustainability*, including references to the source material. The table also provides an expert-judgement estimation of the net impact for each sustainability indicator based on the reviewed literature (on a Likert scale indicated by - - to + +). For the sake of readability, Table 1.1 presents the findings of this literature review in a synthetic way, omitting the references and averaging out the weights for each indicator (+/- usually means conflicting findings between studies). This is later explained in the following sections.

Table 1.1 modes of urbanization and aspects of sustainability (summary)

	Compact	Polycentric	Diffuse
Economic sustainability			
GDP, wealth	+/-	++	+
Public finance	+ +	+	-
Jobs	+ +	++	+/-
Accessibility	+/-	++	+/-
Business areas	++	++	+/-
Housing demand	-	+	+
Transportation costs	+/-	+	- -
Energy consumption	+	+	- -
Ecological sustainability			
Reducing mobility (by car)	+ +	+ +	- -
Reducing pollution, including CO2	+ +	+	- -
Green urban areas	-	+	-/+
Biodiversity	+/-	+/-	--
Land consumption	+	+	- -
Natural hazards	-	+	+/-
Climate change	+/-	+	+/-
Consumption of resources	+/-	+	-
Renewable energy	+/-	+/-	+/-
Space for future water retention	+	+	+
Circular economy	+	+	-
Social sustainability			
Health	+/-	+/-	+/-
Affordable housing	+/-	+/-	+ +
Equity/inclusion	+/-	+	- -
Public and recreational space	+/-	+	+/-
Variety (high-rise, suburban, etc.)	+	+	+
Mixed-use areas	+	++	-
Satisfaction with home environment	+/-	+	+

[2] Although urban form differs between the continents, the richness of impact literature on urban containment and transit-oriented development in North America proved quite helpful in assessing the different aspects of sustainability. Moreover, many of the findings are generic enough to hold in both contexts (e.g. more transit opportunities affecting obesity or containment home prices).

1.3 Compact urbanization/containment

Urban containment is a strategy to achieve a compact urban form. It restricts urban growth to no or virtually no new unbuilt land being converted to urban use. The concept was developed in the 1970s due to rising social and environmental problems related to scattered, uncontrolled and low-density urbanization (Nelson et al. 2007). Urban containment policies are designed to limit urban expansion outside delineated boundaries and encourage infill development and brownfield redevelopment inside the urban area (Nelson et al. 2004). Moreover, urban containment policies attempt to "confront the reasonable development needs of the community, region or state and accommodate them in a manner that preserves public goods, minimises fiscal burdens, minimises adverse interactions between land uses while maximising positive ones, improves the equitable distribution of the benefits of growth, and enhances quality of life" (Nelson et al. 2004: 1). The first and most important strategic way to achieve a compact urban form is the suppression of urban expansion by means of a growth boundary in order to create a compact city structure. Development within the delineated boundary is at moderate to high density. Sometimes the containment of a strong urban boundary is combined with a strategy to allow the expansion of several neighbouring villages (satellites) within their own boundaries. This strategy seeks to retain traditional rural land cover types as agricultural land, forest and grassland as a 'green belt' around the city (Millward 2006).

One of the most comprehensive empirical sources available on the effects of this mode is *The Social Impacts of Urban Containment* by Nelson et al. (2007), which relates to the experience in the United States. This source has been supplemented with others which focus on Europe or adopt an international comparative approach.

1.3.1 Economic sustainability

In an empirical survey of US metropolitan areas[3], Nelson et al. (2007) found a 30% higher net value (not amount) of urban construction under containment regimes, implying positive economic sustainability (p. 107). Other studies argue that this positive relationship is due to agglomeration economies that induce growth of GDP and wealth creation. Companies cluster to decrease transport costs and facilitate communication; proximity also helps create partnerships between companies (Anas et al. 1998; Nelson et al. 2007). Furthermore, clustering produces job opportunities and the development of business areas (OECD 2012). Inner-city brownfield redevelopment has helped to revitalize urban economies in areas like Berlin and Hamburg (Hall 2014). In the US, cities which had adopted containment strategies prior to 1985 demonstrated more construction activity by 1995 than those that had not (Nelson 2007: 117). In addition to improving accessibility through proximity, a compact city structure improves also the density needed for high-quality transport connections (but with a higher risk of traffic congestion because of density). It also contributes to energy efficiency (Norman et al. 2006; OECD 2012). However, Ouestlati et al. (2015) point out that urban containment policies may cause possible restrictions of economic growth: as house prices increase and land for

[3] The US and European concepts of urbanization and sustainable land use are different due to cultural-hitorical dissimilarities. These differences should be considered.

development becomes scarce, individuals and businesses may decide to relocate to areas where more space is available.

1.3.2 Ecological sustainability

Because urban containment reduces the amount of land converted to urban use, it scores, by definition, well on this aspect of *ecological sustainability* (OECD 2012). Nelson et al. (2007) show that these policies were effective in curbing ‘exurban’ development, defined as urbanization which is too diffuse to be viably served by water or sewer infrastructure (p. 49). Recent studies in Australia (Sushinsky et al. 2013) and Japan (Soga et al. 2014) emphasize the positive net effect of preserving large open areas outside the compact-city boundaries on biodiversity, alongside a proven reduction in the number of species inside the city. Development in compact cities often comes at the expense of the remaining urban green areas, for example in Helsinki (Hautamäki 2019). In Amsterdam, three million square metres of green space was lost over the last decade to urban development (Giezen et al. 2018). Moreover, this mode scores worse on indicators like air pollution than diffuse urbanization modes (Glaeser and Kahn 2010). On the other hand, shorter travel distances and a higher reliance on public transport (OECD 2012; Marshall and Garrick 2012) generally reduce transport-related pollution levels (Glaeser and Kahn 2010). Due to smaller energy consumption per capita and smaller air pollution rates, compact cities are often related to sustainable urban concepts such as eco city, smart city and low-carbon city (De Jong et al. 2015). According to Bibri and Krogstie (2017), sustainable cities maximize efficiency of energy and material resources, create a zero–waste system, support renewable energy production and consumption, promote carbon–neutrality and reduce pollution, decrease transport needs and encourage walking and cycling, provide efficient and sustainable transport, preserve ecosystems, emphasize design scalability and spatial proximity, and promote liveability and sustainable community. Low carbon city concept especially emphasizes sustainable energy consumption, effective carbon neutrality and reliance on renewable energy (De Jong et al. 2015). However, Van Der Waals (2000) is sceptical about the environmental benefits of compact urbanization, emphasizing that effects should be considered from a long-term perspective and that these strongly depend on social and economic trends and policies. Finally, Burby et al. (2001) warn that compact city policies could increase the vulnerability of people and property to natural hazards due to the high population densities. Furthermore, due to lower land consumption rates, there is more flexibility with respect to land-use pattern and future ecological planning (Van Der Waals 2000; Westerink et al. 2012). But since compact cities do not have enough space for the future production of renewable energy (Broekman, POSAD and ECN 2017), land use outside borders of compact cities must compensate for this. Regarding climate change mitigation, the compact city is considered by many as the most appropriate urban form due to reduced releases of greenhouse gases. However, due to reduced green areas, Zhou et al. (2017) warn that urban heat island effect is the strongest in big and compact cities. Generally, climate change adaptation strategies highly depend on the geographical location and the local climate (Pizarro 2009).

1.3.3 Social sustainability

Regarding *social sustainability*, urban densification has been shown to increase housing prices, which has a negative impact on affordable housing (Millward 2006). On the other hand, Burton (2003) and

Nelson et al. (2007) suggest that the compact city has the potential to promote social equity by reducing car dependency and distances, which are important indicators of income, and lowering levels of social segregation. Social sustainability can be enhanced by better accessibility of local services, jobs and recreational spaces. However, as we already emphasized, green urban areas (which often serve as recreational areas) are often diminished when densification occurs (Giezen et al. 2018). Moreover, the impact of urban containment on public health is not straightforward. Some studies emphasize the negative effect of the exposure to traffic noise (Moudon 2009), but other reports stress that inhabitants of compact cities are healthier because they walk and cycle more thanks to shorter travel distances (OECD 2012). Studies of life satisfaction in compact cities show different results: some emphasize the positive effects of transport accessibility and mixed land-use (Mouratidis 2018), while others point out the quality of housing, lower access to environmental amenities, noise and lack of community involvement as negative aspects of living in a high-density neighbourhood (Howley et al. 2009). Furthermore, urban containment policies have a positive impact on social sustainability regarding the re-use of urban areas and mixed-use areas. In Portland, Oregon (US), the urban growth boundary has changed very little in total land area and development in the next 20 years is intended to be accommodated within mixed use, urban infill, redevelopment, and brownfield development sites. A study of the housing market in that city in the 1990-2000 period found that urban containment could not be blamed for gentrification (Nelson et al. 2007), partly because this policy – like elsewhere – was implemented in conjunction with affordable housing policies. In Amsterdam, mixed-use development has been associated with the compact city concept since the 1980s (Hopperbrouwer and Louw 2005). Westerink et al. (2012) analysed compact city strategies in four sample regions in Europe: brownfield redevelopment and inner city renewal was emphasized as important strategies for Leipzig-Halle, while multifunctional land-use and variety in housing were shown to be relevant for The Hague Region.

1.4 Polycentric/clustered urbanization

Smart growth is a concept that emerged in the US during the 1990s in order to deal with the problems arising from urban sprawl, traffic congestion, school overcrowding and air pollution (Stewart et al. 2006). It seeks to integrate economic, environmental, and social aspects of planning and development. Important principles of the concept are land preservation (Daniels and Lapping 2005), transportation accessibility and mixed land-use patterns that provide different urban amenities within walking distance (Handy 2005). One of the most important strategies of concentrated urbanization is Transit-oriented development (TOD).

TOD represents a strategy of concentrated urban growth that considers mixed-use development near, and/or oriented to, public transport systems. Nowadays, it has become the dominant strategy for concentrated urbanization. It corrects some negative effects of the 1970s new-town strategy, notably the growth of private car use. TOD neighbourhoods are typically located within a radius of 400 to 800 metres from a public transit destination (e.g. train station, metro station, tram stop, BRT stop (Bus Rapid Transit), bus stop, or even ferry stop), which is considered to be an acceptable walking distance. According to this mode, these nodes are surrounded by relatively high-density development with progressively lower-density development spreading outward. Common TOD features include urban compactness, pedestrian and cycle-friendly environments, public and civic spaces near stations, and stations as community hubs (Nordregio et al. 2016).

The early concepts of TOD have been developed in the United States and Europe in the late Nineteenth and early Twentieth Centuries, when urban developments started to concentrate along the streetcar and metro lines. After the Second World War, planners in Europe promoted suburban development in satellite suburbs along transit corridors (e.g. Copenhagen, Stockholm) (Hall 2014; Knowles 2012; Cervero 1998). Most recently, TODs have been related to the Smart Growth and New Urbanism approaches. In the United States, TOD has become the dominant growth management concept. Also, in European metropolitan areas, urban development along rail corridors is seen as a target for achieving more cohesive territories and sustainable urban development (Papa and Bertolini 2015).

The final report of the JPI-financed CASUAL project (Co-creating Attractive and Sustainable Urban Areas and Lifestyles) (Nordregio et al. 2016) discerns three types of TODs: single node, multi-node, and corridor TOD. Single node TOD consists of a single circular neighbourhood based around heavy rail stations in an urban or suburban area. Multi-node TOD follows a typical 'beads-in-a-string' pattern by creating a regional network of nodes around heavy rail stations in order to realign entire urban regions around rail transport. Corridor TOD is based around light rail or Bus Rapid Transit (BRT) stops (which are more frequent than heavy-rail stops) and it follows a linear or ribbon-like development pattern along the transit line(s) (Nordregio et al. 2016).

1.4.1 Economic sustainability

Many studies underline a positive impact of TODs on *economic sustainability*. Like the urban containment strategy, it creates enough density to profit from agglomeration economies. Nilsson and Delmelle (2018) noted an increase in median incomes in neighbourhoods close to a new transit due to better accessibility of jobs and services. It is important to note that TODs do not represent only well-connected new residential areas – a lot of services and jobs are located within TODs as well. This mode promotes the location of jobs near transit stations and developing job opportunities around nodes (Van Lierop et al. 2017). In the Netherlands, planners attempt to ensure that major cities benefit economically from each other by reducing travel times between hubs (Balz and Schrijnen 2009). Successful implementation of TOD strategies can be seen in the city of Ørestad, Denmark (Hall 2014; Knowles, 2012) and Denver (US) (Ratner and Goetz, 2013). Since the mid Twentieth Century, Ørestad has been developed as Copenhagen's linear new town around stations on an elevated, driverless mini-metro line. Today it represents an important economic centre with highly developed business, housing, retail, education and leisure functions. Accordingly, Ørestad is contributing to the growth of Copenhagen's urban region, but also relieving pressure from its Central Business Districts (CBD) (Knowles 2012). In this way, TODs enhance the polycentric development of urban regions (Papa and Bertolini 2015). In Denver, transit-oriented strategic planning has prompted a development of mixed-use areas around rail transit stations and increased urban density. Thus, it represents a successful strategy of reducing low-density scattered urban growth (Ratner and Goetz, 2013). Good accessibility to public transportation network decreases car mobility, which has a positive impact on transportation costs, especially regarding gasoline and private car-ownership (Ratner and Goetz 2013). Accordingly, Guthrie and Fan (2016) argue that transit access can dramatically reduce household transportation expenditures. Ratner and Goetz (2013) further argue that better solutions in transport and distribution of functions contribute to lower levels of energy consumption in general. Furthermore, the value added from rail investments can be used to finance transit infrastructure as well as other public spaces (Cervero and Murakami 2009). Regarding the housing market, TODs are linked to new construction and urban development (Knowles 2012), so they are not restricting economic growth as urban containment strategies might. Moreover, amenity-based elements and accessibility benefits of TOD play an important positive role in urban land markets (Bartholomew & Ewing, 2011).

1.4.2 Ecological sustainability

Reduced car mobility and the associated reduction in air pollution levels are the most important contributions of TOD policies to *ecological sustainability*. Sider et al. (2013) found that the emitted NO_x per person is negatively associated with dense, walkable TOD zones. Since TOD policies promote ideas of 'green urbanism' (Nordregio et al. 2016), some authors emphasize the provision of parks and recreational space as an important component of TOD planning (Renne et al. 2005). For instance, one third of Ørestad is allocated for parks, green areas, lakes and artificial canals, whilst large scale leisure space is located in the green belt in the city proximity (Knowles 2012). However, although TOD policies consider certain environmental goals (Kenworthy 2006), van Lierop et al. (2017) argue that this is not a major issue in TOD planning. However, since TODs represent a concentrated form of urban development, the overall consumption of land is lower and more open space is preserved compared with uncontrolled development. Green spaces can contribute to wildlife preservation (Fuller and Gaston 2009), but overall impact on biodiversity cannot be positive since TODs still include new construction and the subsequent deterioration of habitats (Weller et al. 2019). By occupying less land than uncontrolled developments, TODs leave more space available for various possible future uses, including risk mitigation of natural hazards (e.g. water retention) or utilisation of renewable energy sources (Van Der Waals 2000; Kenworthy 2006; Westerink et al. 2012). Loo and du Verle (2017) suggest that TODs have a key role in achieving a sustainable mobility strategy primarily by promoting high energy-efficient and low-carbon public transport. Cervero and Sullivan (2011) estimated that carbon emissions and energy consumption of Green TOD (combination of TOD and green urbanism) can be nearly 30% less than that of conventional development due to more efficient energy and land consumption, lesser heating/cooling expense, waste reuse techniques etc. Also, Salat and Ollivier (2017) pointed out that TOD can improve resilience to natural hazards if implemented strategically, e.g. by providing well-connected evacuation areas in case of emergency or by locating high-density zones in lower-risk areas. Furthermore, smart city strategies, which are related to TODs, often emphasize the importance of the implementation of circular economy (Fusco Girard 2013) and renewable energy. For instance, Smart City Amsterdam aims at 40% CO2 reduction and 25% energy reduction by 2035 based on renewable energy (Zygiaris 2012). But at the same time, the Amsterdam Metropolitan Region does not have enough space to produce 100% of its own energy use in 2040 from renewable sources (Broekman, POSAD, ECN 2017).

1.4.3 Social sustainability

Regarding *social sustainability*, studies mostly note positive or neutral effects of TODs. Gunthrie and Han (2016) emphasize that affordable housing is an important part of most TOD policies, while van Lierop et al. (2017) find that lower-income passengers often represent the majority of transit users. Delmelle and Nilsson (2019) warn that housing prices may increase due to enhanced transport accessibility; however, their research shows that in the US lower-income residents did not move out of new transit neighbourhoods at a disproportionate rate (Delmelle and Nilsson 2019). The majority of transit neighbourhoods do not undergo dramatic changes in their socioeconomic composition in the decade following the placement of the station (Nilsson and Delmelle 2018). Therefore, there is no evidence that TODs promote social segregation and inequity, but neither do they discourage it. In Paris, members of the urban elite live in the city centre (Financieel Dagblad 15-08-2019: 20-21), while many of the poor live in the railway-connected *banlieus*. But TOD-like forms of concentrated urbanization often result in the development of mixed-use areas (Pojani and Stead 2015; van Lierop et al. 2017; Nordregio et al. 2016). These mixed-use areas can be seen in both Ørestad (Knowles 2012) and Denver (Ratner and Goetz 2013). Pojani and Stead (2015) also state that mixed housing supply in TODs should include both low-cost social housing and higher-end high-rise apartment buildings, which enhances urban variety. The quality of life in TODs is increased by the provision of green public and recreational spaces (Knowles 2012; Pojani and Stead 2015; van Lierop et al. 2017) and by the walkable neighbourhood design (Morency et al. 2011; Guthrie and Fan 2016). On the other hand, Pojani and Stead (2015) noted the problem of noise pollution in the TODs in the Netherlands due to the proximity of the railway tracks. These problems were overcome by the construction of defensive walls or by moving the transport infrastructure underground. However, in his comprehensive study of sustainable urbanisation in Europe, Shaker (2015) found that the urban connectively measure was the strongest predictor for explaining the variability of Human Wellbeing Index, thus signifying the importance of anthropogenic corridors for improving conditions of human well-being. Furthermore, Hamidi and Ewing (2020) suggested that compact places appeal to more than half of the young adult population and that this demand should be met by providing dense, diverse, and well-designed residential options through regional transportation plans and local planning and zoning.

1.5 Diffuse urbanization

Diffuse urbanization is very similar to what is commonly referred to as urban sprawl. In our discussion of this mode, we will refer to sources from the vast literature on urban sprawl, acknowledging that definitions vary and that the term has a normative bias. As Bruegmann (2005) points out: “Whenever the word “sprawl” is mentioned today, it triggers in the mind of most listeners an entire litany of alleged woes, ranging from objective ones, such as the loss of cropland, to highly subjective ones like the supposed ugliness of suburban subdivisions” (p. 137).

As a starting point to understanding diffuse urbanization, Longley et al. (2002) found two distinctive morphologically oriented definitions of urban sprawl in the literature. In the literature of the 1950s and 1960s, it was often defined as a contiguous expansion of existing development from a central core at lower densities – the city literally sprawls outwards. Other, more recent, definitions emphasize that this development is often discontinuous; the urban growth is 'scattered' or 'leapfrogs' over vacant land. The EEA definition uses both aspects in its definition:

> ...the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas. […] Development is patchy, scattered and strung out, with a tendency for discontinuity. (EEA 2016: 20)

Other definitions of urban sprawl that emphasize the physical manifestation include (OECD 2018) "an urban development pattern characterised by low population density that can be manifested in multiple ways" (p. 29). Low-density suburbs are often related to high car dependency (Newman and Kentworthy 1999; OECD 2018), but Bruegmann (2005) concludes that although an increase in mobility certainly made sprawl possible it did not necessarily cause it. However, car dependence, poor street connectivity, and a poor spatial combination of land uses are often used as indicators of urban sprawl (EEA 2016). Urban sprawl is also defined as a movement of human population from densely populated metropolitan urban towns and cities into low-density, monofunctional and car dependent communities (Margarita et al. 2017). The monofunctionality of residential suburbs is especially emphasized in the studies of post-socialist cities in Eastern Europe (Ziobro 2019). According to Galster et al. (2001), sprawl is in planning literature also defined as a cause of an externality, such as high dependence on the automobile, isolation of the poor in the inner city, the spatial mismatch between jobs and housing, or loss of environmental qualities.

According to Dieleman and Wegener (2004) urban sprawl is characterised by spatially segregated land uses and leapfrog urban development, which is the opposite of multifunctional land use at one location.

Recalling the dictionary definition of sprawl "to spread out carelessly or awkwardly" (Merriam-Webster), the EEA also notes in its definition that, "Sprawl is the leading edge of urban growth and implies little planning control of land subdivision" (EEA 2016: 20). Similarly, the real-estate slang-based taxonomy *A Field Guide to Sprawl* calls it, "unregulated growth expressed as careless new use of land and other resources as well as abandonment of older built areas" (Hayden 2004: 7). Bruegmann (2005) takes a similar view: "low-density, scattered urban development without systematic large-scale or regional public land-use planning" (p. 18), while Ouestlati et al. define it as, "a multidimensional phenomenon, typified by an unplanned and uneven pattern of urban development that is driven by a multitude of processes and which leads to the inefficient utilisation of land resources" (Ouestlati et al. 2015: 1595). In the study of the metropolitan regions of Barcelona and Milan, Pagliarin (2018) argues that urban sprawl is not unplanned, but originates from local planning practices mainly performed by municipal authorities, while higher-level institutions play a decisive role in land containment: "Urban sprawl is hence not necessarily an unplanned phenomenon, but rather a 'differently planned' local and regional land-use strategy" (Pagliarin 2018).

Stewart et al. (2006) suggests ways in which smart growth principles can mitigate the negative outcomes of urban sprawl in a way that does not totally reject decentralized patterns of development, specifically when low-density living tends to be the preferred choice of some consumers. These principles include mixed land-use planning which provides different urban amenities within walking distance, provision of green areas, and an improved accessibility by public transport system.

Therefore, diffuse urbanization does not necessarily represent a distinctly negative urban form, as urban sprawl is often described.

1.5.1 Economic sustainability

As diffuse urbanization is often created by the lack of controls, some studies argue that it reflects market efficiency: urban land-use is allocated according to demand, which theoretically should result in the greatest wealth creation and therefore has positive effects on *economic sustainability*. Conversely, land-use controls result in a net welfare loss (Cheshire 2018). Longley et al. (2002) point out that 'urban sprawl' proponents generally take an economic perspective, and that there is some agreement it is reflective of (or even contributes to) economic well-being (Bruegmann 2005).

Economic profitability arises from the simple fact that building and development on greenfield is usually much cheaper than the regeneration of brownfields (Bruegmann 2005). More specifically, some studies find that diffuse urbanization is positively associated with increasing wealth (Ouestlati et al. 2015): job growth is closely interlinked with housing demand. Diffuse urbanization is induced by advances in economy and transportation technology, which allow the outward dispersal of manufacturing, retail trade and housing, and increase the spatial demands of the city dwellers. In Europe, 'edge city'-like diffuse urbanization development around airports, technopoles and business parks creates many jobs for high-skilled employees (Bontje & Burdach 2005). But these edge cities are exceptions. Often, high-skilled jobs are more numerous in the city centres while low-skilled jobs are located in the periphery (Ewing et al. 2016). Some studies report that job availability in diffused suburbs is usually low and mostly relies on the establishment of shopping malls, whose operation is not always successful (EEA 2016).

On the other hand, since the majority of jobs is still located in city centres or CBDs (OECD 2018), accessibility of services and jobs is low in this urbanization mode due to the long distances. Moreover, public transport is less developed due to lower population density, so there is a greater reliance on cars (Antoniucci and Marella 2018; Cao and Hickman 2018). Accordingly, transportation costs are much higher than in compact cities (Longley et al. 2002; EEA 2016). Higher costs are also associated with traffic congestion and increasing needs for the extension of urban infrastructure in newly developed regions (Hortas-Rico and Solé-Ollé 2010; Klug and Hayashi 2012; Cinyabuguma and McConnell 2013; EEA 2016). At very low densities, other kinds of infrastructure (e.g. water or sewers) are no longer viable (Nelson et al. 2007: 50) and are too expensive for the local government, which results in an inefficient urban growth model (Gielen et al. 2019). Higher costs also occur as a result of higher energy consumption and higher greenhouse gas emissions per person (Kenworthy et al. 1999; EEA 2016). However, Bruegmann (2005) argues that congestion and commuting times tend to rise, not fall, with density: evidence show that residents of low-density urban areas can travel around more easily, and although being responsible for air pollution, car travel is comfortable and convenient. Furthermore, Bruegmann (2005) criticizes the often stressed statements about the high costs of automobile transport, saying that public transport receives a lot of governmental subsidies. He also states that instead of restricting low-density development and attempting to remake cities to fit traditional transportation modes, we should rather find new modes of transportation and explore more efficient ways of energy consumption (Bruegmann 2005). Regarding housing market demands, diffuse urbanization has a positive effect since it represents a fulfilment of needs for low-cost and low-density housing (Longley et al. 2002; Bruegmann 2005).

1.5.2 Ecological sustainability

The literature is overwhelmingly critical about the *ecological sustainability* of diffuse urbanization. In particular, the EEA Report *Urban Sprawl in Europe* (2016) generally noted negative effects. Higher air pollution per capita due to enhanced use of cars has been emphasized by several studies (Glaeser and Kahn 2010). The problems of higher noise and light pollution are also recorded (Bennie et al. 2014). Since diffuse urbanization represents an extensive loss of agricultural land and open space (Longley et al. 2002), it has a profoundly negative impact on biodiversity. The expansion of built-up areas causes a loss of habitats and species, it increases landscape fragmentation, degradation of ecological networks and a loss of existing green infrastructure (Alberti 2005). However, the intensity of this impact depends on the abundance of green urban spaces and their crucial role in supporting wildlife (Aronson et al. 2017). In low-income suburbs, green areas are scarce and poorly maintained, while in the wealthier neighbourhoods they can be more abundant (Wolch et al. 2014). On the other hand, Bruegmann (2005) points out that concerns about land consumption are often accentuated too much: urban areas occupy much less space compared to agricultural or natural areas. Actually, one should be also concerned about the agricultural consumption of land and its environmental issues.

Regarding vulnerability to natural hazards, studies show opposite views. Harmin and Gurran (2008) argue that the loss of open natural spaces can contribute to increasing natural hazard risks, e.g. by reducing potential space for future water retention in the case of dangerous floods (Hamin and Gurran 2008). On the contrary Westerink et al. (2012) note that the dispersed city has more space for water storage and infiltration, making it less vulnerable to flood risk. Therefore, we can assume that vulnerability highly depends on the type of urban development pattern, i.e. whether it represents a contiguous or a discontinuous development, as was already defined by Longley et al. (2002). Furthermore, a higher proportion of single households leads to a more resource-intensive living style resulting in bigger resource consumption rates compared to compact cities (Dura-Guimera 2003; Howley 2009; EEA 2016). Finally, US studies show that higher greenhouse emissions affect the doubling of the annual number of extreme heat events in the most diffuse cities in comparison with the most compact cities (Stone et al. 2010; EEA 2016). However, Zhou et al. (2017) found the strongest positive correlation between urban heat island and the city size, followed by compactness, making small and diffuse cities most preferable in sense of climate mitigation. In that sense, the results obtained by Stone et al. (2010) in the US may be primary explained by a large surface area of diffused cities. Diffuse urbanization has the highest rate of land consumption resulting in decreased available space for potential future uses, e.g. water retention, renewable energy etc. (Haber 2007; Hamin and Gurran 2009; EEA 2016). However, Bruegmann (2005) argues that citizens of low-density neighbourhoods would probably be able to generate a great deal of the energy they need on their own land, using wind, water, solar, and geothermal power sources.

There are a small number of dissenting voices that argue the ecological sustainability of this mode. Clark, Burall, and Roberts (1993), for example, argue that sustainable development implies a self-support economy which requires more land for buildings and outdoor activities and a general reduction in net residential densities. Pizarro (2009) emphasized that diffuse urban forms, compared to compact cities, represent much better strategies of climate change adaptation in hot and humid climates due to enhanced ventilation of the area.

1.5.3 Social sustainability

Many people choose to live in low-density suburbs due to low housing prices (Ouestlati et al. 2015; EEA 2016; Ewing et al. 2016; Antoniucci and Marella 2018). Therefore, some forms of diffuse urbanization have a positive effect upon *social sustainability*. Also, suburbs are a desirable place to live because low-density housing offers more privacy and larger garden areas than densely built-up compact cities (Longley et al. 2002), and it is easier to achieve private ownership (Lotfi et al. 2019). Other studies conclude that living close to nature reduces stress (Wells & Evans 2003), while Robertson (1990) argues that decentralised urbanization, as a return to the countryside, would help to instil positive rural values.

However, affordable housing can cause negative social effects, especially regarding social equity and mobility. Many studies have shown that social segregation is much more prominent in the cities characterised by diffuse urbanization (Brade et al. 2009; Cassiers and Kesteloot 2012; Antoniucci and Marella 2018). In the US, social mobility in low-income suburbs is particularly aggravated (Ewing et al. 2016). In the city of Detroit, urban sprawl is supposed to cause urban shrinkage and inner city decay, which represents a centre of concentrated urban poverty with high crime rates (Xie et al. 2018). Talen et al. (2018) argue that the dominant patterns in the US suburban landscapes, characterised by an uneven distribution of services and amenities, are likely connected to a desire for separation. Landscape patterns thus enable social separation and separation engenders inequity (Talen et al. 2018). Therefore, we can conclude that diffuse areas are not homogenous but can include both low-income and high-income neighbourhoods. Accordingly, quality of life can be variable. For instance, regarding public and recreational spaces, some studies of diffusely urbanised neighbourhoods emphasized the high level of satisfaction of the residents (Garcia-Coll and Lopez-Villanueva 2018), while others noted a reduction in recreational quality of natural and semi-natural areas (White et al. 2013). However, higher pollution rates can negatively affect human health. Noted problems include respiratory problems (e.g. asthma) as a result of increased air pollution, insomnia and other effects on health as a result of higher noise pollution (Frumkin et al. 2004), increased obesity, stress and decreased physical activity (Costal et al. 1988; Ewing et al. 2003; Garden and Jalaludin 2009; Montgomery 2013).

1.6 Matrix of urbanization modes versus sustainability indicators

Table 1.2 modes of urbanization and aspects of sustainability (full table)

	Compact/containment	**Polycentric/clustered**	**Diffuse urbanization**
	(close to) zero land take, compact cities	*TOD, new towns, smart growth, etc*	*edge cities, sprawl, laissez-faire, etc*
Economic sustainability			
GDP, wealth	+ + agglomeration economies (Nelson et al. 2007; Anas et al. 1998; Storper and Venables 2004; Glaeser 2011) ++ estimated positive results of agglomeration economies in the Netherlands 0,5 – 2% of GDP (De Groot et al. 2010, 55-62) ++ Higher value urban development per capita (30%) than non-containment (Nelson et al. 2007) - - 20% less retail productivity due to UK containment policies (Cheshire et al. 2011) - compact urban form may lead to wage declines on neighbourhood level due to less land conversion (Chapple 2018)	+ increase in median incomes in neighbourhoods close to a new transit (Nilsson and Delmelle 2018; Delmelle and Nilsson 2019) + + example of Ørestad (Knowles 2012) Denver (Ratner and Goetz 2013) better regional cooperation and coordination in Randstad (Meijers 2005) ++ estimated positive results of agglomeration economies in the Netherlands 0,5 – 2% of GDP (De Groot et al. 2010, 55-62) + amenity-based elements of TOD play an important positive role in urban land markets (Bartholomew and Ewing 2011)	+ sprawl can be associated with increasing wealth (Ouestlati et al. 2015) + building and development on greenfield is usually much cheaper than the regeneration of brownfields (Bruegmann 2005) + housing for wealthy people (big houses with gardens) or new factory sites (EEA 2016) +/- encouraging land conversion leads to higher tax revenues but also lower wages (Chapple 2018)
Public finance	+ + High quality infrastructure public services and amenities are usually viable in compact cities such as subways, parks, schools. Sometimes policies require pay-as-you grow (Evers et al. 2000)	+ Adequate public services and infrastructure + the value added from rail investments helps to finance transit infrastructure as well as other public spaces such as open spaces, paths and green corridors (Cervero and Murakami 2009)	- Low density areas usually not viable for high quality infrastructure, services and amenities, costs are paid for by all taxpayers, or passed on to individuals (e.g. septic tanks) (Nelson et al. 2007) - - a significant and positive effect on the unit cost of local public services, which results in an inefficient

			urban growth model, higher expenditures on security, public transportation and community wellbeing (Gielen et al. 2019)
Jobs	+ + central business district, associated with agglomeration economies (OECD 2018) high-skilled jobs (Ewing et al. 2016)	+ jobs located closely to transit stations (van Lierop et al. 2017) not a centre-periphery relationship - major cities do not compete when it comes to job opportunities, but rather benefit economically from each other through reducing travel times between hubs (Balz and Schrijnen 2009 ++ example of Ørestad (Knowles 2012) Denver (Ratner and Goetz 2013)	+/ - establishment of shopping malls – their operation is not always financially successful new jobs related to lost ecosystem services (EEA 2016); smaller concentration of jobs than in the CBD - low skill jobs in the USA (Ewing et al. 2016) + high-skilled jobs in some Edge cities 'European style' (technopoles, airports, business parks) (Bontje & Burdach 2005)
Accessibility	+ shorter intra-urban travel distances, better access to a diversity of local services and jobs (OECD 2012) - Congestion can have a negative result on economic growth (Anas et al. 1998)	+ + railway accessibility, walkable distance to the station (Papa and Bertolini 2015) (van Lierop et al. 2017; Knowles 2012) ++ Combination of concentrated urbanization and railway infrastructure, efficient use of public and sustainable transport Copenhagen, Stockholm (Hall 2014, 215-237; Cervero 1998, 109-154)	- less public transport, greater reliance on cars (Antoniucci and Marella 2018; Cao and Hickman 2018; Ewing 1997) + Congestion and commuting times are lower in low-density cities (e.g. Kansas City, Oklahoma City) compared to high-density cities e.g. New York or Tokyo (Bruegmann 2005)
Business areas	+ + CBD, (OECD 2018), high-skilled jobs (Ewing et al. 2016) + Inner city regeneration leads to economic growth Berlin, Hamburg (Hall 2014, 96-115) + + redevelopment of brownfields, inner city building (Nelson et al. 2007; Couch, Sykes, Börstinghaus 2011; Nordregio et al., 2016; van Lierop et al. 2017 – Vancouver)	++ example of Ørestad (Knowles 2012) ++ the CBD remains the main transit hub and the centre of activities (Loo and du Verle 2017)	- low skill jobs in the USA (Ewing et al. 2016) + High skill jobs in some of the European edge cities (airports, technopoles, business parks) (Bontje and Burdach 2005)

	Westerink et al. 2012 – e.g. Manchester and Leipzig-Halle		
Housing demand / new construction	- possible restrictions of economic growth, as house prices increase, development land becomes scarce and individuals and businesses decide to relocate to other cities where there is still room for new development on the periphery (Ouestlati et al. 2015) - reduced new housing supply (Mayer & Somerville 2000), and increased market volatility (Huang & Tang 2012; Laughlin 2012) - Restrictive land-use policy causes high prices for houses, estimated economic loss in the Netherlands 0,5 % of GDP (Besseling et al. 2008, 13-77) - so further increasing development risk […] makes all houses less affordable because fewer get built (Cheshire 2018)	+ it considers new constructions (Knowles 2012; Ratner and Goetz 2013) + TOD-based design is attractive for housing market due to both amenity-based elements and accessibility benefits provided by transit (Bartholomew and Ewing 2011) + TOD is positively correlated with residential property values around commuter railway stations in the province of North-Holland, so local governments should encourage TOD as one of the strategies for new construction (van der Zwet 2019)	+ fulfilment of low-cost and low-density housing market needs (Longley et al. 2002) + housing market in less dense cities is more resilient and affordable than in denser cities during a recession phase (Antoniucci and Marella 2016)
Transportation costs	+ lower transportation costs per capita (OECD 2012) - Found an increase in local restrictiveness causes a 6.1% rise in commuting distances. The results underline the interdependence of local housing and Labour markets (Cheshire et al. 2018)	+ lower transportation costs (reduced gasoline and car-ownership costs) (Ratner and Goetz 2013) + transit access can dramatically reduce household transportation expenditures (Guthrie and Fan 2016)	- - higher costs because of commuting (Longley et al. 2002; Camagni et al. 2002; Bento et al. 2005; Travisi et al. 2010) A higher demand for transport, increased car use and a higher cost for public transport infrastructure (EEA 2016 - Ewing 1997; Kenworthy et al. 1999) Higher costs associated with traffic congestion and the extension of urban infrastructure in newly developed regions (Hortas-Rico and Solé-Ollé 2010; Klug and Hayashi 2012; Cinyabuguma and McConnell 2013)
Energy consumption	+	+	-

	more district-wide energy utilisation and local energy generation, less energy consumption per capita (OECD 2012) + high-density urban core development is less energy and GHG intensive than low-density suburban development on a per capita basis (Norman et al. 2006)	less energy consumption per capita due to better efficiency, promotion of the renewable energy usage (Cervero and Sullivan 2011, Ratner and Goetz 2013, Loo and du Verle 2017)	Higher costs as a result of higher energy consumption per person (Kenworthy et al. 1999) Higher energy consumption and higher greenhouse gas emissions per person – (Kenworthy et al. 1999; Borrego et al. 2006; Duffy 2009; Waitt and Harada 2012; Jones and Kammen 2014)
Ecological sustainability			
Reducing mobility (by car)	+ + reduced dependency on cars (Nelson et al. 2007; Snellen et al. 2005; OECD 2018, 125) + + residents of the denser communities with more mixed land uses drive fewer kilometers per day than those living in sparser, more homogenous areas (Marshall and Garrick 2012)	+ + (Papa and Bertolini 2015; Nordregio et al. 2016; van Lierop et al. 2017) + Concentrated urbanization close to the cities had a positive effect on sustainable metropolitan development in the Netherlands (Van der Wouden 2015, 70-103; Hall 2014, 143-173)	- - increased mobility by cars (Antoniucci and Marella 2018; Cao and Hickman 2018; Ingram 1998)
Reducing pollution, incl CO_2	+ + reduced transport-related pollution (Nelson et al. 2007; Glaeser & Kahn 2010)	+ reduced pollution from cars, smaller levels of NO_x per capita (Sider et al. 2013) + reduction of carbon emission (Cervero and Sullivan 2011; Hasibuan et al. 2014)	- - „Higher air pollution per capita as a result of vehicle exhausts, fertilising substances, dust, particles, road salt, oil, fuel and other substances which cause air and water pollution, and eutrophication“ (EEA 2016 - Borrego et al. 2006; Rich and Loncore 2006; Navara and Nelson 2007; Tu et al. 2007; Bart 2010); Higher noise pollution (causing insomnia and other effects on health) Slabbekoorn and Peet 2003; Moudon 2009 Higher light pollution, modification of light conditions and other visual stimuli Bennie et al. 2014

Green urban areas	- loss of green space due to urban development and densification (Fuller and Gaston 2009; Giezen et al. 2018) - loss of green urban areas in Helsinki by building new economic and residential locations (Hautamäki 2019)	+ provision of parks and recreational space in California (van Lierop et al. 2017; Rennes et al. 2005), and Ørestad (Knowles 2012)	-/+ lack of green spaces in low-income suburbs, but in wealthier neighbourhoods they are abundant (Wolch et al. 2014)
Biodiversity	+/- inside the compact cities biodiversity is reduced, but large green areas out of the city are left intact so overall it has a more positive impact than the urban sprawl (OECD 2012, Sushinsky et al. 2013; Soga et al. 2014) - biodiversity potential is negatively correlated with urban density (Tratalos et al. 2007) - ecosystem wellbeing index negatively correlated with population density, patch cohesion index (a measure of physical connectedness) and patch density (fragmentation index) (Shaker 2015)	+/- (Kenworthy 2006) planning of TODs is generally considered to take into account certain environmental goals, e.g. green areas which support wildlife, green neighbourhoods which enhance life quality etc. (but it depends on policies in certain states (van Lierop et al. 2017) however, overall impact cannot be positive since it includes new construction and deterioration of habitats - loss of biodiversity in peri-urban zones (Weller et al. 2019) - ecosystem wellbeing index negatively correlated with population density, patch cohesion index (a measure of physical connectedness) and patch density (fragmentation index) (Shaker 2015)	- - The loss of habitats for native species; sometimes creation of new habitats with special conditions, the loss of species and the loss of biodiversity (Alberti 2005; Salvatti et al. 2018) The increased fragmentation of the landscape: barrier effect, habitat fragmentation, disruption of migration pathways, impediment of dispersal, increased road mortality of wildlife, isolation of populations, degradation of ecological networks and loss of existing green infrastructure (Alberti 2005; EEA 2006; EEA and FOEN 2011) The reduced resilience of ecosystems (Scalenghe and Marsan 2009; Shochat et al. 2010) - Loss of biodiversity in peri-urban zones (Weller et al. 2019)
Land consumption	+ preservation of agricultural land and open space (Nelson et al. 2007; OECD 2012)	+ higher preservation of open space compared to urban sprawl (van Lierop et al. 2017) + dense, compact and a balanced mixed land-use pattern around transit stops (Loo and du Verle 2017) + better coordination between transport and	- - Loss of agricultural land and open space (Longley et al. 2002; EEA 2016 - Camagni et al. 2002; Pauleit et al. 2005; Eigenbrod et al. 2011; Wilson and Chakraborty 2013) Removal and alteration of vegetation over large areas (Pauleit et al. 2005)

		land use (Duffhues and Bertolini 2016)	
Natural hazards - risk and vulnerability	- high population density – higher vulnerability (Burby et al. 2001)	+ TOD can make cities more resilient to natural hazards if implemented strategically, i.e. planning should include identification of high and low risk zones, well-connected refuge zones in case of emergency etc. (Salat and Ollivier 2017)	+ more space for water storage and infiltration in the case of flood – lower risk (Westerink et al. 2012) - the loss of open natural spaces can contribute to increasing natural hazards risk, e.g. by reducing potential space for future water retention in case of dangerous floods (Hamin and Gurran 2008)
Climate change adaptation and mitigation	+ smaller impact than urban sprawl due to lower GHG releases (reduced car mobility, enhanced mass-transit system, lower infrastructure and energy costs (Hamin and Gurran 2008; Pizarro 2009) - Compact cities with large surface area have the strongest impact on urban heat island (Zhou et al. 2017) However, appropriate urban form strategy regarding climate adaptation depends on the geographic location (Pizarro 2009)	+ smaller impact than urban sprawl due to lower GHG releases (reduced car mobility, enhanced mass-transit system, lower infrastructure and energy costs (Pizarro 2009) However, appropriate urban form strategy regarding climate adaptation depends on the geographic location (Pizarro 2009)	- - a doubling of the annual number of extreme heat events in the most sprawled cities in comparison with the most compact cities (Stone et al. 2010). + Regarding urban heat island mitigation, small, disperse, and stretched cities are preferable (Zhou et al. 2017) However, appropriate urban form strategy regarding climate adaptation depends on the geographic location (Pizarro 2009)
Consumption of resources	+ optimum use of land resources (OECD 2012), often related to sustainable urban concepts that maximize efficiency of energy and material resources, create a zero–waste system, promote usage of renewable energy and carbon–neutrality (Bibri and Krogstie 2017) - Market interventions imply lower efficiencies (Cheshire 2018)	+ TOD is seen as a sustainable mobility strategy which reduces carbon footprint (Loo and du Verle 2017) + more efficient energy and land consumption, lesser heating/cooling expense, waste reuse techniques contingent on high volumes (Green TODs - Cervero and Sullivan 2011)	- A higher proportion of single households, which leads to a more resource-intensive living style (Dura-Guimera 2003; Howley 2009)
Space for future renewable energy	+ more flexibility with respect to land-use pattern (Van Der Waals 2000; Westerink et al. 2012)	+ Smart City Amsterdam aims at 40% CO_2 reduction and 25% energy reduction by 2035	- decrease in the availability of land (Haber 2007); less flexibility with respect to land-

	+ Austrian Spatial Development Concept – linking renewable energy production strategies with agricultural policies, landscape and local development (OECD 2012) district wide renewable energy utilisation and smart grids (OECD 2012) - In 2040, the Metropole region Amsterdam will not have enough land to produce 100% of its own energy use from renewable sources (Broekman, Posad, ECN 2017)	based on renewable energy (Zygiaris 2012) more flexibility with respect to land-use pattern (Van Der Waals 2000; Westerink et al. 2012) - In 2040, the Metropole region Amsterdam will not have enough land to produce 100% of its own energy use from renewable sources (Broekman, Posad, ECN 2017) gie + using renewable energy/fuels produced from the built environment to power transit vehicles (Green TODs - Cervero and Sullivan 2011)	use pattern (Westerink et al. 2012) + citizens of low-density neighbourhoods should be able to generate a great deal of the energy they need on their own land using wind, water, solar, and geothermal power sources (Bruegmann 2005)
Space for future water retention	+ more flexibility with respect to land-use pattern (Van Der Waals 2000; Westerink et al. 2012).	+ more flexibility with respect to land-use pattern (Van Der Waals 2000; Westerink et al. 2012).	+ more space for water storage and infiltration (Westerink et al. 2012)
Space for future circular economy	+ more flexibility with respect to land-use pattern (Van Der Waals 2000; Westerink et al. 2012).	+ smart growth is associated with circular economy principles (Fusco Girard 2013), more flexibility with respect to land-use pattern (Van Der Waals 2000; Westerink et al. 2012)	- less flexibility with respect to land-use pattern (Westerink et al. 2012)
Social sustainability			
Health	+ better human health because of cycling and walking, recreational activities (OECD 2012) - Exposure to traffic noise (Moudon 2009) +/- compactness is not significantly associated	+ walkable neighbourhood design, green areas (Guthrie and Fan 2016), modal shift from car to transit contributes to the volume of daily physical activity (e.g. walking to and from transit stations) (Morency et al. 2011) -	- - Respiratory problems (e.g. asthma) as a result of more air pollution (Frumkin et al. 2004) Increased obesity, stress and decreased physical activity (Costal et al. 1988; Ewing et al. 2003; Garden and Jalaludin 2009) + Living close to nature reduces stress (Wells and

	with body mass index in young adults for those staying in the same place for the entire period (Hamidi and Ewing 2020)	noise pollution (Pojani and Stead 2015)	Evans 2003)
Affordable housing	- - high housing prices (Millward 2006; Pozdena 2019) +/- inconclusive because UGB usually linked to affordable housing policies (Nelson et al. 2007)	+ + lower-income passengers often represent the majority of transit users, i.e. housing prices are low (van Lierop et al. 2017); -/0 housing prices may increase due to improved accessibility (Delmelle and Nilsson 2019) + affordable housing is an important part of the TOD policies (Guthrie and Han 2016)	+ + (Ouestlati et al. 2015; Antoniucci and Marella 2018; EEA 2016; Ewing et al. 2016)
Equity/inclusion	+/- reduced car dependency (which is an important indicator of income) and lower levels of social segregation, but high housing prices can have a negative effect (Burton 2003; Nelson et al. 2007) + high social upward mobility (Ewing et al. 2016) +/- Polarization of incomes, but less spatial segregation in Dutch cities (Buitelaar & Raspe 2016) ++ Evidence of racial desegregation in US cities by improving city centres and ‘opening up suburbs’ (Nelson et al. 2007: 92)	+ in the USA lower-income residents have not moved out of new transit neighbourhoods at a disproportionate rate (as a consequence of railway introduction) (Delmelle and Nilsson 2019) majority of transit neighbourhoods do not undergo dramatic changes in their socioeconomic composition in the decade following the placement of the station (Nilsson and Delmelle 2018)	- - social polarization between centre and suburbs (Antoniucci and Marella 2018; Inner city decay in the USA (Xie et al. 2018) Segregation based on income (Thurston and Yezer 1994; Power 2001; Brade et al. 2009; Cassiers and Kesteloot 2012) - Low social mobility in USA (Ewing et al. 2016) -- Social separation and uneven distribution of resources, services and amenities in the suburban landscape in the USA (Talen et al. 2018)
Public and recreational space	- decrease of green areas (Giezen et al. 2018) + better accessibility to recreational space and services (OECD 2012)	+ Abundant and well-planned, friendly to pedestrians and cyclists, provision of public parks, sports centres, libraries and other public facilities (Knowles 2012; Pojani and Stead 2015; Loo and du Verle 2017; van Lierop et al. 2017), example in Denver (Ratner and Goetz 2013)	+ (high level of satisfaction of the residents – Barcelona Metropolitan Region – Garcia-Coll and Lopez-Villanueva 2018) - The reduced recreational quality of natural and semi-natural areas White et al. 2013

Variety (highrise, suburban, etc)	+ variety in housing (Westerink et al. 2012 - The Hague Region) social mix in housing (Westerink et al. 2012 - Manchester)	+ mixed housing supply to include both low-cost social housing and higher-end high-rise apartment buildings (Pojani and Stead 2015) + A variety of housing types with high-rise and mixed-use buildings above/near transit stations (Loo and du Verle 2017)	+ the studies have noted that diffuse urbanization considers both wealthy and low-income neighbourhoods (EEA 2016)
Mixed-use areas	+ (Nelson et al. 2007; Giezen et al. 2018) associated with compact city concept in the Netherlands (Hopperbrouwer and Louw 2005), multifunctional land use in The Hague Region (Westerink et al. 2012)	++ inter-mixing of housing, shops, restaurants, workplaces, libraries, day-care centres and other activities place many destinations close together, thus inviting more walking and bicycling (Cervero and Sullivan 2011; van Lierop et al. 2017; Pojani and Stead 2015) ++ new TODs are planned for residential, office, scientific, research and educational uses (Nordregio et al. 2016) e.g. in Denver (Ratner and Goetz 2013)	- Conflicts with other land-use interests because of a decrease in the availability of land for agriculture, renewable energy supply and industrial purposes; higher pressure on protected areas; and conflicts with conservation management because of light and noise pollution and recreational activities (Haber 2007) - spatially segregated land uses and leapfrog urban development, it is the opposite of multifunctional land use at one location (Dieleman and Wegener 2004)
Satisfaction with home environment	+ public transport, accessibility to city centre and land use mix demonstrate a positive association with neighbourhood satisfaction (Mouratidis 2018) + compact places appeal to more than half of the young adult population (Hamidi and Ewing 2020) - problem is not (only) high density housing *per se*, but also the quality of housing, access to environmental amenities, services and facilities, noise, lack of community involvement (Howley et al. 2009)	+ Generally positive perceptions of residents in Vinex neighbourhoods and growth centres in the Netherlands (Lörzing et al., 2006) + + the urban connectively measure (COHESION) was the strongest predictor for explaining the variability of Human Wellbeing Index (Shaker 2015) + higher life satisfaction in green, walkable neighbourhoods, but no clear connection between transit and life satisfaction (Pfeiffer et al. 2020) +	+ + Desired place to live for many people because low-density housing offers more privacy and larger garden areas than densely built-up parts of cities (Longley et al. 2002; Bruegmann 2005) + Return to countryside installs positive rural values (Robertson 1990) + the bigger size and private ownership of the dwelling (Lotfi et al. 2019)

		compact places appeal to more than half of the young adult population (Hamidi and Ewing 2020)	

1.7 Application of assessment framework

After identifying distinct modes of urbanization on particular examples of urban development, the impact of that particular development on the three categories of sustainability can be assessed according to the remarks written in the Table.

When applying this framework to draw conclusions regarding the sustainability of urban developments some important caveats need to be borne in mind. First, although we have attempted to make the normativity transparent by splitting up sustainability into its component dimensions and by citing scientific sources as to the impacts, there is still an inherent disciplinary bias as this topic is generally studied by environment and planning scholars. Second, we wish to ensure that trade-offs are not ignored by aggregating effects across dimensions (ecological versus economic sustainability) or by balancing differing findings in the literature (one study showing high negative impacts and another showing high positive impact does not necessarily mean zero impacts). Bruegmann (2005) echoes the methodological point made above:

> Because of the complexity of urban systems, however, it is often difficult to draw up such a balance sheet. […] this problem is compounded by the fact that the 'solution' to any given problem depends on the vantage point of the person doing the proposing (p. 222).

Third, there are countless intermediating factors, particularly governance, which calls for great caution in assuming that the findings of one study in a particular territorial context will be relevant for others. Addressing this point Dawkins et al. (2002) with respect to housing prices, found that, "the effects of urban containment appear to be much more dependent on the style of policy implementation, the structure of local housing markets, the pattern of existing land ownership, and the stringency of other local regulations" than the practices of local planners. Therefore, even if causality is demonstrated as regards the impact of a mode of urbanization (i.e. it is a significant factor), other factors may be much more powerful in determining the final effects.

1.7.1 Object of application

As stated, this sustainability assessment framework can be used to gauge the impacts of urban developments, for example those taken from case studies or from the pan-European analysis. First, however, the modes of urbanization have to be identified from the empirical evidence. Initially the idea was to link urbanization modes to land-use efficiency (e.g. urban development per capita). If the studied urban area showed low-density expansion in that period, it can be classified as a diffuse urbanization; if the studied urban area showed no expansion, it can be identified as an urban containment or polycentric mode. However, as expected, this classification is rather simple, and it only captures recent development, whereas the vast majority of the urban structure was determined prior to 2000. Moreover, it is possible that the new development is different from the existing structure. Another possibility would be to use the cluster analysis using land-use and socioeconomic data. This typology, however, does not seem to bear any resemblance to the three modes of urbanization as discussed above.

A more direct analysis is needed. Given that it is very difficult to identify urbanization modes in an automated manner (this was also attempted in OECD 2018 with mixed results), the SUPER performed a manual morphological analysis. The methodology and preliminary analysis of results were presented in Annex 1, Section 3.4.

2 Modelling urbanization in LUISETTA

2.1 Introduction

The impact of policies and trends can be illustrated by modelling potential urbanization patterns using quantitative land-allocation models. For instance, a PBL study simulated the effects of the national government's decision to abolish its urbanization policies using the *Ruimtescanner* model (Kuiper and Evers 2011). At the EU level, the EU Joint Research Centre (JRC) has developed the Land Use-based Integrated Sustainability Assessment (LUISA) modelling platform for this purpose, which is similar in essence to the Dutch *Ruimtescanner* model (e.g. Kompil et al. 2015; Barbosa et al. 2016). The JRC model has recently been made available in an open source version called LUISETTA. Although some functionality from the LUISA platform has been removed from LUISETTA, the land-use and economic and demographic modules relevant to the SUPER are still included.

The LUISETTA model has been used in this project to produce an impression of potential future land-use changes and urban morphologies by means of three scenarios. The model runs until 2050 based on inputs which are elaborated below. The scenarios correspond with the three modes of urbanization outlined earlier in this annex of compact, polycentric and diffuse urbanization. This section describes the data on which this model runs, its internal workings, displays preliminary output as well as the technical choices made in adapting the scenarios to the capabilities of the model.

In brief, the scenarios hold all environmental, economic and technological variables constant. The factors which vary are societal attitudes, which is expressed in the adoption of different policy packages reflecting these attitudes. The compact scenario describes a disenchantment with the suburban lifestyle and its perceived unsustainability. A combination of densification and containment policies, drawn from the SUPER intervention database, are implemented to create compact cities and spare the open countryside. These are maintained throughout the scenario period. The situation in 2050 is described using the LUISETTA model output (this Chapter) and the sustainability assessment framework (Chapter 1) as a basis. The same approach is applied to the other two scenarios. The polycentric scenario describes a situation where the feeling of community within small and medium sized towns is extolled. The convenience of walkability within these urban areas coupled with good public transport accessibility between them comprises the social attitudes of the scenario. The policy package here is a combination of planned communities (e.g. new urbanism, post-war growth centres) and transit-oriented development. The diffuse scenario describes a situation where individuals and families have a strong preference for spacious surroundings, privacy, and comfort. The policy package is one of stimulating home ownership, self-build and expanding road capacity; it also entails the relaxation of environmental and planning controls on development. As with the other scenarios, the situation in 2050 is described using other parts of the SUPER project as a base. The models themselves are presented in Chapter 3 of this Annex in more detail.

2.2 Methods

2.2.1 Data used and required for modelling purposes

The LUISETTA model uses self-contained databases for its calculation of future land use. This means that, in theory, the baseline scenario can be run without any additional input whatsoever. Approximately 40 datasets are incorporated into the model, including information on age, population, accessibility, distance to roads and water, slope of the terrain, soil contamination, high-value farmland, etc. The model also contains an updated population grid (Rosina et al. 2018) and includes burnt areas, roads, accessibility, water, administrative jurisdictions and Natura 2000 areas.

The basemap for the model is a high-resolution (100m) version of the 2012 Corine land cover map, updated using sources such as the GHSL (Rosina et al. 2018). The model only contains information for EU member states (EU28). Projections for non-EU ESPON countries (Iceland, Norway, Switzerland, Liechtenstein) were calculated based on national demographic projections from Eurostat, which were then distributed over the respective NUTS2 regions in these countries using the same assumptions contained in the LUISETTA model. Specifically, the projections in household size converge to 1.8 across Europe in 2150. The trends for urban land-use per household are based on 2000 and 2012 data.

2.2.2 Model setup and operation

The LUISETTA model was employed to get an impression of the potential extent and distribution of future urbanization and other land use changes. As stated, this is the open-source version of LUISA (Land-Use based Integrated Sustainability Assessment model), which has been extensively described in the scientific literature (e.g. Kompil et al. 2015). Some modelling components from the LUISA platform have been removed from LUISETTA, but land use and economic and demographic developments are still available. Therefore, the scientific literature on the LUISA platform is applicable to the way LUISETTA was run in the SUPER project. A detailed report specifically for the LUISETTA platform is forthcoming (Jacobs-Crisioni et al., forthcoming)

The core of the LUISA modelling platform is a harmonised 100-meter resolution land use and land cover map that upgrades the minimal mapping unit from 25 ha to 1 ha (Rosina et al. 2018). This is used in combination with physical-geographic information such as slope and accessibility, 1km population grids (Batista e Silva et al. 2018) and economic projections, in order to enable land-use changes to be calculated under differing socio-economic and policy scenarios. For example, it is possible to model a ‘business as usual’ or ‘laissez faire’ scenario versus a ‘no net land take’ or ‘compact development’ scenario (as demonstrated in Barbosa et al. 2016). The major inputs and outputs are available for download online.

The version of LUISETTA used by PBL contained a baseline scenario. This scenario contained values for 32 parameters which were calibrated for the full LUISA modelling suite. This was deemed a viable starting position for a baseline (policy-poor) scenario for urban development. These parameters adjusted the “location specifics” (LocSpec), which inform the suitability maps (more information below, see also Figure 2.3).

Not all the concomitant input data was available in LUISETTA however, and because a full recalibration effort was not feasible, a plausible baseline scenario was created by giving a strong weight to the variable nearness to existing population (Neigh_Qi). Consequently, the adjusted baseline scenario simulates new urbanisation occurring predominantly near existing urban areas. Other parameters with a relatively strong effect on location specifications were nearness to water (ln_water and Neigh_ln_water) and nearness to roads (ln_roads and Neigh_ln_roads). Table 2.1 provides an overview of all the variables and their weights in the baseline.

Table 2.1: model parameters and weights used for LUISETTA application in SUPER, with the altered parameter highlighted.

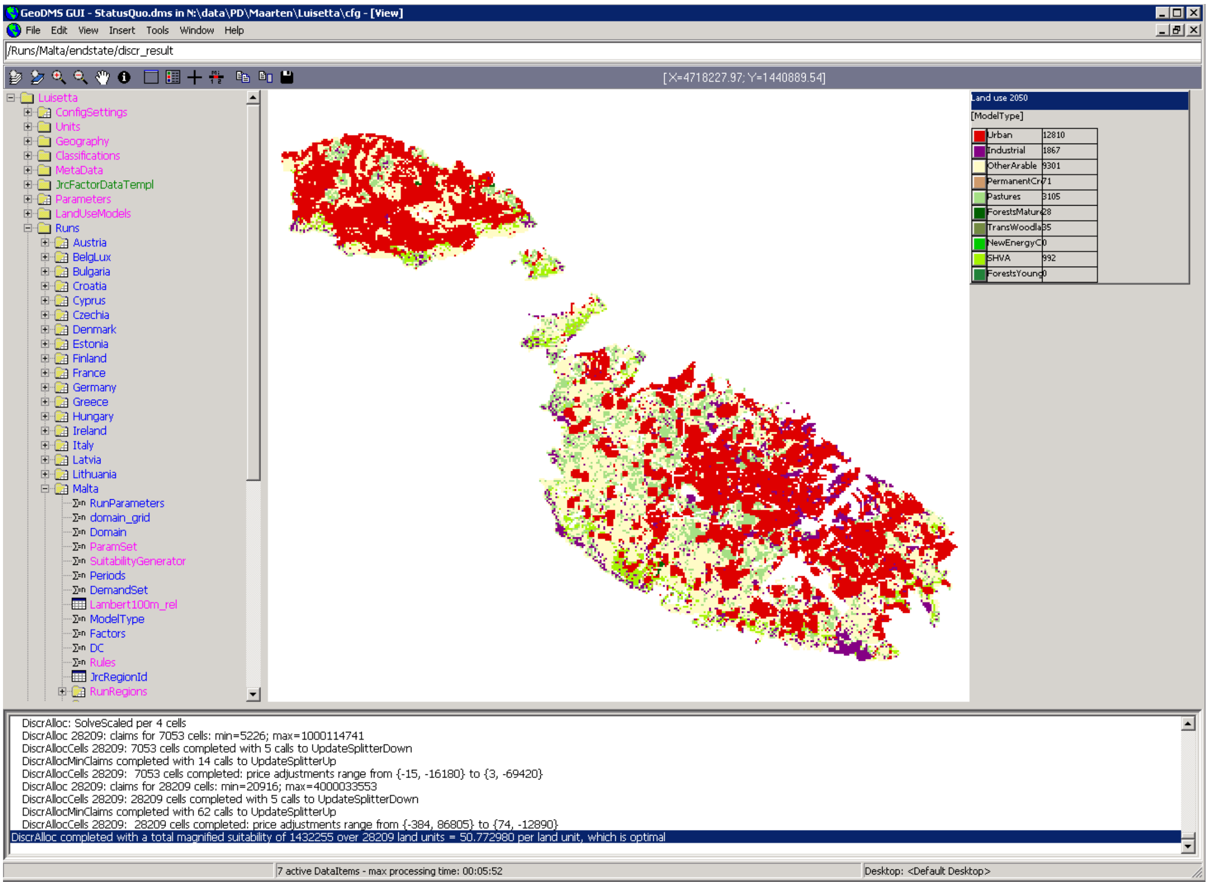
Constant	**1.604**	**nda**	-0.848	**Neigh_Town Access**	-0.057
Elevation_100	-0.031	**Qi**	0.019	**Neigh_slope100_cont**	-0.203
ln_yieldmaize	-0.043	**Neigh_Elevation_100**	0.033	**Neigh_RelPotAccess**	-0.807
ln_yieldbarley	0.030	**Neigh_ln_yieldmaize**	-0.155	**Neigh_sosl_100**	0
ln_yieldsugbeet	-0.044	**Neigh_ln_yieldbarley**	0	**Neigh_natura2000_v2011**	-0.218
ln_yieldsunflow	0	**Neigh_ln_yieldsugbeet**	0	**Neigh_nda**	-0.331
ln_yieldwheat	0.111	**Neigh_ln_yieldsunflow**	-0.050	**Neigh_Qi**	5
ln_yield rapeseed	0	**Neigh_ln_yieldwheat**	0.140	**ln_roads**	-0.271
TownAccess	0	**Neigh_ln_yieldrapeseed**	0.023	**ln_water**	-1.127
slope100_cont	-0.084			**Neigh_ln_roads**	0.190
RelPotAccess	0			**Neigh_ln_water**	0.830
sosl_100	0				
natura2000_v2011	-0.724				

Figure 2.1: A modified example script illustrating the code for calculating land use changes

```
// The following prepares input for the land allocation
container ScaledTransPot: Expr = "for_each_nedv(ModelType/Name,
    'Int32(DynamicComponent/TransPot/'+ModelType/Name+' * CaseData/SuitScaleFactor)', domain, Int32)";
// The following is a check
attribute<uint8> check (modeltype): expr = "rlookup(CaseData/DestClaimTableName, CaseData/UniqueDestRegionRefs/Values)";
attribute<string> demandregions (modeltype): expr = "CaseData/UniqueDestRegionRefs/Values[check]";

// The following is the actual land allocation module with the inputs
container d_alloc: Expr =
    "discrete_alloc(ModelType/Name, domain, "   // Call to the geoDMS function
    "   ScaledTransPot, "                        // Map with potential for land use
    "   MakeDefined(rlookup(CaseData/DestClaimTableName, CaseData/UniqueDestRegionRefs/Values), UInt8(0)), "
                                                 // Initialisation of some needed data
    "   CaseData/UniqueDestRegionRefs/Values, " // Information defining the regions
    "   CaseData/AtomicRegions, "                // Information defining the regions
    "   CaseData/AtomicRegions/UnionData, "      // Information defining the regions
    "   Claims/DemandMin, "                      // Information on the demand to be allocated
    "   Claims/DemandMax, "                      // Information on the demand to be allocated
    "   Int32(value(0 / 0, EUR_HA)),"            // Baseline value
    "   FeasibleSolution"                        // Argument for the function
    " )"
```

Figure 2.2: The GeoDMS operating environment showing output for Malta



The model runs between 2012 and 2050 in five year intervals and performs three important tasks for each five-year round.

- First, it considers a set demand for different types of land use, for example hectares of urban fabric. This demand is derived from projections provided by other models at the NUTS2 level which have been incorporated into the model.
- Second, the model distributes this demand over the landscape based on a combination of factors, including the characteristics of the landscape and preferences for the land use type. This produces a map of land-use change pressure (see Figure 2.3 for an example). As far as urban development is concerned, the suitability of locations is based on distance to roads, water, existing population, and relative accessibility.
- Third, a decision is made to alter the land use or not, bearing in mind the variable transition costs between different types of land use. These costs are defined in a transition matrix that includes all possible transitions between land covers.

The modelling framework allows for the input of maps that modify the LocSpecs. As outlined above, LocSpecs define the suitability of a given 1 ha pixel for urban land use. The model then allocates demand for new urban space to areas with non-zero urban suitability, starting with those areas deemed most suitable. The basic idea is to insert a map which creates a spatial multiplier to the LocSpecs with values that typically run from 0 to 2. Multiplying by 0 makes that location completely unsuitable for urban land use. Multiplying by 2 makes that location twice as suitable as compared to the baseline.

2.2.3 Scenarios

Given the architecture of LUISETTA, at least three methods can be used to create scenarios:

- By altering demand for urban land, which should result in different development pressures;
- By altering location characteristics by inserting a map that modifies the attractiveness of locations (e.g. by making locations near train stations more attractive, or by making rural areas less attractive);
- By altering the cost of transitions, for example by making the transition from industrial/commercial to urban use 'cheaper' and therefore more likely.

The modes of urbanization outlined earlier were translated into scenario input by altering two of these aspects: demand and location characteristics. Under specific explicit considerations of e.g. transformation of industrial land, it would be useful to also consider altering transition costs, but this was not deemed appropriate (too specific) given the specifications of the scenarios. Since the model works with exogenously defined demand for urban land in hectares, the policy-poor LUISETTA baseline data was employed for the diffuse urbanization scenario.

The following three images within Figure 2.3 show how the LUISETTA model allocates demand in the baseline scenario; the area shown is Nivelles in Belgium. In the first image, the original situation is displayed from the 2012 basemap. The second, middle, image is the suitability map, showing urban areas in black (unsuitable), protected nature in green (relatively unsuitable), and highly suitable areas in darker shades of brown. The third image shows the allocation in 2020 resulting on the balancing of demand, suitability, and transaction costs according to the algorithm's internal logic.

The manipulation of suitability to produce the compact and polycentric scenarios is presented in Figure 2.4. The maps to alter the baseline scenario were based on the integrated land-use basemap in LUISETTA. We then performed a smoothing function on this map to distinguish large and medium-sized urban areas. Buffers were then drawn around these urban areas, outside of which attractiveness was greatly reduced in order to encourage development within the buffer (simulating an urban growth boundary). For the compact scenario, we used a strict smoothing function, so that only the larger and more densely built-up urban areas were included on the map. For the polycentric scenario, we used a less strict smoothing function, so that smaller cities become focal points. Originally, we had tried to insert a map increasing the attractiveness of rail stations to simulate transit-oriented development, but this proved unsuccessful (it did not change results). It was not determined why this approach failed, but perhaps it was associated with the fact that this map was not derived from the baseline map. Therefore, the polycentric scenario in the model is truly 'polycentric' in the morphological sense rather than transit-oriented development, such as described in the assessment framework. Because of this, the storyline of the scenario was adapted somewhat to reflect the model's shortcomings in this regard.

Figure 2.3: Simplified suitability map for urban land use (2012-2020 transition)

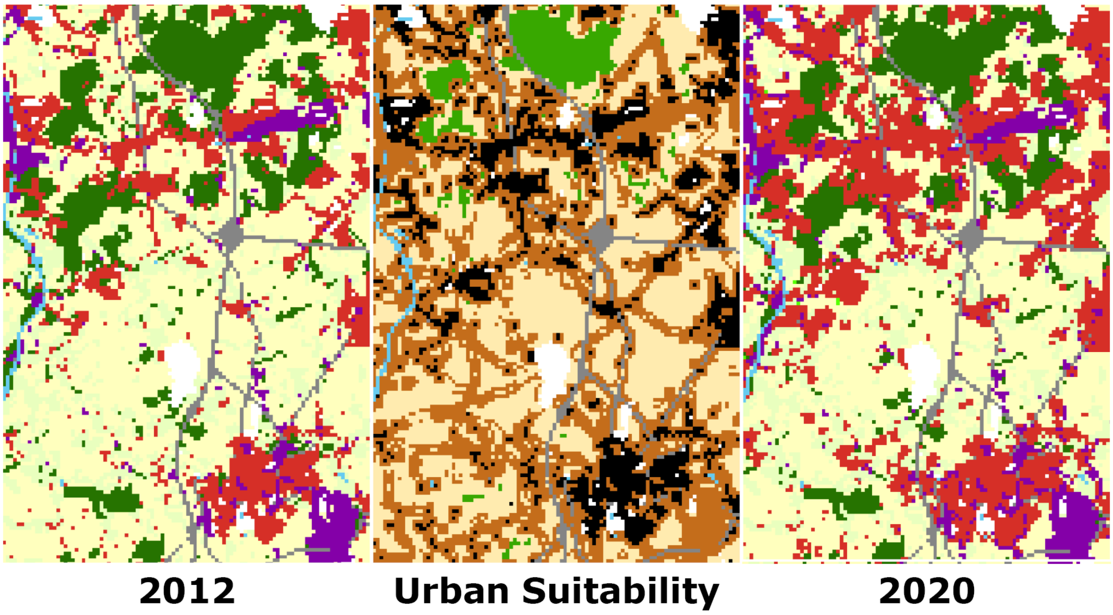
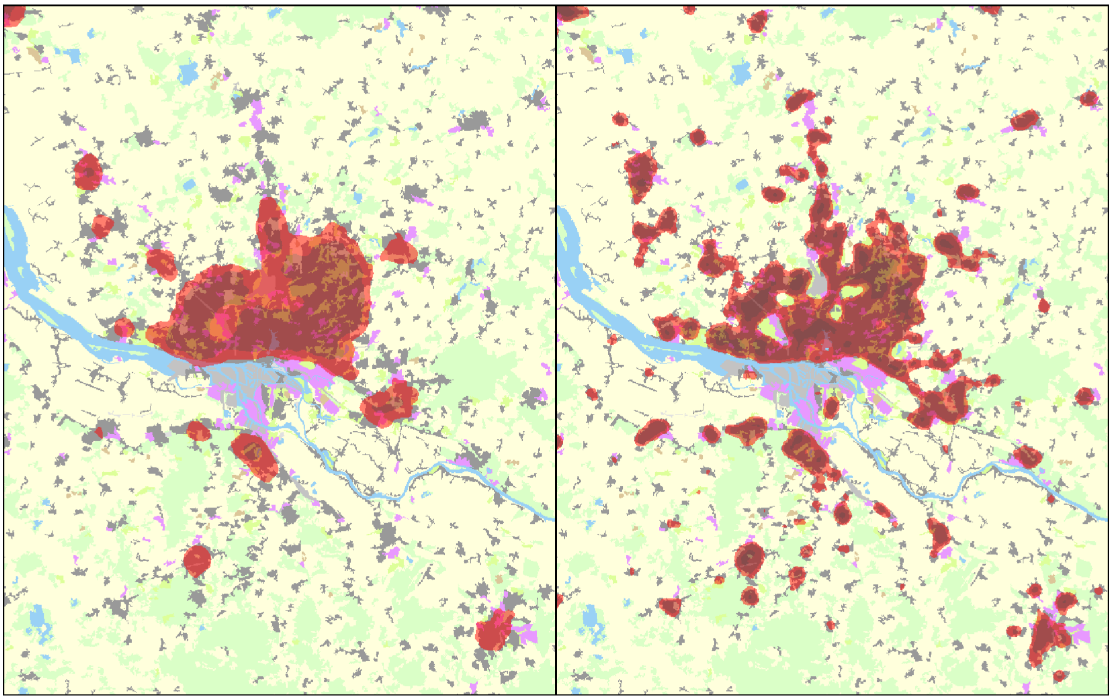


Figure 2.4: Hamburg's preferential sites of future urbanization in 2500 (left: compact) and 1000 (right: polycentric) scenario. In diffuse, only proximity to existing urbanization and roads is considered (see image above showing urban suitability).



Simulating densification

In the compact scenario, a significant portion of new development should be realized in existing urban areas. Because LUISETTA cannot simulate density, all new demand is accommodated outside of existing areas, as urban areas are already considered 'urban' and therefore off-limits. Run normally, the compact scenario would produce just as much urbanization on greenfields as the diffuse scenario, which is at odds with both scenario logic as well as empirical reality. In order to deal with this problem, we adjusted the demand for urban land downwards in the compact and polycentric scenarios, which is tantamount to saying that this demand is being realized by infill development or densification. Demand was cut in half in the compact scenario and by a third in the polycentric scenario.

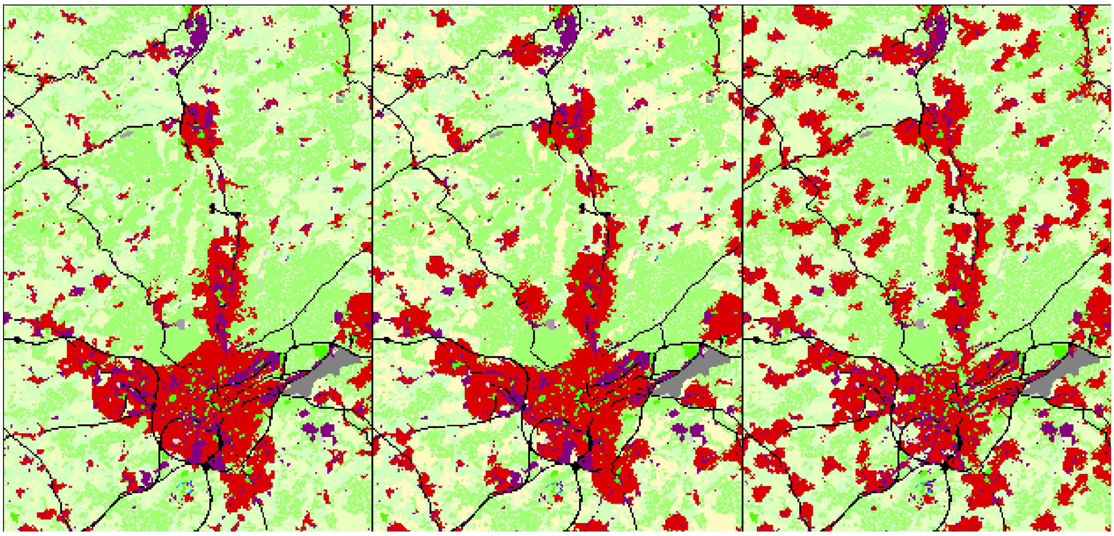
For the adjustment of location characteristics that have a strong impact on the distribution of new urban areas, we again followed the baseline scenario for diffuse urbanization, which simply defines existing urbanization and roads as attractive locations (see Figure 2.3). For the compact and polycentric scenarios we increased the appeal of areas near urban agglomerations and lowered the attractiveness elsewhere (see Figure 2.4). This was done by calculating the percentage of urbanised land within a radius of 2,500 meters and 1,000 meters for the compact and polycentric scenario respectively, squaring this percentage to make the gradient stay closer to existing urban contours.

2.3 Results

The output of the model is a modified high-resolution (100 m) version of the CLC2012 map for each five-year period between 2015 and 2050 for all EU countries, with pixels classified into urban, commercial, agricultural and natural categories. Urban use in LUISETTA refers to all urban uses except industrial/commercial, and infrastructure, which were coded as separate classes.

This output can be analysed both visually and statistically. In terms of statistics, the number of pixels in different land-use classes can be counted and aggregated to administrative boundaries. The output maps were analysed at the NUTS2 level (2016 borders) using ArcGIS in combination with Python and SQLite to extract statistical information. The data was then transferred from SQLite to Excel for further processing. Using Excel, we can present aggregated changes in land use as well as changes in average population density per region and per scenario. This allowed us to display differences between the scenarios for these variables. A caveat is in order regarding the administrative boundaries. We used NUTS-2016 to match the other analyses of the SUPER project. However, LUISETTA uses NUTS-2010 to perform its calculations. this could cause a differences for areas where the regional division changed between 2010 and 2016, especially where a clear difference in regional growth factors has been included in the model.

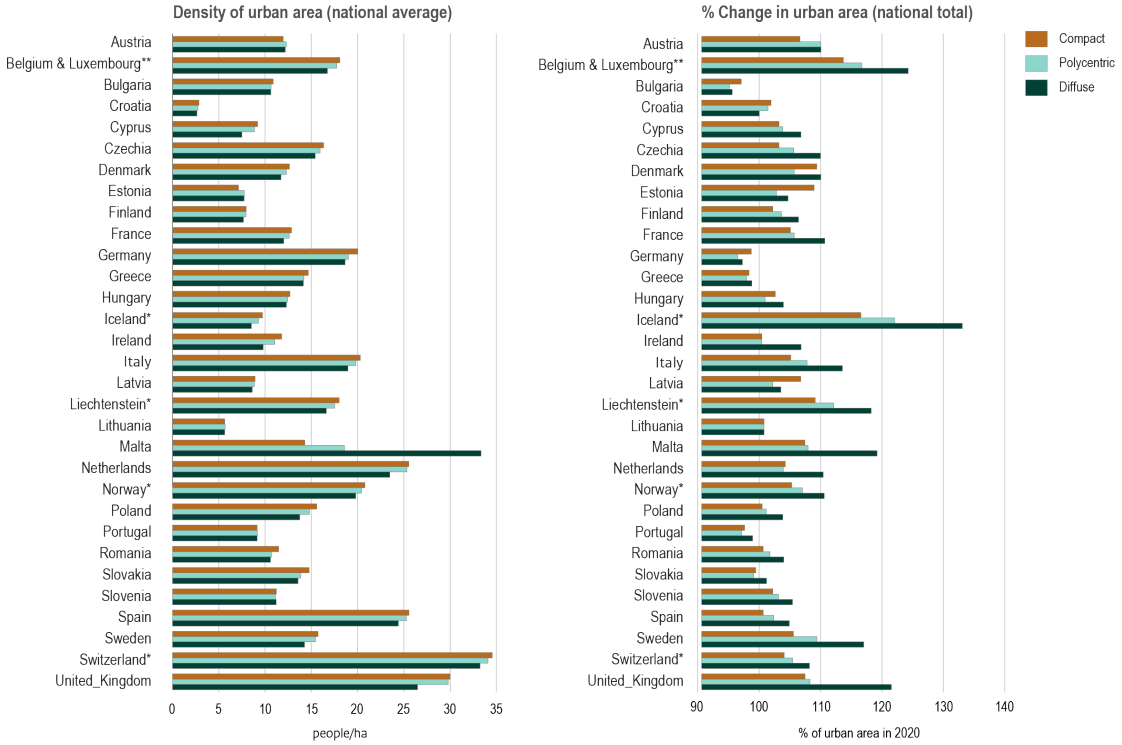
Figure 2.5: Urbanization around Luxembourg City in 2050 in the compact (left), polycentric (middle) and diffuse (right) scenarios



Because the demographic data was fed in at the NUTS2 level, we aggregated the outputs at this level as well as the national level. Figure 2.6 shows the national figures for the density of urban area and change in total urban area (relative to the starting year of 2020); Iceland, Norway, Liechtenstein and Switzerland were calculated using a slightly different method (see section 2.2.1). The modelled data show an especially large difference between diffuse urbanization and the other two scenarios in a number of countries. Compact urbanisation tends to lead to less urbanisation than polycentric, although the distinction is less sharp in some countries, most likely due to existing urban morphology. If we look at the average national density these figures do not necessarily lead to a large divergence in density, although figures at this scale of aggregation do not and cannot show the large changes that may take place at the level of new developments (nor is LUISETTA equipped to model this).

When interpreting the results, we need to remember that changes in land use are modelled through variable demand, suitability of sites and transaction costs. The reduction of 50% in demand in the compact scenario did not produce commensurate 50% reduction in urbanization. In some cases, changes in land-use preferences may not matter much, for example when the area that is available for urbanisation is roughly the same in all three scenarios. If we take the diffuse scenario as baseline, the model shows an average decrease of 4% of urban area across Europe for both compact and polycentric. However, there are clear differences between countries. In a few countries, the model even computed more urban development (Bulgaria, Croatia, Germany, Latvia) in the compact scenario than in the diffuse scenario. The compact scenario leads to the largest decreases in urbanization in Iceland (17%), the UK (14%), Malta (12%), Belgium and Luxembourg (11%) and Sweden (11%). In a few countries, the polycentric scenario leads to a larger decrease than the compact scenario: most notably Estonia (6% difference), Latvia (5% difference), and Denmark (4% difference). At first glance, these national differences might be explained by the predominance of major urban centres, their shape, and the potential for infill. More analysis and more knowledge of the inner workings of the LUISETTA model would be needed to explain these differences with a higher level of confidence.

Figure 2.6: Change in urban land and average national density per country in the three scenarios



*Data for Iceland, Liechtenstein, Norway and Switzerland were calculated using a different method
** The LUISETTA model produces a combined output for Belgium & Luxembourg

3 SUPER scenarios

3.1 Introduction

Creating narratives about future development is a common spatial planning tool, particularly for strategic decision-making (Albrechts et al., 2003; Throgmorton, 1996; Zonneveld, 2007). The purpose of a scenario is to explore possible future pathways where the level of uncertainty is too high to warrant a prognosis, but high enough to avoid mere speculation (Dammers et al., 2013). In general, one can distinguish two types of scenarios: those that hold policies constant except for a set number of external variables (environmental scenarios) and those that vary according to policies (policy scenarios). The SUPER scenarios are of the latter type; they seek to explore how three different policy orientations could result in divergent urbanization and land use trajectories, and the implications of this on sustainability. As such, they provide insight into different long-term policy strategies. These kinds of scenarios have a long tradition in ESPON research (e.g. ESPON, 2006).

Given the *policy scenario* nature, all external variables such as demographic and macroeconomic development, technology and climate change are held constant. Differing societal attitudes comprise the scenario-specific variables, which result in the adoption of a plausible policy package in that scenario. Using slightly different terminology, the scenarios follow the longstanding debate on urban sprawl in the spatial planning literature. In the first scenario, 'compact', urbanization is halted by 2050 by gradually directing all development inwards in large urban regions, resulting in a compact urban structure. In the second, 'polycentric', urbanization is diverted to areas well-serviced by public transport, resulting in clustered development. In the third, 'diffuse', urbanization occurs along roadways in peri-urban and rural areas, resulting in a scattered settlement pattern.

Table 3.1: Key elements of the scenario storylines

Elements	Compact	Polycentric	Diffuse
Constants			
Demographic development	Slowdown in EU population growth and ageing. Regional differentiation following prognoses.		
Macroeconomic development	Low to medium growth in EU, regional variation		
Technological advancement	Transport and information innovations		
Climate change	More extreme weather events		
Variables			
Attitudes on mobility	Walkability	Multimodal	Private car
Attitudes on density	Positive	Mixed	Negative
Attitudes on governance	Collectivist	Interdependence	Independence

In the scenario writeup, each storyline consists of three main parts. The first concerns the **rationale**, which serves as a general introduction, and is aligned to the LUISETTA model input. It consists of a provocative, but not entirely implausible, piece of fiction to make it clear that these stories are not about making predictions, but about describing possible and diverging futures based on a given scenario logic. The storytelling contains common elements, such as identical sentences on demography, technology and climate change effects to emphasize that the model input is consistent across scenarios. The societal reactions to these common drivers differ, however. Given this, the rationale section explains how the quantitative and qualitative demand for urban space is modified by scenario-specific societal attitudes (e.g. the magnitude of aging is the same in all scenarios, but the housing preference of elderly people varies).

The second section presents the scenario **policy package**. It begins with a brief description of policy aims to produce a plausible link between the societal attitudes described in the rationale and the instruments chosen to influence urbanization and land use accordingly. The second part describes the package of interventions implemented in the scenario, making specific reference to evidence produced in the SUPER project (intervention database and case studies).

The last section discusses the scenario **impacts**, based on the LUISETTA model output and the SUPER sustainability assessment framework. It starts with a reflection on urbanization and land-use change using the 2050 image. Each scenario will contain observations, such as a description of the kinds of areas which saw the most urbanization, and how this affected overall urban form by means of zooming in on specific areas. This is followed by a description of impacts in each scenario using the three dimensions of sustainability. The indicators in the table below, which are the same as those used for the sustainability assessment framework (see Table 1.2), serve as a guide for this.

Table 3.2: Key indicators for the three scenario storylines

Economic	Ecological	Social
- GDP, wealth - Public finance - jobs - Accessibility - business areas - housing demand/construction - Transportation costs - Energy consumption	- car mobility - pollution - greenhouse gasses - green urban areas - biodiversity - land consumption - natural hazards - climate change adaptation and mitigation - resource consumption - renewable energy - water retention - circular economy	- health - affordable housing - equity/inclusion - public and recreational space - housing variety - mixed-use areas - satisfaction with home and surroundings

3.2 Compact scenario[4]

3.2.1 Rationale

Starting in 2020, a prudent policy of urban containment was promoted throughout Europe to avoid the wasteful, haphazard urbanization which had resulted in the destruction of natural

[4]A note on scenario names: we opted for names that are as neutral as possible . We also chose adjectives to ‘development’ that reflect the final morphological outcome (e.g. compact). Finally, the scenarios should sound different enough to avoid confusion (i.e. not containment, clustering and cluttered).

resources, especially land consumption, and undermined the vitality of cities. A selection was made from sustainable urban development policies that had proved successful in the past plus some innovations. The result was that urbanization occurred in or near existing cities. By 2050, redevelopment, regeneration or infill development had become the norm.

Looking back, there were various reasons behind this course of action. Attitudes regarding where and how to live had changed considerably. The generation that had grown up with the Twentieth Century ideal of a single-family home and private car had passed on. The notion that people would willingly commute for hours to a large home in a sprawling suburb or remote village and waste their weekend mowing lawns and taxiing children back and forth to dispersed activities, seemed by 2050 as alien as anachronistic – a tiny apartment at a good location was preferable. In short, a change in mindset had occurred in which people preferred convenience and flexibility to size and luxury in their housing decisions.

Many factors influenced this change. One was increased environmental awareness of citizens as the effects of climate change became increasingly unavoidable; compact urban living was widely praised for its sustainability. Moreover, the demographic pressure in Europe had stabilized and the population aged significantly; there was a greater need to be close to healthcare and sheltered-housing facilities in case of sudden illness. The digital connection had become so pervasive and sophisticated that cyberspace was as important as physical space. This was reflected in new attitudes towards mobility and proximity: being used to the convenience of the online world, physical amenities should also be close at hand. Europe's great cities, with their mixed uses, walkability and excellent public transportation was an ideal environment. As a result, the pressure for new homes, especially those distant from the amenities and services in urban centres, waned whereas large cities thrived.

The millennials decided to reinvent urban areas to suit their needs. In order to produce urban areas large enough to provide the quality they demanded – especially given the demographic developments – an ambitious containment programme was introduced. The aim of the strategy was to restrict urban growth to no or virtually no new unbuilt rural land being converted to urban use in order to retain traditional rural land cover types as agricultural land, forest and grassland around the city and to create the densities necessary for high-quality urban amenities and infrastructure (Millward, 2006). Various policies enacted in the 2000-2020 period provided inspiration for policy packages throughout Europe. These were territorially differentiated for maximum impact.

3.2.2 Policy package

In urban areas, especially metropolitan regions, various options were available. The most obvious is to restrict urban expansion by imposing legal boundaries, thus increasing densities and creating a more compact urban form. One of the most studied containment strategies is the 'urban growth boundary' in Portland, Oregon (USA), but in Europe we also find London's

Green Belt, Corona Verde in Torino, Grüner Ring in Leipzig and the Metropolitan Cork Green Belt. Similar strategies include regulations capping urbanization (e.g. the zero-growth plan of the municipality of Cassinetta di Lugagnano), or legal devices that address sustainable land use issues (e.g. in Tuscany, the 2014 regional law on soil consumption n.65/2014). These interventions are sometimes called ‘outside game’ strategies because they concern outward expansion (Rusk, 1999). These were supplemented with interventions oriented to the ‘inside game’ that promote inner-city development. Inspiration was found in interventions transforming underutilized areas (e.g. Reinventing Paris), enhancing the quality of existing urban spaces (e.g. BENE – Berlin Programme on Sustainable Development) or regenerating brownfield areas (e.g. Dublin Docklands and the Royal Seaport eco-district in the City of Stockholm).

In rural areas, the focus was on limiting building in the countryside. Examples include swiss anti-sprawl measures, German and Belgium caps on development, regeneration schemes and farmland protection regulations such as in Valencia. Some countries possess transfer of development rights schemes (e.g. the Dutch ‘red for green’ or the Portuguese *Perequação* policy), which make planning permission for new buildings conditional on the demolition of old ones. Finally, measures such as community-led regeneration processes were considered such as the regeneration of abandoned areas in Casoria (Italy).

3.2.3 Impacts

By 2050, the decades of consistent policy decisions on urbanization and land-use could be read in the physical landscape. Green areas bordering large cities were sacrificed for urban development, while those further afield (e.g. within a green belt) remained untouched. Within cities, unbuilt spaces became scarcer and population densities higher as buildings increased in height and as apartments were subdivided. Rural areas retained their rural character. Some reflected on this development positively, while others were more sceptical about the sustainability of this policy course. Did it serve the long-term economic, ecological and social goals it aspired to?

Figure 3.1: Sample of compact scenario 2050 output for five selected regions

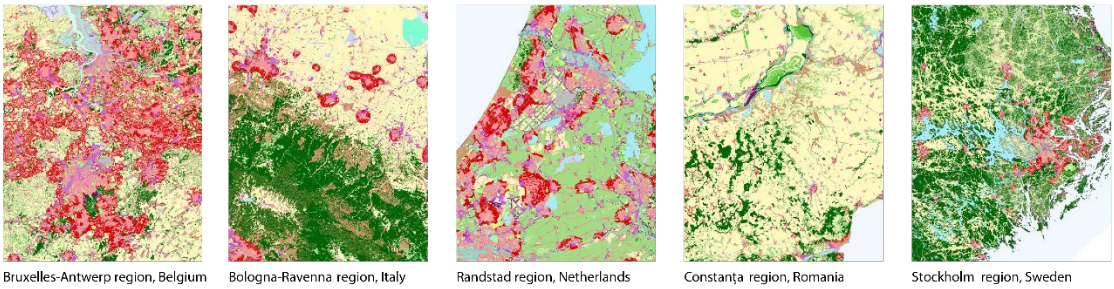


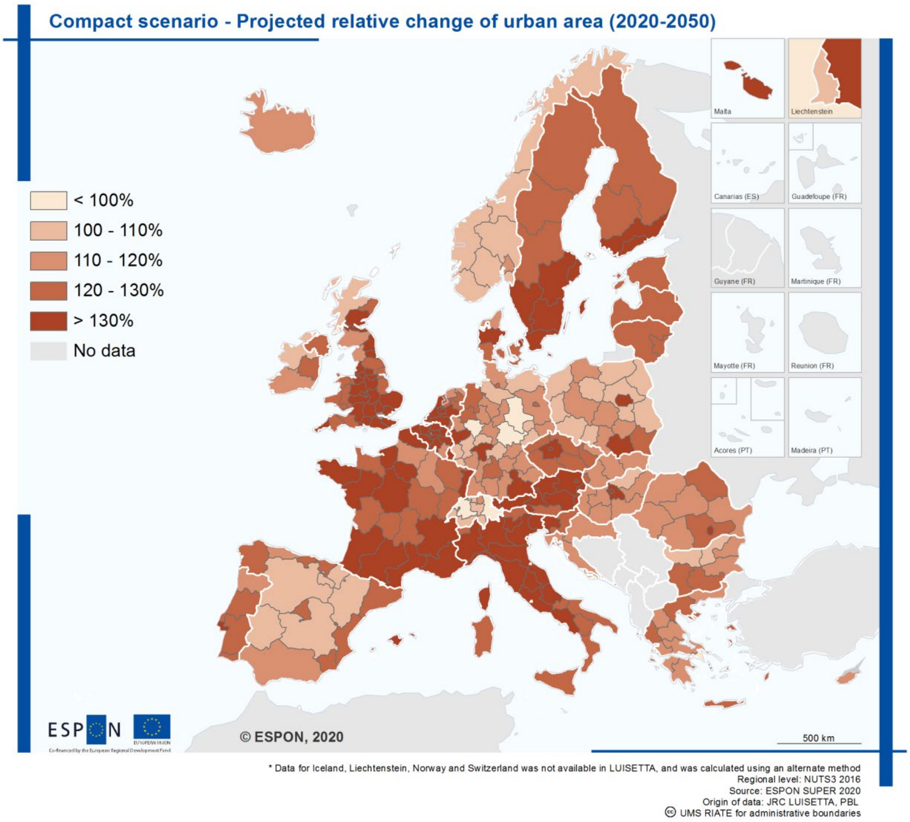
Figure 3.1 displays the typical urbanization pattern produced by the compact scenario by 2050 in the LUISETTA model. The dark red regions show the new urban fabric; the light red

areas were already built-up at the beginning of the scenario period. Here we can see that new development clings to existing urban areas, generally the larger cities. Some large polycentric regions such as the Randstad and Ruhrgebiet coalesced, whereas the scattered suburban development around cities like Milan and Warsaw had filled in. In Belgium, we see Brussels filling in towards the south, as well as the spaces between Charleroi and Mons. In the area between Bologna and Ravenna in Italy, development only occurred around a few large cities. The same is true for Stockholm, where the main centre attracted most urbanisation. This tendency was less evident in Constantia (Romania) due to the low development pressure overall.

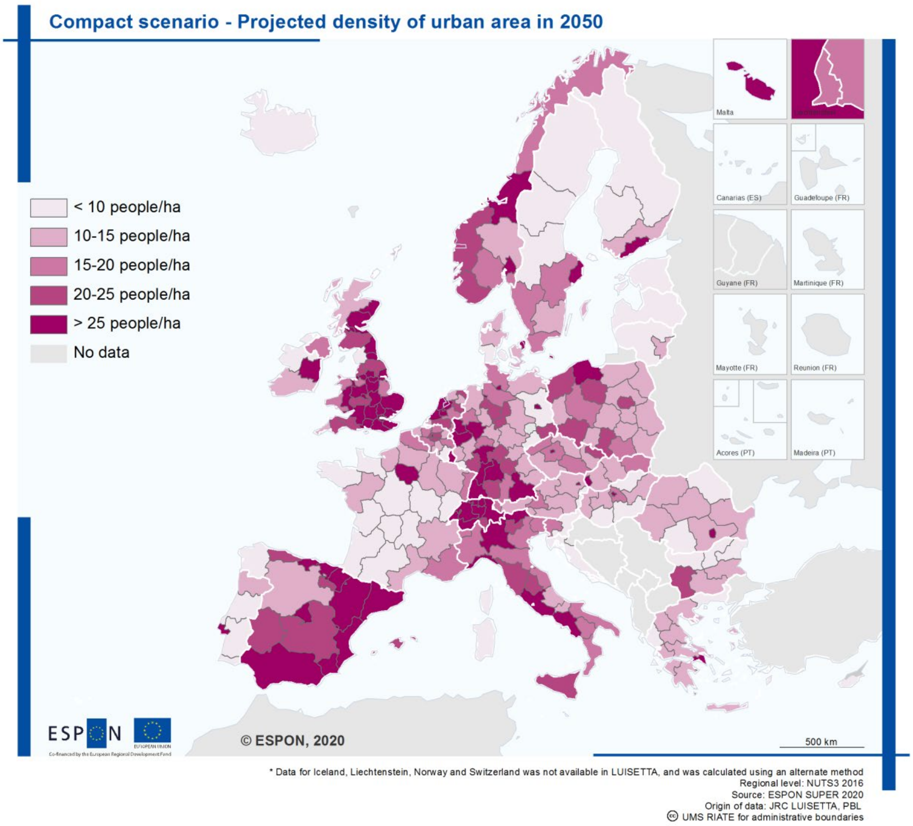
As Map 3.1 illustrates, the compact scenario produces urbanization in areas with large urban centres, and many of the biggest cities can be discerned in the figure as the areas gaining the most built-up area. Still, not every area gaining population gained the same amount of extra urban space. Due to lower attractiveness or transaction costs regarding building locations, some areas were not able to produce enough space to keep up with demand. In these situations, there was further densification in the existing urban fabric – for example, by redevelopments replacing single-family homes with apartments, adding floors to existing buildings or subdividing homes into smaller (studio) units, sometimes to sublet. As displayed in Map 3.2, we can see this densification in more areas than just large cities: also large parts of Spain, Italy and southern Germany show more people living per hectare of urban fabric.

As regards **economic sustainability**, there were some clear advantages. Real estate values increased considerably, as predicted (e.g. Nelson et al., 2012, p. 107; Nilsson & Delmelle, 2018) and urban economies flourished from the opportunities provided by brownfield redevelopment (Hall, 2014). The proximity afforded by high densities allowed companies to decrease transport costs and facilitate communication between firms (Anas et al., 1998; Nelson et al., 2012). The compact city structure created inner-city jobs, aided the development of central business districts and resulted in higher energy efficiency (OECD, 2012). In a compact city, heat exchange between buildings is greater, reducing energy costs (Boyko & Cooper, 2011; Naess, 2006; OECD, 2012, p. 61). The need of materials for buildings and road infrastructure also decreases due to efficiency gains (Naess, 2006). However, land-use controls might result in a net welfare loss if one considers the slowed growth outside the main cities (Cheshire et al., 2018). Finally, with respect to transportation, the compact city structure made high-quality transport connections more viable, but also increased the risks of congestion and overcrowded public transportation (de Nazelle et al., 2010; Litman, 2019).

Map 3.1: Compact Urbanization - Change in urban area relative to starting year (2020-2050)



Map 3.2: Compact Urbanization - Density in population per ha of urban fabric (2050)



As regards **ecological sustainability**, the sparing of non-built space outside the city boundaries can be viewed positively (Soga et al., 2014; Sushinsky et al., 2013). These policies proved effective in curbing 'exurban' development, defined as urbanization which is too diffuse to be viably served by water or sewer infrastructure, and which is highly car dependent (Nelson et al., 2012, p.49). Given that urban form influences the choice between walking, public transport and private vehicle (Owen, 2009; Pooley & Turnbull, 2000; Rajamani et al., 2003), private car use decreased. Moreover, lower land consumption rates gave flexibility with respect to future ecological planning (Van Der Waals, 2000; Westerink et al., 2013). Innovations such as green roofs, vertical gardens and tiny urban forests provide much-needed ecological services in compact urban areas. Nevertheless, development in compact cities usually comes at the expense of urban green areas, for example in Helsinki (Hautamäki, 2019) and Amsterdam (Giezen et al., 2018). Given the fact that the new development in this scenario is at a higher density, this trade-off should be positive on balance in quantitative terms. Qualitatively it can be debated whether a hectare of community garden, park or football field in a city is more valuable in terms of sustainability than a distant hectare of agricultural land. In fact, sacrificing these kinds of green spaces can aggravate local pollution concentrations (Glaeser & Kahn, 2010), urban heat island effects and vulnerability to natural hazards (Burby et al., 2001). Finally, it proved increasingly difficult to find space for renewable energy in the compact city (Marco Broekman et al., 2017).

As regards **social sustainability**, the containment scenario held some disadvantages. Housing prices tended to rise, and where no vigorous affordable housing policy was implemented, lower-income households became priced out. In some places, this manifested itself in discriminatory practices, such as against immigrants. As feared, contagious diseases can spread more rapidly in densely populated areas. In addition, there are increased nuisances such as noise and pollution as well as diminished access to green spaces (Giezen et al., 2018). Inhabitants of compact cities are potentially healthier because they walk and cycle more (OECD, 2012), but are simultaneously exposed to more air pollution unless this is also reduced by other measures. In addition, the shorter distances reduce car dependency, thus lowering social segregation and improving access to local services, jobs and recreational spaces (Nelson et al., 2012). Finally, smaller physical distance between people increases interaction between different social classes and origins, tradition, custom and culture (Jacobs, 1961).

3.3 Polycentric scenario

3.3.1 Rationale

Starting in 2020, a policy of urban clustering had been promoted throughout Europe to avoid both the disadvantages of haphazard urbanization, which deplete natural resources and undermine the vitality of cities, and the disadvantages of urban containment which create big-city problems and ran counter to the housing preferences of many citizens. A careful selection was made from sustainable urban development policies that had proved successful in the past plus some innovations. The result was to encourage urbanization in and around midsize towns, preferably near rail stations. By 2050, a more polycentric pattern of development began to emerge.

Looking back, there were various reasons behind this course of action. Attitudes regarding where and how to live had consistently shown that people appreciated urban lifestyles with amenities nearby, but also wished to live somewhere where the open countryside was within arm's reach and avoided big-city problems like traffic congestion and noise and air pollution. In the wake of faceless globalization, pandemics, climate change and other external threats, people desired the security and scale of a midsize community. So, despite bold predictions of grand revolutions in urban development heralded by new technologies and rapid societal change, the desired city structure in 2050 followed the ancient polycentric pattern of towns.

Many factors influenced this change. Rebelling against the populist revolt of previous generations, interdependence was embraced: the theory of neo-medievalism and post-territorialism which had seemed absurd in 2020, gradually became accepted as functional relationships became more important than jurisdictions – even national borders. In addition, environmental awareness of citizens increased as the effects of climate change became increasingly unavoidable; the reaction to extreme weather events demanded cross-border cooperation and walkable human-scale communities with good public transportation fit the environmentally aware mindset. Moreover, the demographic pressure in Europe had stabilized and the population aged significantly; many elderly people sought out the familiarity of traditional town structures and appreciated the comfort and sociality of collective transport. Moreover, digital connection had become so pervasive and sophisticated that cyberspace was as important as physical space. This became reflected in new attitudes towards mobility and proximity. The ideal of owning a private car waned, spurred in part by the availability of other transport services.

The millennials decided to reinvent urban areas to suit their needs. A policy package was devised to promote 'smart' polycentric growth that sought a balance between economic, environmental, and social aspects of planning and development while making efficient land-use decisions (Daniels & Lapping, 2005). An important aspiration is to provide good access to urban amenities (Handy, 2005), often by locating new compact neighbourhoods within one kilometre from a rail station or by building light-rail connections in midsize towns (Bertolini et al., 2012; Papa & Bertolini, 2015). A number of policies enacted in the 2000-2020 period provided inspiration for policy packages throughout Europe. These were territorially differentiated for maximum impact.

3.3.2 Policy package

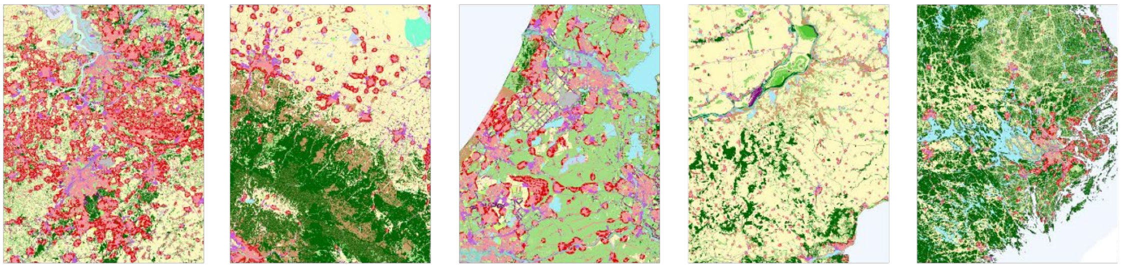
With respect to urban areas, a number of developments provided inspiration. One of the most prominent examples was Ørestad, Copenhagen's linear new town built around elevated light-rail stations. There were other examples in Europe, such as the Dutch *stedenbaan* project and many densification schemes near S-Bahn stations in Germany. Other urban plans that promote a polycentric urban structure and low-density expansion included the 2007 General Urban Development Plan of the City of Sofia and the City of Stockholm which integrated land use, housing and transport planning was pursued (Paulsson, 2020). Finally, the Helsinki region introduced agreements on land use, housing and transport (MAL) to great effect.

The same philosophy could also be applied in rural areas, by encouraging new development around rural stations rather than in car-dependent areas, or by favouring development contiguous to current buildings. At the regional level, the general development plan of the City of Stara Zagora encourages a new polycentric urban model for the future development of the city and its surroundings and the Tri-City metropolitan area in Poland planning promotes a harmonious development of the metropolitan area, enhancing public transport.

3.3.3 Impacts

By 2050, the decades of sustained policy decisions on urbanization and land-use could be read in the physical landscape. Some green areas near large cities had been sacrificed for urban development, but others remained largely intact. Cities spawned new settlements along infrastructure routes, particularly at train stations, like a string of beads. This allowed those living in these clusters, proximity to the surrounding rural area, while at the same time providing access to urban amenities via the rail line. Some reflected on this development positively, while others were more sceptical about the sustainability of this policy course. Did it serve the long-term economic, ecological and social goals it aspired to?

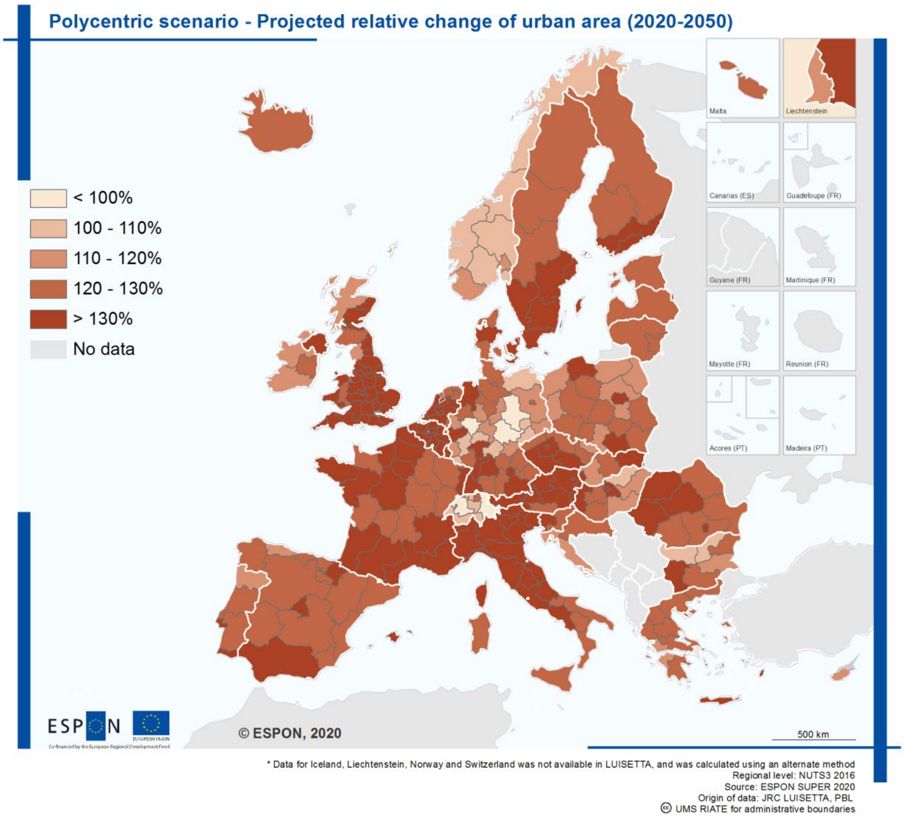
Figure 3.2: Sample of polycentric scenario 2050 output for five selected regions



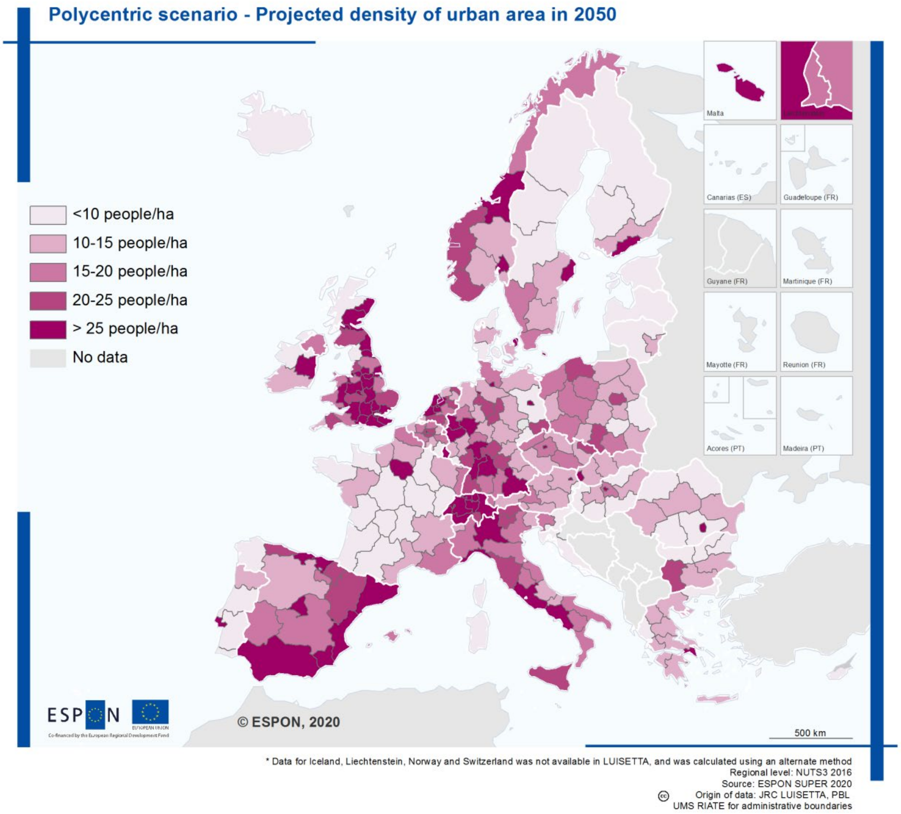
Bruxelles-Antwerp region, Belgium | Bologna-Ravenna region, Italy | Randstad region, Netherlands | Constanța region, Romania | Stockholm region, Sweden

Figure 3.2 displays the typical urbanization pattern produced by the polycentric scenario by 2050 in the LUISETTA model. The dark red regions show the new urban fabric; the light red areas were already built-up at the beginning of the scenario period. Here we can see that smaller towns are preferred locations for new development. In the Randstad region and Bologna-Ravenna region, it accentuated the already polycentric urban structure but sometimes resulted in towns growing into each other. Similar tendencies were apparent in the case of the, the Constantia region in Romania, but were dampened by the low growth overall. Stockholm which already had polycentricity as a long-term planning strategy saw development continue on the ‘fingers’ stretching outwards from the core city.

Map 3.3: Polycentric Urbanization - Change in urban area relative to that in starting year (2020-2050)



Map 3.4: Polycentric Urbanization - Density in population per ha of urban fabric (2050)



The aggregated model output for the polycentric scenario regarding urban development shows that conversion to urban land use occurred mainly in more populated regions. Partly for this reason, some countries show internal divisions such as France, Germany and Italy, while others are more homogeneous (Belgium). The polycentric scenario also produced increased densities (Map 3.4). The main cities gained more population than urban fabric, but this tendency was also visible many regions, particularly along the Mediterranean coast. In areas with less development pressure like rural France or Scandinavia or Romania, this was less pronounced.

The polycentric scenario clearly had a positive impact on **economic sustainability**. Like the urban containment scenario, it created enough density through clustering to profit from agglomeration economies (Rosenthal & Strange, 2008; Storper & Venables, 2004). On top of this, it created more space for business, thus relieving pressure from the Central Business Districts (Knowles, 2012). Many major cities benefitted economically from each other by reducing travel times between hubs, although some continued to compete with each other, thus undermining synergy (Balz & Schrijnen, 2016; Meijers, 2005). Because this scenario did connect the urbanization process to the development of public transport infrastructure, the accessibility of services and jobs of many residential areas improved. The polycentric scenario provided housing supply for both low income and high-income households. In many urban areas, open green spaces could be preserved.

This scenario had mostly positive impacts on **ecological sustainability**. In many urban areas, dense, walkable zones and good public transport connections reduced car mobility and air pollution levels (Sider et al., 2013). Because of the polycentric spatial pattern, residential areas were often close to open green spaces like parks and recreational space. Given the polycentric pattern more space was available for various possible future uses, including risk mitigation of natural hazards (e.g. water retention) or utilization of renewable energy sources (Kenworthy, 2006; Van Der Waals, 2000; Westerink et al., 2013), than in the compact scenario. On the other hand, some urban areas did not have enough space to produce all of its own energy use from renewable sources, as predicted (Marco Broekman et al., 2017). Also, the polycentric scenario often led to a reduction of biodiversity in the area since new construction was still considered (Weller et al., 2019).

Regarding **social sustainability**, both positive and negative effects were noted. Affordable housing was an important part of most clustering strategies. However, housing prices may increase due to enhanced transport accessibility, depending on regulations and policy schemes (Nilsson & Delmelle, 2018). In some areas the clustering strategies discouraged social segregation and inequity, by deliberately building mixed residential areas. But in other areas they promoted it, by allowing the affluent to live in the historical city centres, whereas the poor were driven to the urban fringe. Often, the quality of life in residential areas increased by the provision of green public and recreational spaces (Knowles, 2012; Pojani & Stead, 2015; van Lierop et al., 2017) and by the walkable neighbourhood design (Guthrie &

Fan, 2016). In some residential areas, noise pollution grew because of the proximity of railway tracks (Pojani & Stead, 2015), although new technologies reduced this impact.

3.4 Diffuse scenario

3.4.1 Rationale

Starting in 2020, a bold policy of urban diffusion was embarked upon to allow and encourage Europeans to enjoy the pleasures of countryside living. It was felt that citizens should have more control over where and how they wanted to live. Why should hard-working people be forced by government bureaucrats to live in crowded cities when there was ample space outside to enjoy the fruits of their labour? The increased demand for housing in a natural environment was facilitated by planners. Urban design concentrated on granting as much privacy and green space to individuals as possible through large-lot zoning and long driveways. Given the low densities, public services and infrastructure were minimal: new developments – mostly as detached family homes or second homes – were built on existing roadways and were often self-sufficient. By 2050, low-density urban functions had displaced agriculture in high-growth regions and most families in Europe revelled in the comforts of a spacious home with an even more spacious yard.

Looking back, there were various reasons behind this course of action. Attitudes regarding where and how to live had become increasingly individualistic rather than collective. Since 2020 a countermovement of ‘unplugging’ gained in popularity as tranquillity and privacy became luxuries; ideally this should occur in a somewhat remote setting, where the hum of delivery drones was less intrusive. After the Corona pandemic of 2020, the prospect of being quarantined to a large house with a garden was seen as far preferable to being confined to a tiny apartment, to say nothing of the enhanced risk of contagion in dense urban areas.

Many factors influenced this change. One was increased environmental awareness of citizens as the effects of climate change became increasingly unavoidable. Many sought high ground in order to avoid the flooding after extreme weather events. The increasing heat-island effects had further increased the popularity of building a home in an attractive, green environment. Moreover, the demographic pressure in Europe had stabilized and the population aged significantly; there was enough space to spread out, and many desired to spend their retirement years in spacious, more rural, surroundings. Many coveted the ideal of off-the-grid living in remote eco-communities. Moreover, digital connection had become so pervasive and sophisticated that cyberspace was as important as physical space. This could be seen in changing attitudes towards mobility and proximity. It was perfectly possible to work, visit family, shop or play together at any distance. If necessary, one could travel physically in a personal solar-powered self-driving vehicle (equipped with full VR capability) which would skilfully navigate the thick traffic on the roads or, if in a hurry, order a lift from a transport drone.

The millennials reinvented urban areas to suit their needs. Government policy was called on to make it feasible to claim a stake in the good life in the countryside: diffuse development is not unplanned but originates from local planning practices mainly performed by municipal authorities (Burriel de Orueta, 2009; Pagliarin, 2018). To achieve this, planning departments were made leaner, and land-use decisions streamlined and simplified. Self-empowerment was further stimulated by generous fiscal arrangements for homebuilding, private transport and energy independence. More importantly, restrictive measures at higher tiers regarding conservation of landscapes, natural areas and the like were abolished or relaxed. A number of policies enacted in the 2000-2020 period provided inspiration for policy packages throughout Europe. These were territorially differentiated for maximum impact.

3.4.2 Policy packages

In urban areas, governments prioritized the building of eco-villages and promoted self-sufficiency of the new inhabitants. One example is the Oosterwold area in the Netherlands which suspends most planning restrictions, allowing landowners to build whatever they want, provided they do so in coordination with their neighbours and that they pay all infrastructure and service costs (Cozzolino et al., 2017; Jansma et al., 2013). Similarly, the Belgian tradition of allowing new homes along existing roads was viewed as a way to save on public costs. As cities became emptier, more extensive use of them became feasible; the Parckfarm project in Brussels on urban agriculture pointed a way forward.

In rural areas, it was decided to cordon off the most valuable natural areas (Natura 2000) and make the rest open to development, thus maximizing the opportunity for people to realize their dream of a house in the country. Policy can also directly support this dream, by for example providing fiscal incentives for housing outside urban areas, as was done in Lithuania to promote shrinking areas near large cities. Finally, amnesty could be granted for illegal second-home development, such as in Croatia.

3.4.3 Impacts

Urbanization largely occurred piecemeal: first areas near existing urban areas were built up, and gradually development radiated outwards into more rural and natural areas. **By 2050**, these areas had absorbed a significant portion of the urban population, resulting in an absolute decline within cities, heralding the beginning of a post-urban era. Meanwhile, the countryside surrounding urban areas assumed first exurban, and then increasingly suburban characteristics, until they met the next town. Some reflected on this development positively, while others were more sceptical about the sustainability of this policy course. Did it serve the long-term economic, ecological and social goals it aspired to?

Figure 3.3: Sample of diffuse scenario 2050 output for five selected regions

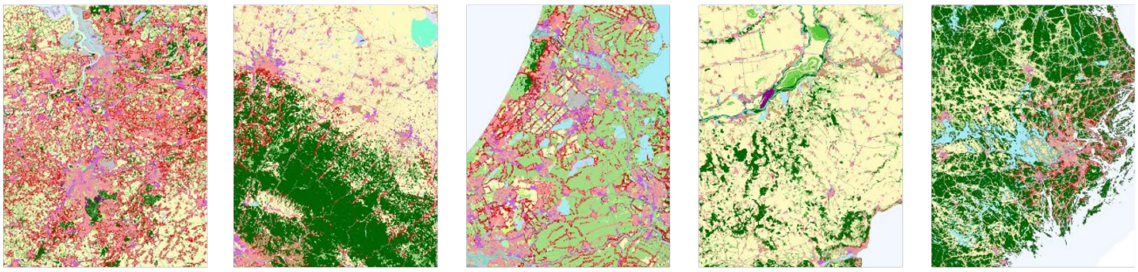


Figure 3.2 displays the typical urbanization pattern produced by the diffuse scenario by 2050 in the LUISETTA model. The dark red regions show the new urban fabric; the light red areas were already built-up at the beginning of the scenario period. The diffusion of low-density urbanization along roadways was visible throughout the European territory. The Brussels-Antwerp area become an even more amorphous urban field than before and the scattered development in Romania became slightly more so given the low development pressure. On the other hand, the Randstad exhibits extensive ribbon development, which is uncharacteristic for the Netherlands. Not only agricultural land was consumed: in the Bologna and Ravenna region as well as in Stockholm, hills and protected natural areas progressively succumbed to development pressure.

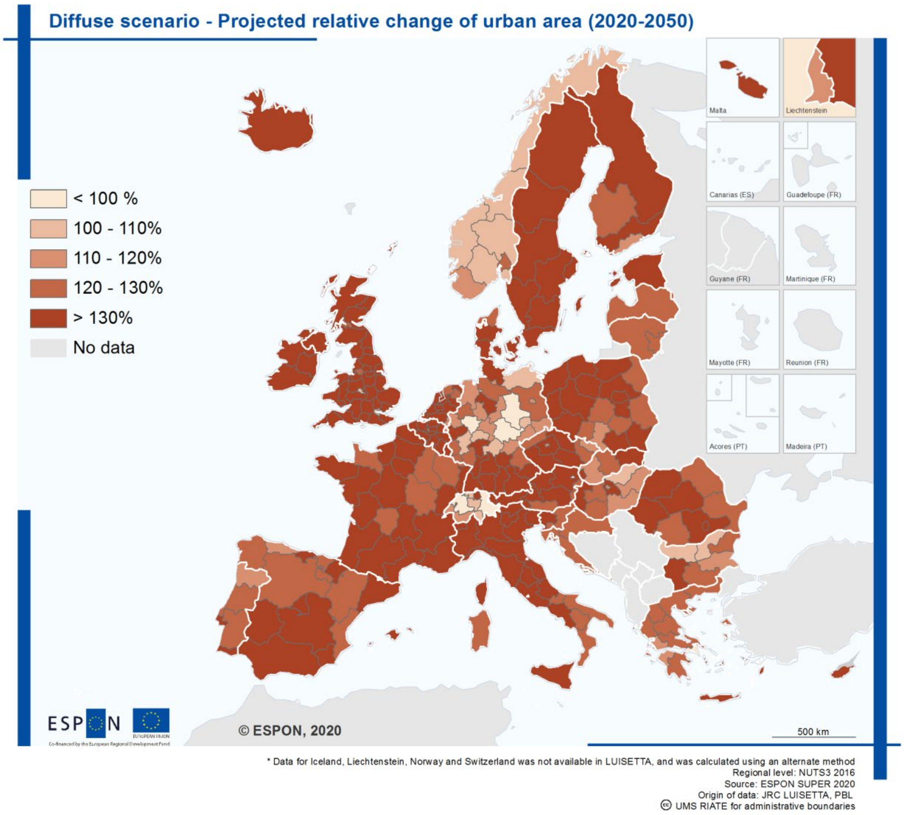
The diffuse scenario shows the most net increase in urbanization of the three scenarios; there is a 120-140% increase or more across the majority of the territory modelled, making it difficult to discern hotspots (see Map 3.5). Areas which show less urban growth include parts of Germany, Bulgaria, Switzerland, and Norway (although the latter two were calculated using a slightly different method). Despite the local diffusion and reduction of densities, at the regional level many areas increased their density. This is most pronounced in high-growth urban regions which comprise the ‘Blue Banana’ stretching from the UK to Italy and along the Spanish coast.

In many urban areas, the diffuse development scenario had positive as well as negative impacts on **economic sustainability**. The allocation of urban land followed the rules of the market. Because of lower land prices, building and development on greenfield were usually much cheaper than the regeneration of brownfields (Bruegmann, 2006). This resulted in lower prices for both industrial buildings, offices, and housing. Therefore, low land prices stimulated housing demand and job growth (Oueslati et al., 2015). This was followed by an advance in economy and transportation technology, which allowed more dispersed spatial distribution of people and economic activities. However, many locations in the dispersed urban pattern could not be connected to public transport. Travelling by car remained the default way of transportation. Accordingly, transportation costs were much higher than in compact cities (EEA & FOEN, 2016; Longley et al., 2002). Higher costs were also associated with traffic congestion and increasing needs for the extension of urban infrastructure in newly developed regions (Cinyabuguma & McConnell, 2013; EEA & FOEN, 2016; Hortas-Rico & Solé-Ollé, 2010; Klug & Hayashi, 2012). Costs for local public services increase including the security, waste collection, sanitation, road cleaning; and public lighting (Gielen et al., 2019). Furthermore, low-density living increased energy consumption per person (Couch et al., 2008; EEA & FOEN, 2016; Newman & Kenworthy, 1999). Despite the development of technology and transport, the majority of jobs were still located in city centres or Central Business Districts (OECD, 2018), and accessibility of central services and jobs was lower due to long distances. Over time, as jobs followed suit, some became closer to residential areas, but the lower densities did not necessarily mean shorter distances.

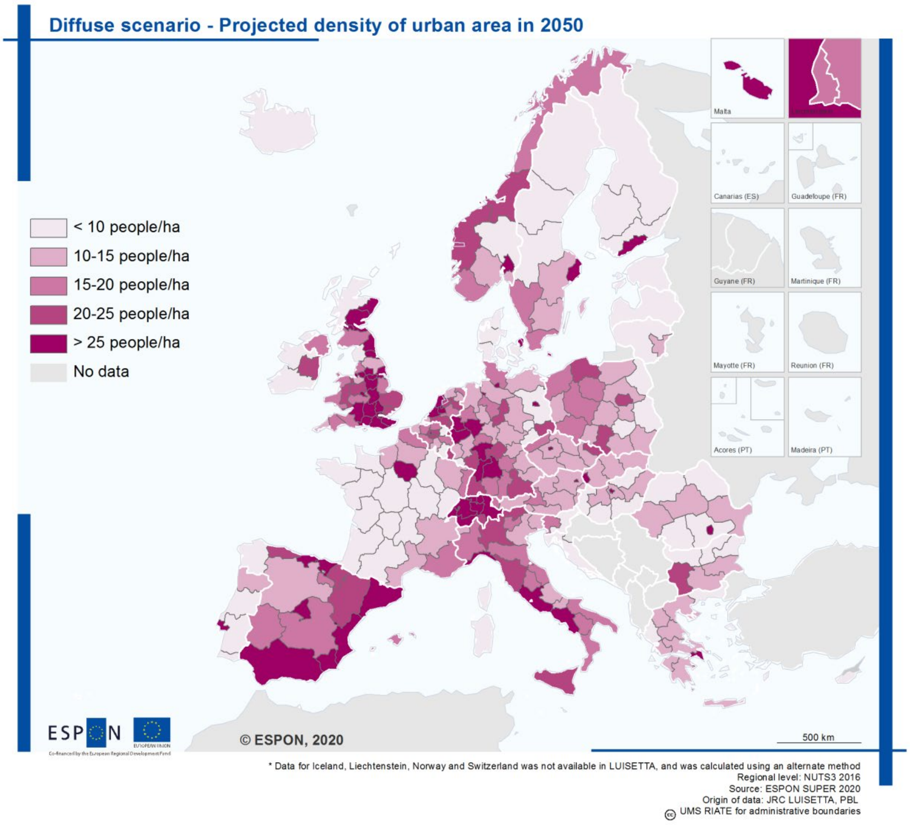
Regarding **ecological sustainability**, this scenario had mostly negative impacts. Air pollution levels as a whole were higher than in the other scenarios, due to enhanced use of cars and less regulation regarding emissions (Glaeser & Kahn, 2010; Norman et al., 2006). On the other hand, this pollution was less acute given the more extensive use of space. Problems of higher noise and light pollution were also observed (Bennie et al., 2014), but with the same caveat that this was dispersed over a larger area. Because of the extensive land use, there was a loss of agricultural land and open space, resulting in a decrease of biodiversity of species dependent on this kind of land use. On the other hand, the greater number of green and open urban spaces (e.g. unbuilt plots, large backyards, parks) provided other species with a new habitat. Regarding climate change, this scenario had negative as well as positive impacts. Transition to more sustainable energy sources proved to be more difficult than in the other scenarios due to higher land consumption rates, and the dispersed spatial pattern increased the surface area of urban ‘heat islands’ (EEA & FOEN, 2016; Stone et al., 2010). However, well-planned diffuse urbanization provided more land for buildings and outdoor activities, including urban green space (Wolch et al., 2014) and allowed for better climate adaptation strategies (e.g. space for water retention).

Regarding **social sustainability**, this scenario had positive as well as negative impacts. Because of low housing prices, people could easily move to low-density suburbs, which offered a desirable place to live for most people (García-Coll & López-Villanueva, 2018), as they offered privacy and large gardens (Longley et al., 2002). For many inhabitants, living close to nature reduced stress and provided a feeling of well-being. But there were also negative impacts, especially regarding social equity and mobility (Kenyon, 2011; Morency et al., 2011). In many urban areas, segregation was much more prominent than in the other scenarios (Antoniucci & Marella, 2018). Moreover, in some urban areas the dispersion led to inner-city decline, disadvantaging those who chose to remain (Xie et al., 2018).

Map 3.5: Diffuse Urbanization - Change in urban are relative to that in starting year (2012-2050)



Map 3.6: Diffuse Urbanization - Density in population per ha of urban fabric (2050)



3.5 Reflection on sustainability

The three scenarios elaborated in this chapter are not intended as predictions nor as a scientifically valid ex-ante assessment of policy choices. Instead, they offer a structured way to reflect on the inestimable complexity and diversity of Europe and the various trade-offs and synergies inherent in land-use decisions. They are also intended to drive home the fact that the direction urbanization takes is the result of human decision-making, and therefore can be influenced by concerted action. In short, the scenarios need not be likely or realistic as long as they are plausible enough stimulate a discussion on the advantages and disadvantages of policy directions with respect to sustainability.

How can we compare the scenarios with respect to sustainability? The individual outcomes described above were based on the sustainability assessment framework presented in Chapter 1, and cited sources drawn directly from Table 1.2. This already establishes a link between the storyline and the scientific literature. In order to make a more general comparison across scenarios, we consulted the more synthetic Table 1.1 which provided a simpler overview.

From this analysis we find that none of the three scenarios is a clear 'winner' in terms of sustainability. Even diffuse development, usually labelled as sprawl, is not negative on all counts. The wide variety of results and the futility of trying to balance fundamentally different values (e.g. health, jobs, biodiversity) in a scientific manner means that one cannot tally the results to obtain a net sustainability score, even within individual dimensions. Moreover, the large number of ambiguous results (+/-) confirms that such aggregation would lead to unfounded conclusions anyway. Most importantly, the scores were given on the basis of best judgement of researchers, and do not reflect actual preferences of elected officials who are charged with actually making the decisions in a particular territory. The weight given to indicators is ultimately a political choice.

Looking closer at the economic dimension, a disciplinary bias might be present. The few economic and 'sprawl apologist' studies consulted argue that diffuse development is closest to market distribution, hence efficient and wealth-producing. Most of the other collected sources disagree due to missed agglomeration effects, high energy and transportation costs as well as the strain on public finance. The compact and polycentric scenarios score roughly equally but in different categories. Regions suffering from stagnant housing production may look more favourably on polycentric, for example, whereas those with severely limited budgets may gravitate towards compact urbanization.

The ecological dimension presents a similar overall picture but is riddled with internal dilemmas and feedback. For example, the lower overall pollution levels in compact and polycentric is offset by higher concentrations. To make an educated policy decision, it is therefore necessary to assess this trade off with respect to the local situation, for example, if unhealthy concentrations have already been reached. Similarly, the ecological benefit of conserving land through density in the compact and polycentric scenarios also implies less space for ecological services and renewable energy. Which route is most attractive will again depend on local policy objectives. The diffuse scenario is generally negative on all environmental indicators except space for water retention.

The social dimension, finally, presents a much different picture. Here, the diffuse scenario does not lag behind the others, showing some clear advantages over the other two in terms of individualistic indicators such as housing affordability and satisfaction with residential environment. It fares less positively in terms of mixed-use areas and social inclusion. Although urban containment should drive up housing prices, such policies are generally implemented alongside affordable housing policies, which offsets this impact. Interestingly, given the heightened interest in health with respect to COVID-19 pandemic, the results were too mixed to offer any real guidance on this matter.

In conclusion, the scenarios and the assessment framework provide a way for decision-makers and policymakers to talk about urbanization and land-use decisions. It opens up a space for policymakers, and indeed everyone, to reflect on fundamental choices without becoming mired in the minutiae of everyday struggles or notions of plausibility or feasibility. As such it provides a structured forum for discussion, which can promote a common understanding of long-term issues, find common ground, and pave the way to commitment to strategic collective action.

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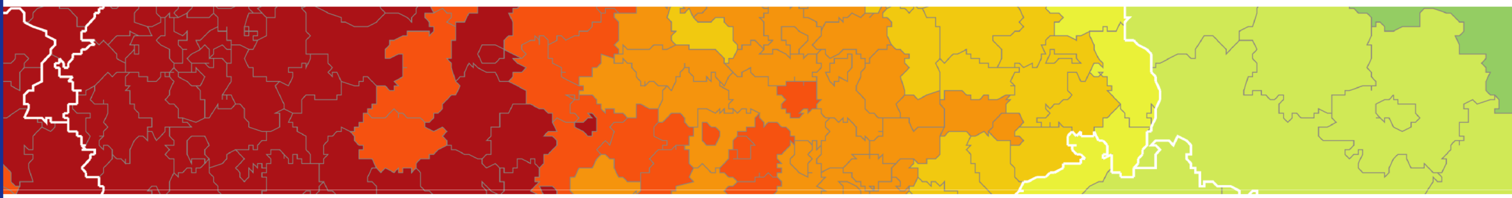

ISBN: 978-2-919795-39-0

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ESPON EGTC
4 rue Erasme, L-1468 Luxembourg - Grand Duchy of Luxembourg
Phone: +352 20 600 280
Email: **info@espon.eu**
www.espon.eu, **Twitter**, **LinkedIn**, **YouTube**

The ESPON EGTC is the Single Beneficiary of the ESPON 2020 Cooperation Programme. The Single Operation within the programme is implemented by the ESPON EGTC and co-financed by the European Regional Development Fund, the EU Member States and the Partner States, Iceland, Liechtenstein, Norway and Switzerland.