Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# Integrating ecosystem services in the assessment of urban energy trajectories – A study of the Stockholm Region

Ulla Mörtberg [a,*], Romain Goldenberg [b], Zahra Kalantari [b], Olga Kordas [a], Brian Deal [c], Berit Balfors [a], Vladimir Cvetkovic [a]

[a] KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
[b] Stockholm University, SE-106 91 Stockholm, Sweden
[c] University of Illinois Urbana–Champaign, USA

## HIGHLIGHTS

- A diffuse urban pattern leads to low access to jobs and high energy consumption.
- A dense monocentric urban pattern implies high energy efficiency and low access to ES.
- A dense polycentric urban pattern allows for a combination of urban functions.
- ES needs to be integrated into sustainability assessments of urban policy options.

## ARTICLE INFO

*Article history:*
Received 2 March 2016
Received in revised form
20 August 2016
Accepted 13 September 2016

*Keywords:*
Energy efficiency
Urban transport
Accessibility
Urbanisation
Integrated sustainability assessment
Urban ecosystems

## ABSTRACT

Urban development trajectories are changing towards compact, energy-efficient cities and renewable energy sources, and this will strongly affect ecosystem services (ES) that cities are dependent on but tend to disregard. Such ES can be provisioning, regulating and cultural ES, around which competition over land resources will increase with energy system shifts. Much of this can be foreseen to take place within urbanising regions that are simultaneously the living environment of a major part of the human population today. In order to inform critical urban policy decisions, tools for integrated assessment of urban energy and transport options and ecosystem services need to be developed. For this purpose, a case study of the Stockholm region was conducted, analysing three scenarios for the future urbanisation of the region, integrating a transport energy perspective and an ES perspective. The results showed that a dense but polycentric development pattern gives more opportunities for sustainable urban development, while the dense monocentric scenario has apparent drawbacks from an ES perspective. The methodology is compatible with a model integration platform for urban policy support and will thus enable integrated policy assessment of complex urban systems, with the goal of increasing their sustainability.



## 1. Introduction

Changes in urban development trajectories towards compact, energy-efficient urban agglomerations and renewable energy sources will have major impacts on ecosystem services (ES), which cities are dependent on but tend to overlook. Increasing competition over land resources between construction and ES interests are taking place within urbanising regions, the living environment for a majority of the human population today (UN, 2015). ES can be defined as the contributions of ecosystems to human well-being and include habitat, provisioning, regulating and cultural ES (de Groot et al., 2002; MEA, 2005; Balmford et al., 2008; TEEB, 2012). While habitat services support the other ES, provisioning services are the goods obtained from ecosystems, such as food, timber, bioenergy feedstock and fresh water. Regulating services are the ecosystem's control of natural processes, such as climate regulation, disease control, erosion prevention and water flow regulation. Cultural services are nonmaterial contributions of ecosystems to human well-being, such as recreation and aesthetic values. Regulating and cultural ES give direct benefits to urban citizens and are essential for attractive cities in promoting liveable urban landscapes, recreation values and the health of citizens (Bolund and Hunhammar, 1999; Gómez-Baggethun and Barton, 2013). A major challenge is therefore to simultaneously develop compact, energy-efficient and liveable cities (Grimm et al., 2008; EEA, 2009; OECD, 2012; Elmqvist et al., 2013; World Bank, 2014). In order to

* Corresponding author.
*E-mail address:* mortberg@kth.se (U. Mörtberg).

http://dx.doi.org/10.1016/j.enpol.2016.09.031
0301-4215/© 2016 Published by Elsevier Ltd.

inform important policy decisions, integrated sustainability assessment of urban energy and transport options and access to ES is necessary.

More than half of the world's population lives in cities and two-thirds are expected to live in cities by 2050, while the fastest growing urban agglomerations are forecasted to be medium-sized cities with populations of 1–5 million (United Nations (UN), 2015). A dominating trend of the urbanisation process today is that the physical extents of urban areas are expanding faster than urban populations that will lead to a significant land-uptake for urban expansion along with the increasing number of urban residents (Angel et al., 2011; Seto et al., 2013; Hennig et al., 2015; UN, 2015). The scattered, low-density settlement patterns that often spread around growing cities can be called urban sprawl (Black, 1996; Ewing, 2008; Hennig et al., 2015). This has been characterised by incremental development with little comprehensive public planning, an orientation towards individual car transportation, poor accessibility of related land uses to one another, and a lack of functional open space (Ewing, 2008; Botequilha-Leitão, 2012). Main impacts of urban sprawl come from the inefficient and segregated land use with high travel demands and low energy efficiency, and from loss of open space and ES, with economic, social and environmental consequences (Real Estate Research Corporation, 1974; Deal and Schunk, 2004; Ewing, 2008; Travisi et al., 2010; OECD, 2012; Wilson and Chakraborty, 2013).

Urban policy and planning are increasingly focusing on the compact city, in order to achieve more sustainable urban development. This means promoting compact, intensely used cities with a minimum of transport, as well as attractive and liveable cities that preserve valuable open space (Jenks et al., 1996; Williams et al., 2000; Cities Alliance, 2007; EEA, 2009; OECD, 2012; World Bank, 2014). The idea behind the compact city is not only to reach high densities when it comes to e.g. number of residents per area, which may lead to unwanted effects such as increased traffic congestion and a lack of vegetation and open space in cities (OECD, 2012). In order for a compact city to be sustainable, not only is high density important – mixed land use is seen as equally important, as well as access to public open space and public transport (Table 1). According to the OECD (2012) and the World Bank (2014), the compact city is therefore characterised by shorter intra-urban travel distances, less car dependence, and better access to a diversity of local jobs and public services, and implies an optimum use of land resources. Among the assumed key benefits of the compact urban development are high energy efficiency, and attractive and liveable cities.

### 1.1. Urban form and energy efficiency

Cities consume more than 67% of the total world energy supply and produce more than 70% of $CO_2$ emissions, and are therefore recognised as having a major stake in the global climate change mitigation efforts (UNEP, 2011; Gudipudi et al., 2016). Increased energy efficiency and reduced $CO_2$ emissions in cities are considered to be related to improvements in the transport and building sectors that in turn can be influenced by urban development policies (Lefevre, 2009; Clark, 2013; Gudipudi et al., 2016). In this context, urban sprawl is thought to directly counteract the efforts to meet the provisions of the Kyoto Protocol to reduce greenhouse gas emissions (Bart, 2010; Hankey and Marshall, 2010; Jones and Kammen, 2014), while intensification of urban land use with increased population and employment densities has often been advocated as a pathway toward reaching the energy and climate objectives (Clark, 2013). According to Steemers (2003), the intensification of land use coupled with the sharing of physical infrastructure (e.g. roads, buildings, energy and water supply etc.) leads to a decrease of energy use per capita. This inverse relationship between urban density and energy consumption is well supported in the literature (Kirby, 2008; EEA, 2009; Gudipudi et al., 2016). For instance, Newman and Kenworthy (1989) found a negative relationship between density of cities and per capita energy consumption related to transportation. At household level, Liu and Sweeney (2012) showed that the heating energy consumption per household in the Greater Dublin Region is likely to be 16.2% lower in the compact city scenario than in the dispersed city scenario. As for the cross-sectoral perspective, a study of all inhabited areas in the US by Gudipudi et al. (2016) revealed a sub-linear relationship between population density and the total emissions (calculated as the sum of transportation and building emissions) on a per capita basis.

The potential of urban compaction and densification to increase the energy efficiency and decrease the $CO_2$ emissions of the transport and building sectors is connected with a number of both positive effects and negative externalities (Steemers, 2003; Gordon, 2008; Clark, 2013). In the transport sector, compaction and densification of population and jobs has been associated with shorter intra-urban travel distances, increasing pedestrian and bicycle access and access to public transport, decreasing car dependence, reducing the cost of transporting people, goods and services, as well as reducing overall fuel consumption (Steemers, 2003; Clark, 2013; Yin et al., 2013; Gudipudi et al., 2016). At the same time, the positive impact of densification is connected to negative externalities, such as increased roadway congestion (also associated with air pollution); limited housing affordability that in turn accelerates urban gentrification processes; and a lack of open space in cities (OECD, 2012; Clark, 2013). In the building sector, increased density implies increased energy efficiency through more efficient technologies in energy generation and consumption, such as combined heat and power, district heating and cooling; efficient heating, ventilating, air conditioning and building operation systems; as well as the urban symbiosis solutions for closing the loop of energy, materials and waste (Steemers, 2003; OECD, 2012). Also, densification can lead to reduced unit heating and cooling costs through decreased interior building volumes – a result of land prices rising under densification – and because of attached buildings generally having lower energy losses than detached ones (Steemers, 2003; Clark, 2013). However, the benefits of densification are combined with the negative effects from reduced availability of solar and daylight, and the shift from naturally ventilated to air-conditioned offices as a result of air and noise pollution (Steemers, 2003).

### 1.2. Attractive cities and ecosystem services

Desired attributes of sustainable cities are that they should be attractive and promote liveable urban landscapes and a high

**Table 1**
Comparing urban sprawl with assumed benefits of compact cities (adapted from OECD (2012) and World Bank (2014)).

| Urban sprawl | Compact cities |
|---|---|
| Low density, dispersed activities | High density, diverse activities |
| Segregated land use | Mixed land use |
| Inefficient land use | Efficient land use |
| Low accessibility to goods, services and activities | High accessibility to goods, services and activities |
| Private and gated open spaces | Public parks and facilities |
| Loss of green space | Conservation of green space |
| Movements particularly by car | Walking access |
| Road network designed for maximised vehicle movements, barriers to non-motorized transport | Public transport |
| Low energy-efficiency | High energy-efficiency |