PACT: Pathways for Carbon Transition

Deliverable D1

Urban schemes with decarbonised transport and energy systems

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1 Abstract

An increasing part of energy consumption takes place within cities. Cities as complex systems have different energy needs as well as different possibilities for energy supply. In consequence of different historic development but also of geographic situation, economic development and other influences like cultural aspects the energy-structure of cities differs. The focus of this paper will be on the relation between urban form and energy needs respectively possibilities of energy supply. Understanding of this relationship will be used for envisioning future long term energy scenarios for different imaginable settlements in Europe. Urban form influences heating, cooling but also the transport sector which shows its importance. It is difficult to deal with urban form because of definition problems, measurement problems, lack of data and practical research. Nevertheless without solving all problems the different aspects of urban form linked to the issue of energy is presented in this paper.

2 Introduction

2.1 The importance of land use patterns

In a time of increasing worry concerning the relationship between the man and its environment, the land-use issue is at the cross-road of the energy and climate perspectives. For instance, the European Environmental Agency has recently studied various land-use scenarios for Europe, taking into account economic, environmental and social issues (European Environment Agency, 2007). In particular, adapted solutions of mobility and energy supply for each type of socio-economic area and each time horizon will be required to meet the challenge of the post-carbon society.

Land use patterns as well as urban form are continuously changing in Europe and all over the world. This fundamentally happens due to economic reasons, such as transforming natural land into those for agricultural use or developing natural or agricultural land towards built-up area. The increased transformation of land for urban usage and growth of agglomerations is still following the regionally differentiated patterns of economic development. However, even in the economically declining regions, which suffer from depopulation as a consequence of general demographic changes, the extension of the built-up area continues. Recent literature has proved that urbanisation and population dynamics became decoupled recently. In a study investigating 15 European urban areas it has been found that during the 12 years from the mid-1980s to the late 1990s the urban population has declined by 2.8%, whereas the built up areas have grown approximately 9% (cf. (Kasanko et al., 2006)). This indicates that the US problem of urban sprawl is also the reality in Europe.¹

¹ This phenomenon is closely connected with the urban form, which is elaborately discussed in Dl. 1.1.
It also shows that land use pattern cannot be analyzed without regard to the current and future demographic development with respect to the sustainability: In a prospering growing region a certain land use development has to be appraised differently from the same development in an already declining region. Moreover, it is important for the analyses of the adaptation of transport infrastructure in the second part of the paper. Within this paper, the level of countries is regarded, which gives some hints of the demographic situation of the country as a whole and should be included when developing a typology in order to cluster the European countries. However, it bears the danger of averaging of regionally growing or declining tendencies.

Kasanko *et al.* also concluded that analysing and understanding land use dynamics "*is an extremely challenging task even in one urban agglomeration not to mention at national or European level*" (2006: 128). Due to the difficulty of collecting comparable data (Antrop, 2004), research on European urbanisation has been only little since recently. However, by having access to a comprehensive geographical database for different times it is possible to compare the absolute share and the changes for different land use categories in different countries and develop a land use typology.

**Fig. 1 Distribution of land uses in Europe (based on 100m grids)**
2.2 Land use patterns and transport infrastructure

The land use pattern, especially the built-up area interacts closely with the way people live, the location of their work, use of public and private services and how they spend their spare time. All this forms a certain mobility pattern. Moreover it strongly influences the need and relations of transporting goods. Each land use type will have specific implications for the transport infrastructure. Therefore the trunk lines of the development and the status quo of the fast modes rail and roads need to be considered and compared with the nationwide land use pattern.

The interaction between changes in land use/ built-up areas and transport infrastructure has been described in American planning literature as 'land-use transport feedback cycle'. It is based on the recognition that trip and location decisions co-determine each other and that therefore transport and land use planning needed to be co-ordinate. The set of relationships implied by this term can be briefly summarised as follows (see Fig. 2):

Fig. 2 The 'land-use transport feedback cycle'

Source: (Wegener, 2004)
The distribution of urban land uses, such as residential, industrial or commercial, over the urban area determines the locations of human activities such as living, working, shopping, education or leisure.

The distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities.

The distribution of infrastructure in the transport system creates opportunities for spatial interactions and can be measured as accessibility.

The distribution of accessibility in space co-determines location decisions and so results in changes of the land use system (cf. Wegener 2004: 3).

When envisioning the post-carbon society below, the transport infrastructure will be analysed for each land use cluster. By doing so, the extent of the interactions described above can be analysed in relation to the prevailing land use pattern and dynamics. Based on this, certain implications can be determined.

### 2.3 Land use patterns and energy infrastructure

Moreover, energy demand and the sources from which it is generated are influenced by the land use pattern. Thereby energy depends both directly and indirectly on land use patterns. The direct link arises because the production and distribution of energy requires space for plants, facilities and the networks. Even more space is required for the production of renewable energy, such as wind farms and biomass.

Nowadays energy supply in Europe is based on carbon sources, such as coal, oil and gas to a great extend. The production and use of these sources can have serious environmental impacts. However there are also non-carbon sources, such as nuclear power and renewable. The problems of nuclear energy, however, is well discussed (limitations of uranium resources, unsolved nuclear waste problem) so that a post carbon society can be only regarded as sustainable, if it is based on renewable energy sources.

Most of future energy scenarios suggest that future energy systems will increasingly rely on diffused renewable energy in both reference projections and carbon constraint cases, mainly because of the growing energy needs and the foreseeable depletion of fossil fuels resources. It has become strong evidence that biomass in particular would play a crucial role in low GHG concentration scenarios (Kitous, Criqui, Bellevrat, & Chateau, 2010). Biomass use would even theoretically allow for negative emissions, working as an atmospheric carbon sink, associating biomass combustion in power plants and carbon capture and storage (Azar, Lindgren, Larson,
& Möllersten, 2006). The ADAM\textsuperscript{2} project, which projected a higher share of renewable energy production in the total energy requirement, has tackled the issue of centralized vs. diffused energy supply. According to the EnerFuture scenarios\textsuperscript{3}, the share of renewable will increase by a factor 3 to 5 during the first half of the 21\textsuperscript{st} century. Fig. 1 shows the potential development of renewable energies in the future European primary energy supply. In particular, the scenarios provide an indication of the weight of land-intensive renewable energy technologies\textsuperscript{4} in this energy supply. This would increase from 75% today to almost 85% by 2050. More generally, the EMF21\textsuperscript{5} makes appear the role of land-use in GHG emissions mitigation, in particular when introducing land-use change and forestry mitigation options.

**Fig. 3 Share of renewable energy in TPES in EU-27 and land-intensive technologies deployment**

![Graph showing the share of renewable energy and land-intensive technologies](image)

However, diffused energy is still difficult and expensive to collect due to their low surface density, in comparison with traditional concentrating energy sources such as fossil fuels or nuclear. Collecting diffused renewable energy at large scales may induce huge transformations of landscapes, which would be shaped (again) at the human image. Attention must be paid to the way distributed energy production would

\textsuperscript{2} ADAM aims to support the EU in the development of post-2012 global climate policies, the definition of European mitigation policies to reach its 2020 goals, and the emergence of new adaptation policies for Europe with special attention to the role of extreme weather events. See the project website: http://www.adamproject.eu/.

\textsuperscript{3} The two scenarios presented on Fig. 3 come from Enerdata’s EnerFuture Forecasts service and are produced with the POLES model (April 2010 update). They integrate last developments realized for the ADAM and PACT European project (FP6 and 7), in terms of land-use modelling. They represent a business and usual case (S1 – Recovery) and a long term concentration target of 500 ppmv CO2eq without overshoot or a possible 450 ppmv CO2eq target with overshoot (S3 – Renewal). Renewal does not take into account particular additional support to renewable energy development, but only integrates a global climate policy. Alternative energies relative deployment compared to Recovery is a result of a carbon constraint applied to the energy system, which improves their competitiveness.

\textsuperscript{4} See next section for details on land-intensive renewable technologies

diffuse on territories, to ensure a certain level of biodiversity and natural resources conservation.

Generally renewable energy can be collected from all types of land use – urbanised and non-urbanised areas, although the implemented technologies may largely differ, in particular because of land availability. However, there are other constraints such as the social acceptability. Such difficulties are already observed with wind energy, often accused to damage landscape and to produce nuisance (the NIMBY syndrome - Not In My BackYard). As a consequence, new technologies should be implemented in the right place at the right moment to be efficient, in terms of satisfaction of needs, economic performance and social acceptability.

Therefore specific attention must be paid to the future energy demand and supply potential, in order to design the best future energy networks as possible, at the lowest environmental and economic cost.

Within this paper the potential complementarities and competitions between renewable energy supply and other land-uses is tackled. First, the potential role of renewable energy sources in a post-carbon perspective and their main technological features and relationship to land-use will be described. Thereafter the future challenges of harvesting renewable energy sources will be assessed for each land use cluster, based on a quantification of the potential of the use of solar and wind energy. Finally the difficulties and associated risks, in particular in relation with the land-use issue will be addressed.

2.4 Analysing land use patterns at the European Scale

2.4.1 Indicators

Within the discussion of land use and urban form, one of the key problems researchers face is the task of measuring land use patterns and change processes. Thus accessible indicators are needed to determine both land use type as well as the land use intensity (or compactness), which can be described as continuous or discontinuous urban fabric.

In order to measure the land use pattern and urban form and their changes on different scales, different approaches can be found in the literature. Generally studies use either statistical data for certain administrative units (municipalities, regions, or countries) or geographic-spatial data (going down to the level of site development. Furthermore a combination of both can be often found.

Statistical data can be obtained from the statistical authorities and comprise data on population, employment, planned and realised urban development.
In order to specify the compactness of development (or the degree of urban sprawl), density figures are often consulted. Most well-known research on compactness uses only population densities - usually in gross figures. It has been associated most strongly in sustainability arguments with the need to travel and the likelihood to choose to travel by car (for example (Barrett, 1996); (P Newman & Kenworthy, 1989)). Beyond the population it is In fact the area and density of built environment (net or urban density) that affects the loss of open or rural land ((Burton, 2002); (Sherlock, 1991)) and also the length of roads and other network infrastructure.

In contrast, geographic data are obtained from remote sensing technologies, such as aerial views or from photo-interpretations of satellite images. The most important database for Europe is called CORINE Land cover, whereas “CORINE” means ‘COoRdinate INformation on the Environment’, which is based on the results of IMAGE2000, a satellite imaging programme undertaken jointly by the Joint Research Centre of the European Commission and the European Environmental Agency (EEA).

The study of (Galster et al., 2001) used geographic data on the base of 1ha-grids, based on aerial photographs. They defined the following categories to specify urban land use:

- ‘Density’ (= the average number of residential units per spatial unit of developable land, p.687).
- ‘Continuity’ (= the degree to which developable land has been built upon at urban densities in an unbroken fashion, p.688).
- ‘Concentration’ (= the degree to which development is located disproportionately on relatively small space of the total area rather than spread evenly throughout, p.690).
- ‘Clustering’ (= the degree to which development has been tightly bunched to minimize the amount of developable land occupied by residential or non-residential uses, p.691).
- ‘Nuclearity’ (= the extent to which an urban area is characterised by a mononuclear (as opposed to poly-nuclear) pattern of development, p.694).
- ‘Mixed Uses’ (= the degree to which two different land uses commonly exist within the same small area, p.695).
- ‘Proximity’ (= the degree to which different land uses are close to each other across a bigger area, p.699).

However within the current PACT Project we have access to CLC which allows us to include the aspect of ‘continuity’ of urban fabric, when categorising the countries into land use types. This spatially specific information is a good indicator for the urban
density of built environment, rather than falling back on statistical data collected for a larger area, hiding the different patterns of land use as well as densities.

2.4.2 Datasources

2.4.2.1 Moland Project/ Database

The Institute for Environment and Sustainability in Ispra (Italy) (=Joint Research Centre of the European Commission) monitors land use/cover dynamics as a continuously evolving activity since 1998. The aim of MOLAND is to provide a spatial planning tool that can be used for assessing, monitoring and modelling the development of urban and regional environments.

Within the research project territorial data sets have been completed and validated for 25 European areas and for six mega-cities outside Europe, and the assessment of the derived data is progressing rapidly. Moreover, several new areas – six European and one non-European – are currently being studied. The analysis of the data sets is therefore quite advanced, and allows several investigations to be performed. In general geographical data from the early 1950s, the late 1960s the 1980s and the late 1990 have been created within this project.

There are a couple of studies on the compactness of land use pattern and urban form using this multi-temporal land use databank as data source. One example is a comprehensive Study by the Joint Research Centre conducted in 2004 (Kasanko et al., 2006). Investigating 15 medium-sized and large European urban areas, one of the main findings was that in all selected cities the built-up area has grown considerably over the study period from 1950s to 1990s throughout Europe; the average growth rate has been 87% ((Kasanko et al., 2006): 116). However the growth rates have converged towards the end of the study period. “Taking into account the relatively good representativeness of the studied cities, it can be assumed that urban land use dynamics have reached a certain degree of maturity in Europe […]” (p. 117). These findings have to be kept in mind when extrapolating the trends of land use changes analysed in this study.

Concerning the kind of land taken by urban expansion it has been found that the growth of built-up area since the 1950s has taken place mostly on previously agricultural land. The reason is that this land is technically more suitable for construction than natural (forest) areas both topographically and in economic terms. Moreover, natural areas are often considered as valuable recreational areas, so that urbanisation in those areas is usually avoided (p. 121).

However, although requested in time, it has not been possible by the editorial deadline to access and use the data for the current Deliverable. Thus, the results presented here will be based on the CORINE land cover data on the level of countries.
2.4.2.2 CORINE Land cover data

The CORINE Land cover data have been created by the European Environmental Agency (EEA) for the years 1990 and 2000. The provision of a third dataset with basis year 2006 is in progress at the moment. They show the actual land cover and land cover changes in ecosystems such as forests, lakes, pastures etc. and the impact of human activities (such as housing, food production, transport etc.) on land use. More than forty land cover classes are used to map changes over time, “all of which tell their own story of how decisions made across Europe have led to alternations in the landscape” ((European Environment Agency, 2004): 4).

Thanks to the comprehensive provision of geographical data on the EEA homepage, CORINE data are the main source for the results of this Deliverable. Thereby the land use classes have been aggregated to

- built-up area (continuous and discontinuous)
- agricultural area
- natural land (cf. Table 1)

Afterwards the polygons of the aggregated land use types have been geographically intersected with the boundaries of each country. Additionally specific land cover classes have been intersected separately in order to analyse the share of disperse, discontinuous urban fabric (marked in yellow in Table 1) and the amount of transport infrastructure (marked in turquoise in Table 1) respectively. Thereby “discontinuous urban fabric” is defined as area, where buildings, roads and artificially surfaced land cover between 50 and 80% of the total surface area of the one unit of a size of less than 25 ha ((European Environment Agency, 1994): 102).


<table>
<thead>
<tr>
<th>CLC_Code</th>
<th>LABEL</th>
</tr>
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<tr>
<td>111</td>
<td>Continuous urban fabric</td>
</tr>
<tr>
<td>112</td>
<td>Discontinuous urban fabric</td>
</tr>
<tr>
<td>121</td>
<td>Industrial or commercial units</td>
</tr>
<tr>
<td>122</td>
<td>Road and rail networks and associated land</td>
</tr>
<tr>
<td>123</td>
<td>Port areas</td>
</tr>
<tr>
<td>124</td>
<td>Airports</td>
</tr>
<tr>
<td>131</td>
<td>Mineral extraction sites</td>
</tr>
<tr>
<td>132</td>
<td>Dump sites</td>
</tr>
<tr>
<td>133</td>
<td>Construction sites</td>
</tr>
<tr>
<td>141</td>
<td>Green urban areas</td>
</tr>
<tr>
<td>142</td>
<td>Sport and leisure facilities</td>
</tr>
</tbody>
</table>

Table 1: Legend of Corine Land Cover Database

((European Environment Agency, 2009a), clc_legend.csv)
Agricultural Land

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>211</td>
<td>Non-irrigated arable land</td>
</tr>
<tr>
<td>212</td>
<td>Permanently irrigated land</td>
</tr>
<tr>
<td>213</td>
<td>Rice fields</td>
</tr>
<tr>
<td>221</td>
<td>Vineyards</td>
</tr>
<tr>
<td>222</td>
<td>Fruit trees and berry plantations</td>
</tr>
<tr>
<td>223</td>
<td>Olive groves</td>
</tr>
<tr>
<td>231</td>
<td>Pastures</td>
</tr>
<tr>
<td>241</td>
<td>Annual crops associated with permanent crops</td>
</tr>
<tr>
<td>242</td>
<td>Complex cultivation patterns</td>
</tr>
<tr>
<td>243</td>
<td>Land principally occupied by agriculture, with significant areas of natural vegetation</td>
</tr>
<tr>
<td>244</td>
<td>Heterogeneous agricultural areas</td>
</tr>
</tbody>
</table>

Natural Land

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Broad-leaved forest</td>
</tr>
<tr>
<td>312</td>
<td>Coniferous forest</td>
</tr>
<tr>
<td>313</td>
<td>Mixed forest</td>
</tr>
<tr>
<td>321</td>
<td>Natural grasslands</td>
</tr>
<tr>
<td>322</td>
<td>Moors and heathland</td>
</tr>
<tr>
<td>323</td>
<td>Sclerophyllous vegetation</td>
</tr>
<tr>
<td>324</td>
<td>Transitional woodland-shrub</td>
</tr>
<tr>
<td>331</td>
<td>Beaches, dunes, sands</td>
</tr>
<tr>
<td>332</td>
<td>Bare rocks</td>
</tr>
<tr>
<td>333</td>
<td>Sparsely vegetated areas</td>
</tr>
<tr>
<td>334</td>
<td>Burnt areas</td>
</tr>
<tr>
<td>335</td>
<td>Glaciers and perpetual snow</td>
</tr>
</tbody>
</table>

2.4.2.3 ESPON Territorial Observations

The European Observation Network for Territorial Development and Cohesion (ESPON) is a programme to “support policy development in relation to the aim of territorial cohesion and a harmonious development of the European territory by (1) providing comparable information, evidence, analyses and scenarios on territorial dynamics and (2) revealing territorial capital and potentials for development of regions and larger territories contributing to European competitiveness, territorial cooperation and a sustainable and balanced development”. It has been established in 2006 and a new programme with the focus on 2013, part-financed at the level of 75% by the European Regional Development Fund, is now on the way.

One product of ESPON is “Territorial Observations”. Therewith ESPON will promote its role as provider of comparable facts and evidence on territorial dynamics in support of EU Cohesion Policy. ESPON Territorial Observations aim at providing
policy makers and practitioners with short and concise information on important new evidence to various dynamics of the European territory, its regions and cities.

Source: http://www.espon.eu/main/Menu_Publications/

### 2.5 The importance of cities

The best way to see the importance of cities for human beings is to observe the ongoing urbanisation process. The degree of people living in cities is increasing in the different parts of the world. Nevertheless the pace of this process differs with the regions. The absolute number of people living in cities is increasing. The reasons for the urbanisation process are not discussed here, but it is clear that an increasing amount of people comes along with different problems/challenges like how to supply the inhabitants with water and energy in a sustainable way. Due to the united nation worldwide nearly 70% of the people will live in cities in 2050 (today it’s about 50%). In the case of Europe we have to expect 83.4% of people living in cities in 2050 (Eastern Europe 79.9%, Western Europe 86.5%). In the same period the number of people in Europe will decrease down to 664 m. (nearly 557 m. will live in urban areas). All in all cities become more important as places for living and working.

Cities face to problems of which many can be related to the topic of energy (e.g. increased traffic volumes, ecological overload, fine particles, insufficient housing development etc.). The development of cities has to be seen especially against the background of globalisation, climate change and demographic trends. Also because fossil energy carriers are scarce the cities will face structural changes. With regard to the mentioned problems one target of cities has to be to create energy-saving structures which in a way are related to sustainability. In that context urban form plays a key role.

### 2.6 Urban form

Since at least antiquity people are thinking about cities, their form and there function. In general with the incurrence of cities people had to face up somehow with questions concerning e.g. the urban form. At first we can think of Hippodamos of Miletus (5th century BC). Hippodamos is seen as the founder of urban planning. He is well known because of the Hippodamian plan, a plan to enlarge or even new build cities. He thought about how an ideal city should look like and he implemented the idea of equality (isonomia) of people into the city.

Skipping many centuries there are two models of cities which were developed in the 19th century. The ideas of ideal cities from previous centuries, especially from renaissance period are leaved out here.

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6 Source of the data: http://esa.un.org/unup/
Radial concentric town model (Kohl 1841)
Bandstadt (Ciudad lineal) (Mata 1882)

In the first half of the 20\textsuperscript{th} century three land-use models from the so called Chicago school became well known in city science.

- Concentric zone model (Burgess 1925)
- Sector model (Hoyt 1939)
- Multiple nuclei model (Harris and Ullman 1945)

As described above there are a few general models of urban structure. The main disadvantage is that these models are relatively old or that they refer rather to cities outside Europe (like the models of the Chicago school). Next to this it is disadvantageous that the models are static, so they do not explain processes of land use change. Finally the models ignore physical environment and the city-size is generalized, which can be also criticized.

Next to the direct morphogenetic research there are other approaches to describe cities, like the cultural genetic approach. Cultural genetic research tries to explain cities through their cultural development. Models of Arabic-, Latin American cities are described within the literature of this research branch. Newer Research often focused on city parts like gated Communities or on specific aspects like urban governance, demographic change or cities and risk.

In general it has to be pointed out that a wide area of different branches of research are existing which have cities as a research interest. It could be thought of geographers, spatial and city planners, architects or even computer scientists (modelling cities) and mathematicians (e.g. fractal city). Recognizing that it is general difficult to get a complete overview about research on cities including urban form.

Nevertheless there are some classic studies about urban form. Among others beginning from the 60\textsuperscript{th} of the last century (Jacobs, 1961), (Lynch, 1981) and (Kostof, 1991). Next to that the new urbanism is dealing with questions how cities should be organized (Congress for the new Urbanism, 2000). Urban form and the coherence to sustainability is also a question in recent years which you can see in (Jenks, Burton, & Williams, 1996), (Banister, Watson, & Wood, 1997) or (Jabareen, 2006). There are also current projects dealing with the question of sustainable urban forms.

CityForm (The sustainable Urban Form consortium) research project\textsuperscript{7} is one of these projects which deals with the question to what extent and in what ways does urban form contribute to sustainability. So the main focus lies on the relationship between urban forms and environmental, social and economic sustain as well as the relationship concerning transport.

\textsuperscript{7} Cityform webpage: http://www.city-form.org/uk/index.html

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With the help of aerial views and satellite pictures urban forms as well as the change of urban form can be analysed nowadays. So it is one good possibility to capture urban sprawl respectively compactness in a quantitative way cf. e.g. (Poelmans & Van Rompaey, 2009) or (Hanham & Spiker, 2005). The causes and drivers of urban sprawl respectively compactness which influence the urban sprawl will be described later in a further part of this document. With the help of relatively new programming techniques like micro simulation or cellular automata the change of land-use and therewith the spread or shrinking of urban areas can be mapped (Batty, 2005). Furthermore the development of the road network which changes the urban form as well can be modelled through e.g. L-systems (Parish & Müller, 2001). Also Multi-Agent-Systems can be used to describe different urban issues. So it can be exposed that there are many different approaches which deal with urban/urban form questions using different programming/software techniques. A comprehensive overview about urban modelling techniques in last decades is published by Batty (Batty, 2007). Next to the city development modelling in 2D in recent years the modellers began to analyze and reproduce the urban form in 3D or even 4D if you consider the time factor cf. (Lying & Wei, 2006) and (Weber, Müller, Wonka, & Gross, 2009).

In the next picture the differences in urban form are demonstrated at an impressive example.

Fig. 4 state Georgia (USA)

In fig 1 the state Georgia with its capital Atlanta is mapped. Atlanta is one of the most urban sprawled cities in the USA. As a comparison the size of Spanish City Barcelona is pictured in the right upper corner of fig 1. Barcelona is a very compact city within Europe. The covering area of Atlanta (urban area) is around 70 times larger than the area of Barcelona. Both cities can be compared by population number.

Atlanta: 3.5 m. inhabitants (Year 2000)
Barcelona: 1.6 m. inhabitants (Year 2009)

That means that there are big differences which area is “needed” per capita. As a result of the different amount of land used for urban settlement it can be expected that this has different influences on urban energy issues. It can be resumed that significant differences in population densities within cities can be observed. The connection between urban form and energy demand is a central issue of investigation in the PACT project and will therefore discussed more in detail in the following parts.
2.7 Urban form and energy

The urban form influences the energy structure. The demands of energy as well as the energy supply are depending on urban form. All energy sectors are affected. The transportation sector is affected because of less or longer distances and therefore a variable demand of fuel. Further the presence of an efficient public transport system depends on urban form. The air temperature within cities is influenced by urban form and therefore the heating and cooling sector is involved in this issue. The electricity sector is affected because e.g. cooling needs electricity. Furthermore electro-mobility as a future alternative will need much electricity. In following parts heating, cooling and transport in cities will be discussed more in detail.

In Fig. 5 the relationship between urban form and energy according to Rygole can be seen. Important here is the feedback. The urban form influences the modal split but the use of different technologies changes also the urban form.

Fig. 5 Relationship between urban form and energy

The Commission of the European Communities presented in their green paper of the urban environment the qualitative relationship within the urban system. Their picture of urban relationship is presented in Fig. 6. It indicates the complexity of urban systems, so that it can be imagined that planning processes are quite difficult. The
drivers of the system are due to the Commission the growth of population, the increased living standard and the changing pattern of production and employment. These drivers and resulting chains are influencing the urban form (e.g. increased living standard -> rising car ownership -> noise/pollution -> increasing demand for housing in the suburbs). Chains and linkages like in the figure can be observed. However it is sometimes even not clear in which direction these linkages would interact. Furthermore it is a qualitative description, so the strength of linkage isn’t known. Renting cars do not contradict increasing living standards in general. Noise and pollution can be reduced or even avoided through new technology generation (e.g. electric cars – so there is no mandatory linkage between increased private transport and inner city pollution if the right technology is available).

Fig. 6 Relationship within the Urban System

2.8 Analysing urban development at European scale

Mainly remote sensing technologies have to be taken into account for analysing the current land-use situation and processes like land-use change. Here it can be thought of aerial views but mainly of satellite images. In addition to that historical maps can be analysed. Two projects CORINE and MOLAND which deal with analysing land use will be described later more in detail. Most interesting for the quantitative part of the PACT project is it to see where urban sprawl takes place and how fast this process is going on. This will be in general the basis to estimate future
energy needs. To get an overview about sprawl in Europe see (European Environment Agency, 2006c). In the next passage the possibilities of detecting urban sprawl at European scale will be described more in detail, therefore it is nearly impossible not to use satellite images.

**Satellite images**

There are different satellites which have the target of earth observation. Some of them are used to detect land-use changes. The most important satellites/satellite families in this context are:

- Landsat
- Quickbird
- Ikonos
- Spot

Here it has to be recognized that the satellites have a different spectral, radiometric, spatial and temporal resolution. The monitored area is also varying.

**CORINE Landcover 2000**

CORINE is the abbreviation of Coordinated Information on the environment. This project is funded by the European Union and the European environmental agency. In case of CORINE first in 1990 satellite images were used to detect Europe wide land-use in a harmonized way so that land-use is comparable for the different European regions. For the year 2000 a second dataset for the land-use is available for free. At the moment a third dataset with basis year 2006 is in progress. It has to be recognized that not for all regions and not necessary for both years data is available. So in the end not all regions can be compared due to land-use change within 10 years (it has also to be recognized that the data isn’t exactly from 1990 or 2000 which makes it more difficult to compare data). Next to that it has to be mentioned that the spatial resolution differs from 1990 to 2000. CORINE is mentioned because the data resulting from this project are suitable to use also for the special use of land, the urban use.

There are two land classification classes dealing with urban settlement.

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8 See the Landsat program http://landsat.gsfc.nasa.gov/
10 Commercial satellite: operator GeoEye http://www.geoeye.com/CorpSite/
11 http://www.spotimage.com
12 Technical description of different satellites and further information for land use detecting by satellites you can find under e.g. http://www.landcover.org/index.shtml
The urban fabric class includes the land which is mainly occupied by dwellings and buildings. In addition to that areas which are covered by streets and parking places but also urban greenery belong to the class of urban fabric. Due to the technical (Bossard, Feranec, & Otahel, 2000) description of CORINE continuous urban fabric is defined through the fact that more than 80% of the area is covered by buildings and street network. Therefore more than 80% of the total surface should be impermeable. That means that vegetation and bare soil is the exception in this class.

The minimal polygon area is in general 25ha. If there are two adjacent polygons of which both are smaller than 25ha and one is continuous and the other is discontinuous urban fabric and the summed area is larger than 25 ha than this areas are generalized and declared as discontinuous urban fabric. Discontinuous urban fabric is at this defined as an area where 30%-80% of the land should be impermeable. Main areas are covered by houses and street network. “The discrimination between continuous and discontinuous urban fabric is set from the presence of vegetation visible at the satellite image illustrating either single houses with gardens or scattered apartment blocks with green areas between them” (Bossard et al., 2000). The position error of CORINE data is less than 100 m and the thematic accuracy is at minimum 85% (Meinel, Schubert, Siedentop, & Buchroithner, 2007). The change of land-use can be detected if the concerned area is larger than 5ha, change in isolated polygons need a minimum area of 25ha. The minimum of the edges is 100m. To get an impression from CORINE see Fig. 7.

Fig. 7 Landsat 7

Source: (Keil, Kiefl, & Strunz, 2005)
Fig. 7 shows on the left side one example of the basis data of the CORINE project. You can see a pseudo colour image derived from Landsat 7 data. Starting from such images CLC2000 vector maps were generated which can be received from the European Environmental agency in shape file format. In that project we work on the basis of these vector data so that we do not deal on the level of original satellite data. The availability of the CORINE data, the fact that the data is available for two years (1990 and 2000) and area covered by CORINE is at this the main reason for choosing this data for PACT project.

MURBANDY/MOLAND

The MOLAND project was initiated in 1998 under the name MURBANDY which stands for Monitoring Urban dynamics. The objective was to monitor the development of urban areas and identify trends at the European scale. Since 2004 the project name is MOLAND and the research frame deals with adapting strategies to cope with climate change\textsuperscript{13}. The data basis of MOLAND isn’t area-covering Europe as a whole. MOLAND regards different regions spread over the European continent. The operating scale is 1:25000 (in opposite to CORINE where the scale is 1:100000). A next difference is that the time series is different. In general data from the early 1950s, the late 1960s the 1980s and the late 1990 is available at this project. In that sense the MOLAND data are good supplement to the CORINE data for analysing the urban settlement issue.

\textsuperscript{13} for information about MOLAND see http://moland.jrc.ec.europa.eu/background.htm
3 Urbanisation and Land use Patterns

3.1 Introduction

On the basis of the main trends that have been observed regarding the emergence of urban sprawl in Europe, the following paragraph presents the societal and economic drivers of this phenomenon and reviews the European and local policies implemented to promote a polycentric city’s development.

3.2 Measurement of compact respectively sprawled city structures

Urban sprawl is a complex phenomenon. It has to be seen as multidimensional. Because of the multidimensionality there are different definitions of what urban sprawl is.

According to Galster (Galster et al., 2001) sprawl is defined in literature as a condition of land use that is represented by low values on one or more of the following dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. So sprawl is one name for many different issues so that ambiguities are in existence due to what sprawl is. The term is used for residential as well as non-residential land use, for the causes, the process and the consequences of practices of land use. “Sprawl has become the metaphor of choice for the shortcomings of the suburbs and the frustration of central cities. It explains everything and nothing” (Galster et al., 2001). The different definitions of sprawl can be grouped into six categories according to Galster (Galster et al., 2001) which are not explained here in the document.

Due to the different approaches to define urban sprawl it results that measuring urban sprawl is problematic in general as well (finding the right way for measuring sprawl phenomenon). Different research disciplines like landscape and urban research or even mathematical branches like fractal geometry research developed different indicators measuring sprawl phenomena.

Sprawl can be measured at different scales from building stock level up to much smaller scales (it has to emphasized here that a lot of indicators measuring urban sprawl are scale dependent like Torrens and Alberti pointed out (Torrens & Alberti, 2000)). In addition to it measurement can involve a lot of different indicators (e.g. indicators dealing with commuters). According to (Frenkel & Ashkenazi, 2008) the approaches for measuring sprawl can be divided into five groups: growth rates, density, spatial geometry, accessibility and aesthetic measures. However the
availability of data often determines the approach for measuring sprawl. At European scale it is only tenable to use aggregated data for getting an idea of urban sprawl situation if you like to analyze sprawl for many regions in a fast way. In this sense a few methods for estimating urban settlement situation will be described later in this text.

There is fuzziness when to talk about compact structures and when do we term a city structures as sprawled. No general agreed threshold exists which distinguishes the compactness of settlements. Compactness and urban sprawl aren’t two disjoint categories. There is a fluent passage between both. The relationship between urban form and urban sprawl is diverse because the word “sprawl” is used in a different context. Sprawl could mean contiguous suburban growth but also linear pattern of strip development, leapfrog or scattered development (Gayda et al., 2003).

Fig. 8 Forms of sprawl

In Fig. 8 different forms of sprawl are illustrated (from left to right: linear strip, compact, poly-nuclear and scattered development). Forms of sprawl are described in e.g. (Batty, Besussi, & Chin, 2003) and (Galster et al., 2001). In addition to that leapfrogging is a kind of sprawl which is similar to scattered development but with centres leapfrogging areas. The compact case is what people often have in mind thinking of sprawl (typically the development of suburbs in the 50th in the near of the core cities of the USA). What is clear is that these cases are idealized in the way that in reality a mixture of these developments can be observed. Linear strip as one form of sprawl occurs especially at transport corridors and within coastal areas. In greater extent linear strip could be observed e.g. along the Paris-Brussels axis adjacent to the TGV high-speed railway (cf. (European Environment Agency, 2006c)) which is interpreted as an effect of the distribution of stations. Linear strip at the sea can be found e.g. at French and Spanish Mediterranean coast (e.g. area along Valencia and Murcia). These coastal areas are of special interest because of its vulnerability (Natura 2000 sites…). The changing of Europe’s coastal areas is described e.g. in (European Environment Agency, 2006a).

At the European scale geographical data in terms of satellite images are at disposal. Further information like population density would be interesting but isn’t available in general. So for making statements about compactness of settlements it has to be retracted to the geometrical properties.
A first indicator for urban sprawl could be the relationship between perimeter and area of a settlement.

\[
\text{Degree of urban sprawl} = \frac{\text{perimeter of settlement}}{\text{area of settlement}}
\]

It has to be taken in mind that the identification of the perimeter is general not trivial. Here you can remember Benoit Mandelbrot and his question “How long is the coast of Britain?”. The length of perimeter will increase with finer resolution of underlying maps. With the help of GIS the perimeter of city polygons can be calculated automatically for the given resolution. The perimeter of the settlements includes also inner borders (e.g. green open space). So in general it has to be dealt with interior polygons. Last but not least there is some fuzziness because of determining the catchment area of city.

A second possibility of measuring compactness respectively urban sprawl could be to calculate Shannon’s Entropy (\(H_n\)) which is described among others by (Sudhira, Ramachandra, & Jagadish, 2004).

\[
H_n = \frac{1}{\log(n)} \sum_{i=1}^{n} P_i \times \log \left( \frac{1}{P_i} \right)
\]

Where \(P_i\) is the proportion of built up area in the \(i\)-th zone and \(n\) is the total number of zones. The values of \(H_n\) can range from zero to one, where zero would mean most compact and values closer to one more sprawled situation.

A next further possibility for measuring the irregularity of geometric form is to calculate the Shape-Index (\(SH_i\)). See here also (Frenkel & Ashkenazi, 2008).

\[
SH_i = \frac{L_i}{2 \times \sqrt{\pi} \times A_i}
\]

Where \(L_i\) is the perimeter of the central build-up area of settlement \(i\) and \(A_i\) is the build-up area itself. The idea behind that formula is that a circle is the most compact geometric form.

Cities have fractal properties. A comprehensive overview about cities linked with the topic of fractals can be found in (Batty & Longley, 1994). According to the topic of
fractals one possibility for describing urban forms is to calculate the fractal dimension of the settlements.

The fractal dimension for cities can be calculated using e.g. the box-counting method. See here also (Meiling & Quishong, 2009). The authors describe in this article how it is possible to calculate the fractal dimension outgoing from remote sensing data.

\[ D = \lim_{\varepsilon \to 0} \frac{\log(N(\varepsilon))}{\log \left( \frac{1}{\varepsilon} \right)} \]

D is here the Boxcounting-Dimension. \(N(\varepsilon)\) is the number of areas covered by the city and \(\varepsilon\) is the width of a raster. So the idea is to cover the city area by a raster layer of decreasing raster width with the help of a geographical information system. In praxis of course the decreasing of \(\varepsilon\) has to stop somehow so that the algorithm stops after certain steps.

Above presented possibilities to estimate urban sprawl due to an indicator are considering only the configuration of the settlement. Next to this also the composition of different land-uses should be included if states to the sprawl situation should be stated. Here it can be imagined to calculate simplest the number of patches. The development of the mean size and or the distribution of the size of patches can also be regarded. The largest patch size in per cent of a total area could also be an indicator. Last but not least the change of land-use is important to analyze so that there are not only indicators recognizing the static but also the dynamic component of urban development.

After analyzing the static as well as the dynamics of urban form which could be made within different timeframes and different scales it will be pointed out now how to deal with cities regarding the energy issue more in detail. The urban form is one component of the framework. In a later part (Cities and Energy) it will be given a procedure dealing with cities on local scale illustrating the way explained by an example of a middle European city.

Recommendation

An agreement on one or more solely geometric indicators for measuring urban sprawl and settlement composition would be helpful. Monitor the sprawl situation within Europe every five years with the help of the agreed indicators.

Measuring the urban form is the basis for further research on energy needs and energy supply. Compact urban forms e.g. have a higher heating and cooling demand
because of increased population density. Otherwise more sealed up areas store an increased amount of heat energy which again leads to decreased heating but increased cooling demand. The heating, cooling and transport demand which are related to urban form are therefore discussed more in detail in later sections.

3.3 Urban sprawl trends and drivers

Another definition of urban sprawl is given by the European Environmental Agency. Urban Sprawl is at this defined as a ‘physical pattern of low density expansion of large urban areas under market conditions mainly into surroundings agricultural areas. Sprawling is the leading edge of urban growth and implies little planning control of land subdivision’.

Many of the research studies carried out for comparing urban trends between the mid 1950s and today spotlight the emergence of urban sprawls throughout European cities. In this period of time, European cities have expanded on average by 78% whereas the population has grown by 33%. The data clearly underlines as well that this trend has accelerated since the end of 1990s: the rapidly increase of urban areas and infrastructures consumed more than 8000 km², about the size of Luxemburg.

According to EEA (2006b), urban sprawling has particularly affected:

- Countries or regions with high population density and economic activity (Belgium, Netherlands, Southern and Western Germany, Northern Italy, the Paris Region)
- Regions, cities that had experimented a rapid economic growth and/or a high population density (Ireland, Portugal, Eastern Germany, and Madrid region)
- Smaller towns along new transportation corridors or/and along the coast connected with river valleys

The phenomenon is now increasingly affecting Southern and Eastern countries. The latter, have been characterised by a specific form of compact cities which resulted from central planning, dominance of public transport and no land market. Despite regional differences and developments paths, the 1990s transformation has created patterns of suburbanisation common to many eastern countries, specifically in Poland, Czech Republic and Slovakia.

Two classifications help to define the phenomenon’s distinct features. Based on spatial background, the ESPON FOCI Project identified two main processes leading to urban sprawl: the first is the aggregation of existing small scattered settlements...
around a main urban agglomeration; the second is the creation of new build up areas spread over agricultural land in the vicinity of the urban centre.

The differences among these suburban developments are further analysed by the project URBS PANDENS\textsuperscript{16} that identifies four types of urban sprawls:

- Sprawl and development of second homes (e.g. Sweden and Greece)
- Sprawl in declining areas (e.g. Liverpool and Leipzig)
- Sprawl in regions in transition (from plan to market economy)
- Sprawl induced by capital investments: mainly in industrialised countries with an increase of industrial parks, residential and commercial areas along the main infrastructure road;

The expansion of build up areas has severe economic, social and environmental impacts for the cities and for the surrounding rural areas: it entails an increasing energy and land consumption accompanied by rising greenhouse gas emissions, air and noise pollution.

The drivers of urban sprawl must be carefully considered, as counteracting this trend seems indeed indispensable for cutting GHG emissions from transport and for reducing the city’s reliance on fossil fuels. The following is a framework provided by the ESPON FOCI project to classify the different drivers of urban sprawl according to their nature (social, economic, institutional, and related to transport and land use) and to the territorial scale of their effect (macro, meso and micro):

![Fig. 9 Main drivers of urban sprawls in Europe (ESPON FOCI 2009)](image)


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The framework shows in bold general factors which cause urban sprawl under different circumstances, whereas the remaining factors may become drivers of urban sprawl only under more specific conditions.

In the past decades, cities’ growth was mainly due to the increase of the urban population, whereas now urban expansion is driven by macro global forces, e.g. the shift from manufacturing to services in urban economies. A crucial role has been played also by the rise of car ownership combined with the lack of strong urban planning policies. The different typologies of drivers are discussed below.

### 3.3.1 Social Drivers

In the past decades, the increase in population has favoured the city expansion, however, the phenomenon is nowadays relevant even in some eastern cities whose population is in decline. Conversely, demographic dynamics such as the population composition, age, ideal has greatly influenced the construction of new suburbs. In half of the urban areas studied by the MOLAND project more than 90% of all residents areas build after the 1950 were low density areas with less than 80 % of the land surface covered by buildings, roads and other structures (EEA Report 2007).

This tendency reflects the European citizens’ preference for a new house or second house in suburban/rural areas outside the city. The lower land prices and the expected rise on land value have made the detached or semi-detached houses the preferred choice for many European citizens. Against a stable economic background, the average floor per capita and the shares of household living in individual houses were arising (European Environment Agency, 2009c). In addition, the ‘downward spiral’ affecting some inner cities has enhanced this outward movement.

Living in the suburbs areas is indeed often the choice of the families with small children who consider the suburbs safer and healthy than the core areas. Often this choice is also the only affordable for young families, as the prices of land and houses in the inner cities is too high, due to the pressure of the property market trends. When families move out of the core area, the revenues of municipal tax are reduced, with the consequence of reducing the quality and the quantity of essential services as schools and hospitals. This situation reinforces the citizens perception of the core city as polluted, noisy, unsafe and lacking open space and sports facilities, and creates a ‘downward circle’ that is difficult to reverse.

On the opposite, elderly and singles are least keen to move out of the inner city. In this perspective, it is possible to consider that the registered trends of ageing of population and of smaller household choices due to the increase of divorce and ‘broad individualism’ in Europe might contribute to slow down the movement from inner city to suburbs.
3.3.2 Economic Drivers

Globalisation and European economic integration has also contributed to shape the spatial distribution of population and the urbanisation patterns. The development of information and communication technologies, the shift toward a service oriented economy linked with the transfer of production activities had and still have a major impact on urbanisation.

In addition, the EU market integration has promoted the creation of strong regions, whose strategic economic strengths often overcome that of single states, and has stimulated a high competitiveness among regions/cities. The competition to attract investments and employment opportunities might undermine the land planning rules, favouring a market oriented spatial development. In the past, European policies have been focused on capital cities, reducing the competitiveness of smaller cities and rural areas.

The differential price between agricultural and urbanized land has discouraged the revitalization or the recycling of build space, generating abandoned land within the city cores (ESPON). The high price of land zoned for housing or services in the inner city has brought investors to look at the agricultural land surrounding the city, especially when new transport infrastructures are being developed that make the peripheral locations more accessible. Even taking into account the price’s rise following the process for planning permission, agricultural land price results much lower than the cost of core city land.

The role of municipalities would be, then, crucial for enforcing urban planning and land zoning in the opposite direction of urban compact development, giving priority first to the redevelopment of existing built areas, secondly to areas immediately near to public transport, and only then more far away transit oriented development.

3.3.3 Governance

A wide range of urban planning systems and solutions to urban sprawl have emerged throughout Europe, however, their effective application requires political commitment, administrative and technical coordination and stakeholders involvement.

The way planning is organised and enforced is mainly shaped by local and regional authorities. However, social and economic trends accelerated by European and national policies might hamper – even unintentionally – the formulation of effective urban policies, and promote instead urban sprawl. For instance, the EU Structural and Cohesion Funds act as powerful drivers of macroeconomic changes but have as well induced urban sprawl phenomena in those countries and regions that have benefited the most. Similarly, EU transport policies while extending road infrastructures have made more accessible some rural areas that have led to the creation of new suburbs. Those effects are mainly the result of the lack of horizontal and vertical coordination between institutions at different levels (European, national,
regional, local) that have brought to an overlap of powers, contradictory decisions and a sub-optimal allocation of infrastructure investments.

On the other hand, municipalities have not been always able to promptly react to economic and social pressures, as it is underlined by cases of weak land use policies followed by poor enforcement of the existing plans. The high degree of autonomy the cities have on deciding about land use matters, combined with the need to attract new investors to increase local taxes and revenues, might contribute to the development of a ‘market oriented spatial development strategy’.

Any long term strategy to prevent sprawling has so integrate economic and social measures, tailored to local situations, decided in consultation with civil society and implemented through law enforcement. Major efforts to coordinate and integrate policies have emerged in the last decade, and the most prominent actions taken in this direction both by the European Union and by cities are described in the following paragraphs.

### 3.3.4 Transport

Land use and transport are inter-dependent in a complex way, as land use strongly influences mobility patterns. Best city planning demonstrates that by means of mix land use developments is possible to maximize accessibility, improving quality of life and reduce mobility. The cases of Vauban and Rieselfeld in Freiburg, mentioned later in the chapter showing best practices of sustainable cities, show the opportunities to develop the city along to the tram line track and to attract essential and leisure services in new urban settlements. The area of Vauban, with a high concentration of citizens aware of climate issues, registers a 15% less use of cars as compared to other areas of the city.

Conversely, and more often, highway construction together with the setting of commercial and industrial services act as driver for the creation of new residential areas in the vicinity. The price of housing and the price of commuting between home and work are relevant for the households’ decision of where to live, and the urban sprawl tendency accelerates when the travel costs fall below a certain threshold and income reaches a certain level. New housing is generally considered to be affordable if it requires no more than 30 per cent of a household income. However, true housing costs (excluding environmental costs) need to consider also the household expenditure on transport induced by the new suburban location.

This tendency is supported by exponential increase of private car ownership and by still accessible fuel costs. It is estimated that vehicle-kilometres travelled in urban areas by road are predicted to rise by 40% between 1995 and 2030. In this regard, the Trans – Europeans Transport Networks (TEN-T) Programme have to carefully consider the impacts that new infrastructures have in new Member states in favouring urban sprawl and jeopardizing the environment. However, it is clear that the tendency of households to move to suburbs where more affordable houses may be found will
be challenged if oil prices will grow due to an increasing scarcity of fossils fuels, as the cost of daily commuting trips by cars – almost obliged in car-dependent suburbs – will increase faster and faster.

Thus, looking at the future post-carbon society, integrated transport and land use planning would be highly needed to avoid the growth of car-dependent suburbs, and facilitate instead the creation of transit oriented developments, complemented by the creation of high quality urban transport to link the city centre with its surroundings. The transport hierarchy would then favour walking, cycling, public transport and then, as last option, private cars.

3.3.5 Land

The assessment of European urban forms undertaken in the MOLAND project highlights Bilbao in Spain as the most compact city in Europe, three times denser than the most sprawled city, Udine in Italy. The compact form of the Basque city is favoured by its geographical location between the coastline and the mountain range, but has been achieved also thanks to the active local planning policies and the development of an effective transport system.

Past history and geographical surroundings of the cities are underlying factors that modulate the morphology and trajectories of the cities (ESPON). Generally, southern cities have a longest urban tradition of promoting compact development, even if in the last decade urban sprawling is fast growing. Land planning in northern and western Europe has been rooted in the ideal of individual house in green suburbs, while the compactness of eastern cities still reflect the communist centralised planning regimes characterised by substantial reliance on public transport. As pointed out by the ESPON FOCI Project ‘Urban change is incremental: most of the physic fabric of cities survives for many decades if not for centuries. The social fabric is much more prone to change, but, nevertheless, in general only a few percentage of change per year in the urban fabric’.

3.3.6 Role of European Union and local authorities to promote polycentric cities

The European Union endorses in several policies the role of cities in promoting economic and environmental sustainability, and increasingly promotes the development of sustainable polycentric cities.

The current Structural Funds regulations (2007-2013) have better integrated the urban dimension and territorial cohesion component and projects targeting city can be included in the Specific Operational Programme submitted by the Regions. For

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17 The analysis was conducted on the basis of the following indicators: 1) the Growth of build-up areas (1950-1990s), the Share of dense residential areas of all residential areas (1990s); 3) the share of low density residential areas (mid -1950s onward); 4) Residential density (1990s) 5) The change in growth rates for population and built up areas (1950-1990)6) Available build up areas per person.
instance, European Development Regional Fund have allocated EUR 10 billion to Specific Priority Axis on urban development and many other projects indirectly related to urban areas (European Environment Agency, 2009c).

The EU Urban Thematic Strategy has created a policy framework to promote effective implementation of environmental laws and to promote the adoption of sustainable energy and transport plans. The Strategy encourages the implementation of ‘compact city policies’ through the transfer of good practices on managing urban sprawls and dissemination of the best practices on sustainable urban development. The European Union has as well promoted a number of initiatives to foster sustainable urban development, among them: URBAN, URBACT, INTERREG, ESPON, Equal, CIVITAS, CONCERTO and has supported network of cities such as Convent of Mayor. The EU is proactively complementing the locally driven actions and catalysing national and regional levels toward those initiatives.

However, there is room for improvement especially with regard to the horizontal and vertical policy integration. The involvement of cities and local stakeholders in the preparation of the regional Operational Programme depends on the national procedures which certainty influence the project effectiveness. In addition, the lack of clear environmental conditions in the cohesion framework and the disparities in implementing environmental legislations among Member States limit greatly the sustainable ‘integrated approach’ promoted by EU. Generally, the actual impacts of cohesion policy and projects on other than the target areas, for example by contributing to urban sprawl and regional transport growth are only partially understood, which hinders the adaptation of policies to minimise these adverse impacts (European Environment Agency, 2009c).

Beside those challenges, European cities offer good examples of urban planning practices where an integrated approach has been successfully adopted to promote polycentric developments. Each European City has an individual energy profile in relation to the age, form, density, and mix uses of the building as well as the proximity to energy and transport infrastructures. Tacking this into account, future post carbon city developments should benefit of the experiences and the knowledge acquired by European cities that are acting today as pioneers in testing different technological applications and political processes. Urban district projects exemplify how integrated planning might shape the cities of the future and demonstrate the opportunities of reducing cities carbon footprint by experimenting new technological solutions, and by initiating participatory political processes.

A number of good practices of urban district projects are reported in the following chapter. They follow some common features while promoting sustainable urban development:

- A vision of how the ‘post carbon’ city should look like is being developed by several cities together, with the adoption of integrated socio, economic and environmental plan, policies and programs. The adoption of specific targets, timelines and monitoring frameworks have significantly reinforced the political commitments (e.g. London)
The relationship between the city and the rural hinterland is duly considered and regional cooperation is enhanced in order to avoid an unbalanced socio and economic development that would compromise any city long term strategy. (e.g. Munich)

Stakeholders' involvement is a key component in all the cases, and ranges from active planning participation in Freiburg to awareness raising activities in Stockholm.

In order to favour a compact city and avoid urban sprawl, the majority of the new districts has been developed in brownfield areas owned by the local authority. (e.g. Stockholm)

Public transport has been improved and complemented with the promotion of alternative mobility modes as cycling and walking. Most cities have also adopted measures to discourage car usage, such as congestion charges and parking policies.

The use of energy efficient standards stricter than those required at national level is common to many cases.

Cities often promote decentralised energy generation and they invest in upgrading energy infrastructures.

European and national policies should continue to support the enhanced role of local authorities in planning, developing and communicating post carbon cities, enabling a wider dissemination and generalisation of the good practice examples, such as those presented in the next chapter.

3.4 Envisioning different urban scenarios in the post-carbon society

3.4.1 Introduction

Cities have grown rapidly in the age of cheap oil and now consume 75 percent of the world’s energy and emit 80 percent of the world’s greenhouse gases. Cities are presently growing globally at 2 percent per year (over 3 percent in less developed regions and 0.7 percent in more developed regions), while rural areas have levelled out and are in many places declining. For the first time, half of humanity lives in cities, and it is estimated that by 2030 the number of city dwellers will reach five billion, or 60 percent, of the world’s population.18 In the case of Europe we expect 83 percent of people living in cities in 2050. In the same period the number of people in Europe will decrease down to 664 m. (nearly 557 m. will live therefore in urban areas)19.

19 Source of the data: http://esa.un.org/unup/
Rethinking how we create our built environment is critical in lessening our dependence on oil and minimizing our carbon footprint. Buildings produce 43 percent of the world’s carbon dioxide emissions and consume 48 percent of the energy produced. The urban form is a relevant matter: for example, it is projected that by shifting 60 percent of new growth to compact patterns the US will save 85 million metric tons of carbon dioxide annually by 2030. The bulk of the change towards a post-carbon society needs to come from cities and their government and constituencies (companies, citizens, stakeholders). National governments can do a lot to help to hinder these efforts, but the really important initiatives have to begin at the city level because there is great variation in how cities cope with issues within any nation. Great leadership and innovation can be found in cities.

Cities of course cannot be separated from their hinterlands or bioregions. Although rural regions have generally been declining or are at least static (apart from the movement of people to the coasts in wealthy countries), they also have increased in their oil dependence. Rural economic productivity based on agriculture, tourism, and mining has been growing based on cheap oil. These activities have a large component of oil for travel in the case of tourism, and both agriculture and mining use diesel for transport, machinery and processing, and also depend on chemicals (especially fertilizer in agriculture’s case) made from oil. While therefore the focus of this chapter is on cities, these are to be seen in their relation with energy, food, water and other land resources and population flows from the surrounding countryside.

Although no one can predict the future of cities, we should be able to visualize where we use gasoline, diesel, heating oil and natural gas, and then try to imagine home, neighbourhood, and region without them. How might they look and feel if these resources were not available, or at least were in decline, so that each next step in development of redevelopment/retrofitting of the urban environment had to show how it would help to wean us off these resources? Can we imagine a city where we radically reduce the amount of driving we do? This is not simply a set of abstract arguments about the fate of the planner, but something that has relevance and is potentially understandable to everyone in terms of the places in which we all live.

We need to come up with short-term adaptations for our cities in the face of declining oil, while we plan for longer-term change. Time is needed to do the necessary research and testing on alternative fuel sources. But acknowledging and responding to the problems related to our car dependency goes well beyond finding alternative fuels, it will challenge every aspect of life. We have spent the past sixty plus years building our cities and rural regions around the availability of cheap oil and now must contemplate a different future. We have to find ways to reduce the need for fossil fuels, besides searching for alternative sources. For oil, it will mean designing cities in which we drive 25 to 50 percent less. Trucking will carry 25 to 50 percent less freight, and aviation will have even fewer planes. For our buildings it will mean 25 to

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50 percent less fuel will be necessary for heating and cooling. Is this possible? What technologies will be needed to help make this happen? How will we rethink our cities to meet these goals? The challenge for enabling the transition of our cities to a post-carbon society is to reduce petroleum fuels at a rate that can manage the global climate and peak oil agendas, but not destroy the social fabric of the city in the process. It will not be possible, for example, to have our cities adapt overnight to 5 to 10 percent cuts in supply without experiencing significant hardship. This it is essential that the process of decarbonising and reducing the dependence of cities on oil is initiated as soon as possible. Envisioning and starting to build “post-carbon” cities is needed indeed to avoid a possible collapse due to their vulnerability from dependence on fossil fuels.

3.4.2 Population and urban form

A very simple and abstract way to visualize urban forms is to consider possible patterns of concentration of population, as it is shown in the figure below:

Fig. 10 Urban structure by number of centres and level of concentration

When the population of a country/region of the world increases, we can see two concomitant effects in the spatial distribution of population: an increasing number of centres and an increasing concentration of the population within the centres. Depending on local historical and geographical contextual factors – which should be analysed on a case by case basis – the relative strength of the two effects may be different and create different urbanisation patterns, i.e.:

- Mainly dispersed, when the population is distributed in a large number of small centres
• Mainly concentrated, when the largest share of the urban population is concentrated in one big monocentric city
• Polycentric, with a growth concentrated in a number of centres of different dimensions, forming a network of cities

Looking backward to the development of population and urban growth in Europe, Turok (Turok and Mykhnenko, 2007) pointed out the trajectories of European urban population over the period from the 1960s to 2005. Europe was defined according to the physical meaning of the continent, which is normally taken to include the land area between the Arctic Ocean, Atlantic Ocean and the Mediterranean, Black and Caspian Seas, with the eastern boundary running along the Ural Mountains and the Ural River. The analysis identified 310 cities ranging in size from Bila Tserkva in Ukraine (with 200,000 population) to the Greater London metropolitan area (with nearly 10,6 million). Three clear size bands are apparent:

- 145 “small” cities (47% of all) with between 200,000 and 400,000 people;
- 100 “medium-sized” cities (32%) with between 400,000 and 1 million;
- 65 “large” cities (21%) with a population of over 1 million.

The cities and their trajectories in terms of population growth or decline over the whole period 1960 to 2005 have been detected based on the commonsense idea of a continuous built-up area larger than a certain population size (200,000 inhabitants), i.e. a concentrated spatial form of population and socio-economic development. This analysis excludes therefore any region with less than 200,000 inhabitants, that is to be considered – at least at the European macro-scale – rural or semi-rural (not urban).

It is interesting to note that this is a physical and functional definition (the de facto city) rather than an administrative or legal one (the de jure city). It covers the continuous or near-continuous territory devoted to land uses such as housing, industrial and commercial activity, transport, education and other public services and spaces. In larger urban areas it is equivalent to the idea of conurbation or metropolitan area. The concern of Turok’s analysis is with change in the city as a whole, rather than particular parts such as the core area or the suburban ring. This avoid the possibility of population decline appearing to be a problem where it simply reflects rising incomes or falling households size causing people to choose living at lower densities in the suburbs (i.e. local urban sprawl phenomena).  

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21 In practice the definition was simple to apply in about a dozen of countries where the national statistics agencies provide consistent population figures for spatial units that equate with continuous built-up areas (e.g. “metropolitan agglomerations” in the Netherlands, “census urban agglomerations” in Austria and Greece, etc.). In the other countries the authors had to construct continuous built-up areas by themselves.
The figure below shows on the left hand the number of cities with a growing, stable or declining population trajectories over the period 1960 to 2005, divided in five years intervals (the stable group include cities with +/- 5% absolute population change between 1960 and 2005). The same figure, on the right hand, shows the nine most common trajectories of individual cities.

**Fig. 11 Development of city population within European Cities**

The whole European population trend over the period has been one of first growth and then stability, and this is reflected in the number of growing cities, which has been falling steadily from 1960 until 2000, with a slight recovery in the most recent interval 2000-2005. This trend is mirrored by that of declining cities, which has been increasing until 2000. Concerning the individual trajectories the most common profile, followed by 30% of cities, was continuous growth, whereas there are only 13 cities that have experienced continuous or long-term decline.

Cities of different size tend to show different growth rates. It is indeed well established that large cities have tended to grow more slowly than smaller cities and towns in the post World War II period (Hall et al., 1973; Van den Berg et al., 1982; Breheny, 1999). This is partly because of diseconomies of scale, such as congestion and high property prices, as well as the decline of former dominant industries, physical constraints on land availability and planning restrictions on peripheral urban expansion in many European countries. However, new urban theories suggest that big cities are now better placed than smaller settlements because of the larger scale of opportunities, amenities, infrastructure and skills available to firms and people. This seems to be well reflected by the data shown in the figure below, showing the population growth rates for cities of different sizes:
The growth of all groups of cities slowed dramatically between the 1960s and 1990s. Since the late 1990s the population of European cities has recovered slightly, but growth is still considerably lower than before the late 1990s. Looking at the differences between size bands, during the 1960s small cities expanded at roughly twice the rate of large cities, confirming the received wisdom. Looking back over the four decades, there is a clear evidence of an improvement in the position of large cities relative to smaller cities. However, the absolute improvement in the growth rate of large cities dates back only to the late 1990s.

An alternative approach to that used by Turok's to define cities is based on the concept of “functional urban regions” (Van den Berg et al., 1982), which are similar to travel-to-work areas but with cities always at the core. These can be very much larger than built-up areas because they include the commuter hinterlands of employment centers, including satellite towns. This is useful concept for capturing the economic interactions between the city and its surrounding territory. However, it is a region and not a city concept.

Indeed, the concept of a “city region” first appears in the classic work of Patrick Geddes (Patrick Geddes, 1915). In it, Geddes argued that in certain regions of the world – particularly Europe and North America – individual cities and town were already coagulating in so-called conurbations. The modern concept of the city region is specifically not defined in physical or morphological terms (as it was still in Geddes); neither are such regions based on administrative units, though administrative units must usually be used to define them. Rather, they are defined on the basis of what Manuel Castells has called the “Space of Flows”: flows of people,
information, or goods, on a regular basis, for instance daily commuting or weekly shopping (Castells 1989). They are therefore Functional Urban Regions (FURs) that extend beyond the physically built-up area to encompass all the areas that have a regularly daily relationship with a core city.

More recently, the POLYNET study (Hall and Pain, 2006) analyzed a further evolution of the city region concept, a new urban phenomenon in course of formation in the most highly urbanized parts of the world: the "Mega-City Region". This is a new form: a series of anything between twenty and fifty cities and towns, physically separate but functionally networked, clustered around one or more larger central cities, and drawing economic strength from a new functional division of labour. These places exist both as separate entities, in which most residents work locally and most workers are local residents, and as parts of a wider functional urban region connected by dense flows of people and information along motorways, high-speed rail lines, and telecommunication cables. The Mega-City Region arises from a process of extremely long-distance deconcentration from one or more major cities stretching up to 150 kilometres from the centre, with local concentrations of employment surrounded by overlapping commuter fields.

More precisely, in the POLYNET study, Mega.-City Regions are defined as aggregations of smaller constituent FURs. These comprise a “core” defined in terms of employment size and density, and a “ring” defined in terms of regular daily journeys (commuting) to the core. The Mega-City Region is then defined in terms of contiguous FURs. The POLYNET study analysed and compared the functioning of eight such regions in Europe: South East England, Belgian Central Cities, the Randstad in the Netherlands, the Rhine-Ruhr and the Rhine-Main regions in Germany, the European Metropolitan Region (EMR) Northern Switzerland, Greater Dublin and the Paris Region.

The underlying hypothesis of the POLYNET study was that falling costs of transportation and communication, combined with new informational agglomeration economies, lead to the emergence of a highly complex space of flows within the Mega-City region. There is pervasive geographical deconcentration within these regions, from the heavily urbanized areas which form their cores, including often capital cities (e.g. London, Paris, Brussels), to the smaller metropolitan areas within the outer parts of the same regions, which have been among the fastest-growing urban areas in Europe. It can be shown, indeed, that the small cities in the surroundings of larger cities – i.e. within a 150 kilometres radius – are among the champions of population growth rates in the small size band illustrated by the results of the Turok’s study.

This process of “concentrated deconcentration” generates a progressive redistribution of functions across the Mega-City region: in the core city or cities,
continuing concentration of higher-order service functions (financial and business services, design services, media, higher education, health, and so on); in secondary cities, growth of more routine functions (research and development, high technology manufacturing; niche roles, such as university cities). There are differences in such process of functional distribution between the more “monocentric” regions like Paris, where the high-order functions remain mostly concentrated in the Paris agglomeration, and the more “polycentric” regions like the Dutch Randstad where these functions are more widely distributed across different poles. However, the entire Mega-City complex achieves in any event major agglomeration economies through clustering of activities, not in any one centre, but in a complex of centres with some degree of functional differentiation between them.

3.4.3 Envisioning the urban forms in relation to the time-speed and density factors

Two key factors have been identified to describe different dominant lifestyles and urban forms – the time-speed factor and the density factor – building a 2x2 grid as follows:

![Fig. 13 Urban forms in relation to the time-speed and density factors](image)

The time-speed factor makes a distinction between “doing things fast” or “slow”. “Fast” production or consumption activities require that the number of products made or consumption opportunities exploited in the unit of time are large, by:
• concentrating production, distribution or service activities in large units which exploit economies of scale, and
• connecting these units to local and global markets with fast transport and information infrastructure - to transfer people (workers, customers), goods and information in and out - as well as with efficient energy infrastructure, water infrastructure and waste collection services to satisfy their highly concentrated needs.

This is the paradigm of modern globalised economies and lifestyle, which requires high amounts of extra-somatic energy per capita, high productivity per worker, high capital intensity and global markets to be sustained. In other terms, doing things fast implies doing them big, high energy and natural resources’ consuming, high capital/low labour intensive, and dependent on global markets. The high productivity per worker and speed of the production or consumption processes is the result of an increasing processes’ mechanisation/automation, e.g. by means of automatic tellers in the banking sector or other do-it-yourself devices in the service sector. Mechanisation of agriculture, coupled with the use of fossil-intensive fertilisers, is perhaps the most important example of “speed” factor behind increasing urbanisation, as it pushes out of rural areas people previously employed in agriculture, to find new urban jobs.

“Slow” production and consumption activities do not require the concentration in large production, distribution or service units, as for them it is usually sufficient and more effective to have smaller organisational units, using lesser amounts of extra-somatic energy per capita, lower capital intensity and productivity per worker – i.e. more labour intensive processes – and greater reliance upon local resources and markets. Also the need of fast transport infrastructure is reduced - as it is the need of energy, water, waste disposal etc. – due to the smaller scale of production and consumption processes and the greater reliance upon local resources of labour, energy etc. In other terms, doing things slow implies doing them small, low energy and natural resources’ consuming, low capital/high labour intensive, and dependent on local markets. This was the paradigm of the pre-industrial world, still dominant in the less developed and traditional economies. It is a paradigm that is being recovered now also in post-industrial economies, where preference start to be given again to more environmental friendly and social cohesive production schemes. For instance organic farming and the production of local food within or in the immediate proximity of cities is now again an increasing practice in Europe.

The density factor makes the distinction between “doing things alone” or “together”. We are all doing things “alone” when we drive in our own car and we live in low density suburbs or detached houses in peri-urban or rural areas, whereas we are all doing things together when we live in compact villages, towns or in the inner cores of large cities, when we share collective transport services (public transport or other
forms, such as car sharing and/or pooling) or whenever we walk or cycle around in a compact urban environment. “Togetherness” is seen here as a condition where people live in more physical proximity to each other, when they travel, work, enjoy their life etc. in compact city environments.

The same 2X2 grid representation can be focused on the nexus between the distributions over space of:

- Population (where people live: houses)
- Consumption opportunities (where people consume private and public goods)
- Production opportunities (where people produce)

This is shown in the figure below:

Fig. 14 Urban forms in relation to the distribution of living and employment opportunities

Suburban rings in the first quadrant are featured by the presence of more residents than employment and (especially high-order) consumption opportunities, which generate flows towards the urban core or suburban employment centers. They include moderate to low density mostly residential areas.

Urban cores in the second quadrant are featured by the presence of more employment and higher-order consumption opportunities than residents, which attract
flows from the surrounding suburbs and/or satellite towns. They include high density buildings.

Compact small to medium towns in the third quadrant show a balanced mix of residents and employment and consumption opportunities, all within the city boundary, which generates a relatively greater number of short distance trips. The density in these cities is moderate (if compared to the urban cores) to high.

The sparse developments in diffuse city or peri-urban areas (fourth quadrant) are featured by low density and a scattered distribution of both residents and employment/consumption opportunities.

Finally, the relationship of the 2X2 grid representation with the different urban forms discussed in the previous section can be shown with the help of the following figure:

![Fig. 15 Envisioning the urban forms](image-url)

The first two quadrants – where the lifestyle is “fast” – include the larger cities and Mega-City regions, respectively of monocentric form (first quadrant) with a large central city surrounded by extended low density suburbs - usually the result of a continuous urban sprawl process - and of polycentric form (second quadrant), with one or more urban cores surrounded by smaller satellite towns, as a result of a spatial process of “concentrated deconcentration”.

The other two quadrants – where the lifestyle is “slow” – include the small to medium-size compact cities (third quadrant) with a mixed balance of land uses, a relatively...
stable population over a long period and far from the influence of mega city regions, as well as the more diffuse and rural city patterns (fourth quadrant), including in particular those areas of more favourable climate and lower living costs that attract older retired people and tourist areas. The diffuse city pattern, however, includes also industrial and diffuse employment districts, as in the North East of Italy.

Summing up, the following is a qualitative description of the main features of the different urban forms:

- **First Quadrant**: Large urban areas featured by suburban rings with low density pattern around a monocentric city core. Following a typical urban sprawl dynamic, workplaces and consumption opportunities are mostly concentrated in the central city or – this is a more recent tendency – in suburban production and consumption centres (e.g. office districts near international airports, big shopping malls in the periphery, etc.), whereas the population homes spread in several rings of decreasing density peripheries (the most frequent case for the existing cities in Europe) or in extensive suburban areas with arrays of single houses (the most frequent case in the US). This pattern generates high volumes of car dependent traffic, as alternative forms of transport are difficult to be provided at such low density levels. The concentration of workplaces and consumption opportunities in the city centre or in suburban centres causes congestion problems at daily or weekly rush hours.

- **Second Quadrant**: Network of compact/high density city cores, connected by means of fast transport infrastructure (e.g. high speed trains or highways) which allows travelling comfortably within daytime between the cities. Workplaces, consumption opportunities and residential districts are distributed within the different urban cores, and high quality and fast public transport connecting different places can be provided thanks to the high density of transport demand within and between the cities. This helps to reduce the congestion problems observed in the urban sprawl form, especially if individual car use in the urban cores is restricted. A variant of this form at regional scale is the realisation of satellite towns connected to one large urban core by means of fast and frequent public transport, i.e. creating the so called Transit Oriented Developments (TODs) around the central cities and mobility corridors to speed up the access to the centre.

- **Third Quadrant**: Compact medium to small towns which include a full range of production and consumption opportunities for population living mostly within the city boundaries. These cities are small and dense, relatively far from other cities as they are not connected by fast transport services which would allow return trips within the daytime, and host a variety of economic and social activities which make the city life vibrant and self-reliant. Workplaces and consumption opportunities are located within a short distance from people’ homes, and this –
together with the relative high density – may facilitate walking, cycling and light public transport (bus services).

- **Fourth Quadrant**: Sparse settlements of detached houses in the peri-urban areas and "diffuse city" patterns, the latter characterised by the spread of production, consumption and other urban functions over a large territory without a dominant urban centre. Consumption and production opportunities are usually far away from people's homes, but the distance and travels need can be mitigated by increasing the use of Internet broadband services. Low density in these areas do not allow to provide fast and frequent public transport services, and also the incentive to build fast road connections is limited, which makes transport strongly car dependent and often affected by problems of road network bottlenecks and congestion.

### 3.4.4 Evolution of the urban forms in the post-carbon society

The urban forms discussed in the previous section are being studied now in the PACT project to analyse the transition to a post-carbon society, and how the dominant lifestyle, technologies and infrastructure for urban life, housing and mobility could/should change to drastically reduce the use of fossil fuels and CO$_2$ emissions. These changes may concern different ways of organising production and consumption activities, and different mixes of “fast” and “slow” activities which will characterize future urban daily activity profiles of human beings.

In the following we will envision how the different urban forms may evolve in the post-carbon society.

The city form more vulnerable to the end of the age of cheap oil is clearly **urban sprawl**, in the first quadrant, which is still the dominant one. Indeed, urban sprawl is nowadays the “business as usual” form of urban development, but it may lead to a scenario of collapse if uncontrolled sprawl is continued when cheap fossil fuels become scarce. Serious oil shortages could lead to panic and even social collapse on a large scale. Even a slow decline in oil can unleash forces that are barely imaginable in car dependent suburbs and lifestyle, as the people who have little flexibility in their household income increasingly have to spend a higher and higher proportion of their money for transport fuel and for household power and fuel. Many residents who – following the urban sprawl tendency – moved to the suburbs seeking cheaper housing will be unable to adjust their budgets or lifestyles when faced with skyrocketing oil prices. The options for switching to public transport or walking are often not feasible in the urban environment, alternative heating options are not available, and vehicles cannot be fuelled.

The **ruralised city form**, with a diffuse city patterns (fourth quadrant), may be a possible response to peak oil, provided that the sparse settlements are based on a
more sustainable semi-rural lifestyle, and each city will be responsible for producing a large proportion of its own food. This can be seen to be a kind of suburban agriculture based on hobby farms. In this ruralised scenario most needs are met locally and the economy is devolved down to the individual households primarily, or to small groups. Heating is provided by wood grown locally and there is little need to travel as needs are met locally by a far more self-sufficient economy. The rural evolution of suburbs has been well described by David Holmgren as follows: “Suburban sprawl in fact gives us an advantage. Detached houses are easy to retrofit, and the space around them allows for solar access and space for food production. A water supply is already in place, our pampered, unproductive ornamental gardens have fertile soils and ready access to nutrients, and we live in ideal areas with mild climates, access to the sea, the city and inland country”.

However, there are two problems with this approach. First, it provides a new rational for urban sprawl that will consume land and other natural resources. Second, it is distracting us from seeking region-wide solutions to these issues of energy, water, waste and food production in favour of individualized approaches, which may be not equitable. Cities are collective entities and should solve their problems through common good solutions to avoid the risk of becoming highly exclusive.

There is already a whole array of eco-village experiments emerged as potential models for how rural areas can be productive and sustainable (see for instance the Global Eco-Village Network, www.gen.ecovillage.org), and they are now moving into cities creating intentional communities – “urban eco-villages” – in which the residents share social, environmental and economic goals, such urban eco-villages can play only a specialized role. There is a tradition of agriculture within cities, and potential for urban agriculture to provide a substantial proportion of the city’s food needs, most notably in the Third World. Food production may become available to residents of ruralised cities through many different means such as roof gardens, allotments, community gardens, backyards and through eco-villages specifically designed for urban areas.

However, this urban agricultural production should not be the primary function of the city. There are other rural functions that could be brought more directly into the city fabric of the future. Cities will need to be more closely connected to the creation of renewable energy, the provision of water, and the processing of waste. These functions are moving into smaller-scale technologies that can fit more easily into cities and will be much more energy efficient, but they need to be built into the city fabric as a common good function, to create an equitable society. Of course, while a movement is emerging to reuse vacant lots for growing food, there are limited opportunities for this in the densely populated parts of cities. On the other hand,

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these centres are where traditional urban functions are concentrated and where public transport and walking are feasible due to the densities. This conflict between the need for density and for green open space is a real issue for urban sustainability.

In conclusion, the ruralised city model can be considered a viable option for the future post-carbon society in particular circumstances, i.e. for those peri-urban areas which with the oil shortage will be no longer viable as car-dependent fringe suburbs, and can be phased into being more rural. When this happens, it is possible to imagine a whole array of urban eco-villages colonizing the space. In these places much of a city’s renewable energy could be produced; much of a city’s waste could be mined, treated, and recycled using clever technologies; and some of the city’s specialised food needs could be produced there.

The **compact city form** (third quadrant) was the traditional urban form in the Middle Age Europe. Nowadays is also the form used to build the new “gated communities”, mostly in the US but also in some areas of Europe. These are forms of divided cities where the wealthy recognize that they need to optimize their choices and begin to form exclusive neighbourhoods and self-sufficient centres with all the best public transport and a pedestrian friendly environment. The residents of these compact centres live in walkable, mixed-use urban communities with access to jobs and amenities. They have all necessary services within a short distance and all institutions for supporting such centres available locally. Likewise all the best solar design and renewable technology can be built into these compact areas. In the post-carbon society compact small towns – either new towns built up following the New Urbanist agenda that calls for pedestrian friendly, higher density and mixed-use communities or the old historic towns scattered in many areas of Europe – may function as “eco-enclaves” where residents have a reduced travel need and use more efficiently the energy produced mostly by renewable sources.

However, this model is not a solution for all, as the social and demographic balance of such small towns would be vulnerable to any large inflow of new population, which could not be attracted in the city as there is only small employment or investment opportunities for new residents. The limit of this urban model is therefore that it is relatively closed and isolated, and it may easily evolve into a divided city scenario, where the poor populations are simply excluded outside the city boundaries.

Finally, in the **network city form** (second quadrant) the access and alternate forms of transport and land uses in eco-enclaves that are the province of the residents in the compact small towns are provided for all. Envisioning how this city model will work in the post-carbon society, people will have access to jobs and services by transit or walking as well as by using electric cars for short car journeys. Intercity movements will move toward fast electric rail and will be reduced considerably by the new generation of high quality interactive video conferencing. Green building design and renewable fuels will be a part of all neighbourhoods. The city will develop new rail links to all parts of the city, pedestrian friendly centres will be created across the
city-region using the best green buildings and infrastructure. In the areas between the intensively developed urban cores and corridors, urban eco-villages will be established to help manage the city’s ecological functions such as extra renewable energy production and water and waste recycling; these will be linked into a citywide green infrastructure system through clever control systems (smart grids) and local management. Urban eco-villages will also grow specialized agricultural produce and manage areas of urban biodiversity; they will be largely self-sufficient though they will still be within reasonable distance of the city for many urban functions.

In the rural regions around cities most agricultural and forestry production will focus on food and fibre and biofuels for the city and its region, thus reducing food and fibre miles. The manufacturing of products will become more localized and be more biologically based to replace petrochemicals. The towns where goods are produced will be linked mainly by freight rail to the city. All these changes will be supported by the diffusion and use of intelligent systems to ensure the needed punctuality and flexibility of goods and services provision, and the exchange of real time information flows and knowledge.

Of course the changes towards a post-carbon society envisioned above are not simple changes, and there is little question that the transition will be difficult and it will follow still uncertain pathways. The PACT project will continue then in the next task to analyse in more detail the technological, infrastructure, industrial, behavioural, social and final policy changes needed for a complete reorientation of our society and a new organisation of urban life.

One provisional conclusion we may achieve in this section is that the transition to post-carbon can be seen now in the beginning of a new era of resource productivity and investment in a new wave of sustainability technologies related to renewable energy and distributed, small-scale water, energy and waste systems, building on clever control systems and smart grids, all of which are more local and require far less fuel to distribute. This all means the city can become much more polycentric, aiming mostly to the city network model described in the second quadrant of our scheme. The transport systems that support such polycentric urban form appear to be new electric transit systems for fast cross-city movement and a series of small scale electric and hybrid vehicles for small local trips as well as walking and cycling, which have survived all the city form changes. The polycentric cores and the remaining suburban buildings all need to be renewed with solar and other eco-technologies. It is clear that these changes are not just technological substitutions, they entail also shifts in the business paradigms, in the culture of the utilities that will provide the infrastructure, and in the organisation that can enable new ways of managing our cities.
3.5 Identification of Future Land Use Patterns in the European Countries

In this chapter, the prevailing land use pattern will be identified in a first step. On the base of GIS data from CORINE land cover database, each European country can be categorized according to its share of the main land use types. Secondly, the emerging patterns in the long term are identified. This is done by analyzing the land use changes between 1990 and 2000 and evaluating the future progress qualitatively. Finally these findings contribute to the development of six different clusters of European countries that follow one specific land use pattern.

3.5.1 Identification of prevailing land use pattern

By intersecting the geographical CORINE Land Cover data with the borders of the European countries, statistical data could be gained to analyse the situation of the three major land use categories.

The following

Fig. 16 shows a classification of the countries by their share of built-up area among total area. The occurrence of discontinuous urban fabric is shown by red dots based on geometrically specified polygon-data. The map 1 shows that most of European countries have an urbanised area which is below 5% of the total area. Beyond that a couple of central and western European countries are moderately urbanised, featuring an urbanised area between 5 and 10%. Only three countries, however, have an urbanisation from more than 10%, these are the Netherlands with 12.5 %, Belgium with 20.2% and Moldova in the East with 15.6 %. Looking at the discontinuous urban fabric, it becomes clear that there is little correlation between the share of built up area and its continuity. Among the green, moderately urbanised countries for example, the discontinuous parts of the built up areas occur often in Germany, United Kingdom, Czech Republic, Slovenia, Hungary and Romania, but very little in Switzerland and Ukraine. Moreover, the concentration of this type of sprawled development appears different among the countries: in the UK a concentration of this type of development can be observed in the agglomerations of London, Birmingham, Manchester and Belfast, whereas those discontinuous patterns in Germany and the Eastern European countries occur evenly spread among the area. For the highly urbanised blue states the same finding can be stated.

Thus, the grade of urbanisation is not a suitable indicator for the way new urban development takes place. It is rather a consequence of local interests, planning and urban development laws and their enforcement and the size and location of existing agglomerations.
A slightly different picture arises, when classifying according to the share of agricultural land. First of all, the share of the total country size is much larger, namely up to 72 % (San Marino and the Netherlands). Fig. 17 shows that almost all countries in the core part of Europe are characterised by a high proportion of agricultural area, which occupies more than 55% of the total land. Even the highly urbanised countries Belgium and Netherlands belong to this group of countries. However, only a minor part of the land of most South and East European Countries as well as the Iberian Peninsula is agriculturally used. A negligible role of farming can be allocated to the Scandinavian countries.
Complementary to the share of agricultural land is the share of natural land: All *dark brown* countries of Fig. 18 are characterised by a comparably low share of natural land (26-60%) in Fig.4. Moreover, countries which have a relatively small area for agricultural use are characterised by more than 60% of natural land. This indicates that these two land uses are competitors in European countries. However, other than for the agricultural use, the comparison of
Fig. 16 and Fig. 18 also show an obvious correlation between the built-up area and the natural land. The highly urbanised countries Belgium and the Netherlands have less than 25% natural land left.

3.5.2 Potentially new emerging patterns and demographic development in long term

In order to estimate potentially new emerging land use patterns in the long term, a historical analysis of land use changes has been undertaken. By using CLC GIS data
from 1990 and 2000 and intersecting them with the country boundaries, the following situation can be seen:

The growth rate of built-up area shows that already urbanised countries, such as Germany and the Netherlands are still urbanising quite rapidly. On the other hand, less urbanised countries are also characterised by large growth rates (Ireland, Spain, Portugal), which is likely to continue in future. This phenomenon will be considered when establishing a comprehensive typology.

Fig. 19 Countries by their growth rate of built-up land between 1990 and 2000

The land used for built-up areas has been transformed from other uses, namely natural and agricultural land. In order to gain information on which types of land had
the biggest loss, the following Fig. 20 and Fig. 21 show the loss of agricultural and natural land respectively.

Since the main processes of urbanization happened already before 1990, only a little insight can be given by analyzing one decade. However, these processes happened recently and can therefore give useful hints to what will happen in the future.

Compared with Fig. 16, Fig. 17 shows that the rapidly urbanizing countries only partly gain the needed space by abandoning agricultural land. This is the case only in Ireland and the Netherlands to a significant extent. The urbanization in Portugal and Greece however, did also account for the amount of agricultural land, but thanks to the large agricultural areas in those countries, the loss is relatively low. In Spain, however both the built up and agricultural area grew, but the natural land became less during the decade investigated.

Fig. 20 Countries by their loss rate of agricultural land between 1990 and 2000

Fig. 21 Countries by their loss rate of natural land between 1990 and 2000
Another important development is demographic change, respectively the population development. Some countries already suffer from population decline, which makes a forecast important. The following Fig. 22 shows that most East and middle European countries will lose population within the next 20 years. However the countries in the west, such as United Kingdom, Ireland, Benelux, France, Spain and Portugal will still slowly grow.

**Fig. 22 Annual population growth rate 2000-2030 and estimated population in 2030**
The next chapter of the Deliverable will aggregate the findings above in order to create clusters of European countries belonging to a certain type of land use pattern.

### 3.5.3 Typology of patterns as a base for clusters of European countries

In the following the previous findings on land use and demographic development are taken and a typology of land use patterns can be developed. The following data are taken:

- total share of built-up area, agricultural area and natural land in 2000,
- growth rate of built-up area, agricultural area and natural land from 1990 to 2000,
- growth rate of discontinuous urban fabric from 1990 to 2000, and
- forecasted annual population growth rate 2000-2030

Based on this the countries can be allocated to certain clusters of future land use pattern as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Sub-Type</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. static countries with agriculture/forest characteristic
   1.1 No growth of built-up area, > 60% natural land (2000)  
   Albania, Andorra, Bosnia&Herz., Finland, Iceland, Macedonia, Norway, Sweden
   1.2 No growth of built-up area, > 40% agricultural land (2000)  
   Belarus, Gibraltar, Turkey

2. static urbanised countries
   No growth of built-up area, but share of built-up area > 5% (2000)  
   Cyprus, Slovakia, Liechtenstein

3. moderately urbanising countries with agriculture/forest characteristic (1st sector) + declining population
   3.1 Growth of built-up area <7% (1990-2000), > 60% natural land (2000)  
   Population decline 0,5 – 1,5% p.a.  
   Estonia, Montenegro, Russia, Slovenia
   3.2 Growth of built-up area <7% (1990-2000), > 40% agricultural land (2000)  
   Population decline 0,5 – 1,5% p.a.  
   Croatia, Latvia, Lithuania, Poland, Serbia

4. moderately urbanising urban countries (2nd sector) + declining population
   Growth of built-up area <7% (1990-2000), Share of built-up area 5-10% (2000)  
   Population decline 0,5 – 1,5% p.a.  
   Bulgaria, Czech Republic, Hungary, Romania, Ukraine, Germany, Italy, Moldova

5. rapidly continuous urbanising countries+ growing population
   5.1 Growth of built-up area <12% (1990-2000), > 60% natural land (2000), Population growth 0,5 – 1,5% p.a.  
   Austria
   5.2 Growth of built-up area <12% (1990-2000), > 40% agricultural land (2000), Population growth 0,5 – 1,5% p.a.  
   Greece, France
   5.3 Growth of built-up area <12% (1990-2000), Share of built-up area 5-10% (2000)  
   Population growth 0,5 – 1,5% p.a.  
   Denmark, Luxembourg, Switzerland, United Kingdom,
   5.4 Growth of built-up area <12% (1990-2000), Share of built-up area 20-30% (2000)  
   Population growth 0,5 – 1,5% p.a.  
   Belgium, Malta

6. rapidly discontinuous urbanising countries+ growing population
   Ireland, Spain, Portugal, Monaco, Netherlands, San Marino

The following map (Fig. 23) shows the geographical distribution of the six land use types, defined in

Table 2. It is evident, that there is an northeast-southwest-divide: The rather static and less urbanised green colour gradually turns into red indicating a rapid urban
development. The Scandinavian countries, Belarus, Bosnia and Macedonia and have had almost no urban growth between 1990 and 2000 and there are either characterised by agricultural or forestry based economy or by a large share of open landscape. The other countries in the east and a few countries in the middle, such as Germany, Czech Republic and Italy, are gradually urbanising, but feature the same tendency of population decline. The two red types of rapidly urbanising countries are both characterised by a slightly growing population, but the difference lies in the way urbanisation happens. The orange countries UK, France, Belgium, Switzerland, Austria, Greece, and Turkey are rather continuously urbanising; urbanisation takes place in a compact way, adjacent to already urbanised areas. In contrast the fully red countries have a comparable high share of “discontinuous urban fabric” with low density and in a “leapfrogging” matter. These countries are Ireland, Spain, Portugal and the Netherlands.

![Fig. 23 Countries by Land use type](image)

However, both land use changes and demographic changes are distributed very differently within each of the considered countries. Therefore it would be necessary in a further step to specify the analysis on the level of European Regions, e.g. NUTS 3.

4 Land-use, Transport and Energy
4.1 Adaptations of the transport infrastructure to different categories of land use patterns

Having developed the land use typology, the transport infrastructures need to be analysed. The CORINE land cover database also provides information of the area occupied by transport infrastructure and facilities (CLC codes 122, 123 and 124, cf. Table 1).

In order to evaluate the requirements of adaptation it is necessary to appraise the infrastructure against the land use pattern. It is not helpful to compare the transport infrastructure with the total area of one country, because the total amount or share of transport infrastructure does not determine requirements of adaptations, rather its relationship to the accessible land (=built-up area), its pattern (continuous or discontinuous) and the demographic perspectives of the countries. Therefore the following map Fig. 24 shows the share of area occupied by transport infrastructure among the total land artificially covered (= transport infrastructure efficiency). Additionally the major road network is displayed in this map in order to provide an impression of the differences in density within Europe: In the middle it is most dense, but it becomes sparser towards the countries lying at the edge of Europe. However, much more important is the share of transport infrastructure (roads, rail, airports and ports) in comparison which is displayed by different colors in the same Fig. It can be seen, that Ireland, Sweden, Estonia and Greece are comparably inefficient in terms of transport infrastructure. On the contrary, the yellow countries have a share of transport infrastructure of less than 1%. They are Belarus, Romania and Turkey.

However the efficiency is not a static value, but it can change over time according to the new construction of infrastructure. Therefore Fig. 25 shows the growth rate of area for transport infrastructure between 1990 and 2000 and additionally the railway network, like it has been in 2000. There is a clear decline of the construction of new infrastructure from the North East countries (growth-rate of occupied land below 0.02%) towards the South-West. The largest growth can be observed in Portugal and Ireland.
Fig. 25 Growth rate of transport infrastructure area (1990-2000) and railway network (2000)
The following table compares the share of transport infrastructure and the trend of transport infrastructure occupied area within each land use type and results in recommendations:

**Table 3: Values for transport infrastructure for each country, clustered by land use types**

1. **static population countries with agriculture/ forest characteristic**

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of Transport infrastructure in urbanised area</th>
<th>Transport infrastructure trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania</td>
<td>2.36</td>
<td>0</td>
</tr>
<tr>
<td>Bosnia&amp;Herz.</td>
<td>2.64</td>
<td>0</td>
</tr>
<tr>
<td>Finland</td>
<td>2.40</td>
<td>0</td>
</tr>
<tr>
<td>Iceland</td>
<td>10.99</td>
<td>0</td>
</tr>
<tr>
<td>Macedonia</td>
<td>1.40</td>
<td>0</td>
</tr>
<tr>
<td>Norway</td>
<td>3.36</td>
<td>0</td>
</tr>
<tr>
<td>Sweden</td>
<td>6.85</td>
<td>0</td>
</tr>
<tr>
<td>Gibraltar</td>
<td>8.34</td>
<td>0</td>
</tr>
<tr>
<td><strong>average</strong></td>
<td><strong>4.79</strong></td>
<td><strong>0</strong></td>
</tr>
</tbody>
</table>

2. **static population urbanized countries**

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of Transport infrastructure in urbanised area</th>
<th>Transport infrastructure trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyprus</td>
<td>3.97</td>
<td>0</td>
</tr>
<tr>
<td>Slovakia</td>
<td>4.72</td>
<td>0</td>
</tr>
<tr>
<td><strong>average</strong></td>
<td><strong>4.35</strong></td>
<td><strong>0</strong></td>
</tr>
</tbody>
</table>

3. **declining population urbanizing countries with agriculture/ forestry**

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of Transport infrastructure in urbanised area</th>
<th>Transport infrastructure trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estonia</td>
<td>7.12</td>
<td>0.01</td>
</tr>
<tr>
<td>Montenegro</td>
<td>2.85</td>
<td>0.07</td>
</tr>
<tr>
<td>Russia</td>
<td>1.41</td>
<td>0</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1.61</td>
<td>0.13</td>
</tr>
<tr>
<td>Croatia</td>
<td>2.40</td>
<td>0.13</td>
</tr>
<tr>
<td>Latvia</td>
<td>5.46</td>
<td>0</td>
</tr>
<tr>
<td>Lithuania</td>
<td>4.42</td>
<td>0.002</td>
</tr>
</tbody>
</table>
### 4. Declining population urbanizing countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of Transport infrastructure in urbanised area</th>
<th>Transport infrastructure trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulgaria,</td>
<td>1,56</td>
<td>0</td>
</tr>
<tr>
<td>Czech Republic,</td>
<td>2,30</td>
<td>0,13</td>
</tr>
<tr>
<td>Hungary</td>
<td>2,17</td>
<td>0,14</td>
</tr>
<tr>
<td>Romania,</td>
<td>0,76</td>
<td>0,002</td>
</tr>
<tr>
<td>Ukraine,</td>
<td>1,02</td>
<td>0</td>
</tr>
<tr>
<td>Germany,</td>
<td>2,65</td>
<td>0,04</td>
</tr>
<tr>
<td>Italy</td>
<td>2,89</td>
<td>0,03</td>
</tr>
<tr>
<td>Moldova</td>
<td>0,47</td>
<td>0</td>
</tr>
<tr>
<td><strong>average</strong></td>
<td><strong>1,73</strong></td>
<td><strong>0,04</strong></td>
</tr>
</tbody>
</table>

### 5. Rapidly continuous urbanizing country

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of Transport infrastructure in urbanised area</th>
<th>Transport infrastructure trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>1,79</td>
<td>0,10</td>
</tr>
<tr>
<td>Greece</td>
<td>7,52</td>
<td>0,21</td>
</tr>
<tr>
<td>Denmark</td>
<td>3,15</td>
<td>0,02</td>
</tr>
<tr>
<td>France</td>
<td>3,42</td>
<td>0,13</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>3,38</td>
<td>0,12</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2,89</td>
<td>0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3,52</td>
<td>0,01</td>
</tr>
<tr>
<td>Belgium</td>
<td>3,63</td>
<td>0,12</td>
</tr>
<tr>
<td>Malta</td>
<td>8,27</td>
<td>0</td>
</tr>
<tr>
<td><strong>average</strong></td>
<td><strong>4,17</strong></td>
<td><strong>0,08</strong></td>
</tr>
</tbody>
</table>

### 6. Rapidly discontinuous urbanizing country

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of Transport infrastructure</th>
<th>Transport infrastructure trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poland</td>
<td>3,54</td>
<td>0,02</td>
</tr>
<tr>
<td>Serbia</td>
<td>1,28</td>
<td>0</td>
</tr>
<tr>
<td><strong>average</strong></td>
<td><strong>3,34</strong></td>
<td><strong>0,04</strong></td>
</tr>
</tbody>
</table>
Based on the data above the following implications are given:

- the value for the share of transport infrastructure is relatively high, indicating a low transport infrastructure efficiency in the countries belonging to the land use types (1) and (2).
  - these countries are dominated by non artificial land use such as agriculture and forestry, but the few urbanized area is permeated by transport infrastructure in a quite inefficient way. Thus, the proper dimensioning of transport infrastructure is a major future challenge in these countries.

- the share of transport infrastructure is lower for the countries with declining population, which are moderately urbanizing (3); a very minor part of this urbanization is allocated to the transport infrastructure - the growth rate is 0,04 % in average;
  - on the one hand urban growth of this type of countries should be avoided at all facing the declining population, on the other hand this indicates that the countries of land use type (3) are starting from a relatively low degree of urbanization, and their transport infrastructure grows quite efficiently. This should be done in a most sustainable way, dedicated for vehicles using least fossil fuels, such as electric vehicles, man driven vehicles and energy efficient public transport means.

- the share of transport infrastructure of the land use type (4) countries is much lower and the growth rate of the area occupied by transport infrastructure is about the same than for land use type 3;
  - this indicates that those countries, which have been urbanized before 1990 to a certain level (more than 5% of the total country size), constructed relatively less transport infrastructure to access the urbanized land. The extension of the transport infrastructure should be avoided due to the declining population. Instead the focus should be laid on new efficient mobility concepts combining the efficiency of public transport and the freedom of individual transport to efficiently use the existing infrastructure.

- the greatest need for action is given from type (5) and (6), since they are quickly urbanizing and therefore they will experience lots of changes of land use control and guidance;
these countries are still growing in population, but the share of their transport infrastructure is among the highest of all types; the focus of the growth seem to lie on the transport infrastructure for the rapidly discontinuous urbanizing countries (type 6), which should be guided by promoting powerful mass rapid transit system such as high-speed railways.

4.2 Harmonization of Energy Infrastructure with Land Use and Urban Form

4.2.1 Energy and Urban density

There is a clear difference of the potential of the production of energy regarding to the urban density. Urban cores and medium and small towns are characterized by a high density of both population and built up area, on the other hand sparse developments and suburbs have a low density (cf. Fig. 13). The lowest density can be stated for rural areas, which are the usual location of centralised conventional energy technologies and offer many opportunities to supply renewable energy. On the other hand the demand is rather medium due to the sparse population, so that the current situation requires huge energy transfer between the two land-types, with a total energy consumption globally too high to be “post-carbon compatible”.

In a Post-Carbon society, the energy system should be more balanced between high density, low density and rural areas. All areas should increase their post-carbon compatible renewable energy collection, while old fashion energy supply from rural areas (i.e. centralized CO₂ emitting technologies) will dramatically decrease. Simultaneously, total energy demand would decrease thanks to high energy conservation and energy efficiency. At the end, energy would mostly be produced in-situ, with networks ensuring the remaining necessary energy transfer between different urban forms and rural areas.

Urban areas are and will probably remain with an adverse energy balance, both in high and low densely populated areas. This is because of relative land scarcity and high land value, which has prevented the installation of energy production capacities in such territories, in a time when power generation was profitable in rural areas thanks to low energy transmission costs. Moreover the risks and social acceptability associated with concentrated power generation in populated zones were important reasons for this functional division of urban areas and the countryside.
Reducing energy deficit of urban areas would require increasing on-site energy production and cutting energy consumption in urban areas. Ways to achieve these results could be however much different between high and low density urban areas, because of the differences in urban characteristic. For instance, large quantities of renewable energy are difficult to produce on compact urban areas, while large energy efficiency programs focused on buildings and public transport development are much feasible. On the contrary, energy consumption would remain higher on least dense urban areas because of incompressible energy needs for individual transport. However, larger spaces would enable to collect more renewable energy on these areas.

At the end, requested residual energy supply of urban areas, especially populated ones, in a post carbon world could be satisfied through energy networks (renewable heating and/or electricity) produced in less dense urban or rural areas. One main target of the carbon transition in terms of energy is to minimize energy supply from centralized technologies which are not compatible with a zero or low-carbon energy system.

4.2.2 Energy technologies

The current renewable energy technologies aim at collecting solar, wind and biomass resources. Additionally, more prospective technologies are being under development at a very initial stage: they could help collecting tidal and wave energies, or growing up and transform algae’s for energy purposes. In a very long-term, oceans could be large energy suppliers, and perhaps cover a lot of our needs. Beyond the renewable
there are also plans for long-term energy supply through highly concentrated energy sources like nuclear fourth generation or even nuclear fusion.

Energy technologies can be defined both by the nature of the energy sources which supply them and from their generation scale (see below). Both energy sources and generation capacities can be concentrated or diffused. As defined within Fig. 27, energy technologies can be implemented in urban or in rural areas depending on the category they belong to. For instance solar photovoltaic technology, as a diffused energy source, can be used either as a centralized power-plant in rural areas or as a distributed generation on residential buildings roofs. Today, there are over 1000 large scale PV projects above 1.3 MWp in the world and almost 100 very large scale PV power plants above 10 MWp²³ mainly in Spain (70% of solar capacity in 2008) and Germany (13%). But over a quarter of total installed PV capacity in the world in 2008 remains for on-site electricity generation, and the distributed PV market share reaches over 98% for almost all countries except Germany and Spain.

Fig. 27 Energy sources according to the location of production

4.2.3 Renewable Energy Resources

4.2.3.1 Solar technologies

The Solar energy resource can be collected through two main technologies which transform solar irradiation into electric power: Solar Photovoltaic (PV) and Concentrated Solar Power (CSP). Moreover solar energy can be exploited in thermal form. Some of these technologies can be implemented in very dense urban areas (solar PV and thermal collectors), and others are more suitable for low density areas through centralized production plants (solar CSP and PV).

4.2.3.1.1 Solar Photovoltaic (PV)

PV generates electric power by using solar cells to directly convert energy from the sun into electricity: photons of light knock electrons into a higher state of energy,
which create electricity. Various technologies are gathered under the generic name of photovoltaic: they consist principally of wafers (mono- and poly-crystalline silicon) and thin film cells (amorphous silicon, organic polymers, light-absorbing dyes). Crystalline silicon-based wafers and amorphous silicon thin film cells are currently the most mature and the dominant technologies. There are four primary applications for PV power systems: Off-grid domestic, Off-grid non-domestic, Grid-connected distributed, Grid-connected centralized. In grid-connected cases, PV systems require inverters to convert DC to AC in order to feed power to the grid.

Due to the growing demand for clean sources of energy, manufacturing of solar cells and photovoltaic arrays has expanded dramatically in recent years. This fast development is pulled by direct and indirect monetary incentives. Very common are preferential feed-in tariffs, which vary a lot between countries and which explain the contrasted development of the technology. Between 2000 and 2007, installed power has increased by 37%/year on average and no less than 70% in 2007-2008. In 2008, the EU accounted for more than 70% of world solar electricity production (mainly in Germany and Spain, 43% and 27% respectively of the world PV electricity generation).

4.2.3.1.2 Concentrated Solar Power (CSP)

CSP systems use lenses or mirrors to track and focus a large area of sunlight into a small beam. The concentrated light is then used as a heat source for a conventional power plant. The four main categories of CSP are the Power Towers, the Parabolic Trough Systems, the Stirling Dishes and the Fresnel Mirrors. CSP is still at a very early stage of technological development, so that only a few demonstration projects are currently able to produce electricity. However potential development is supposed to grow sharply in the mid to long-term as soon as the costs decline, thanks to further R&D and future industrial developments. On the other hand, CSP needs very high solar irradiation to generate electricity (over 2000 W/m2), which is given only at a few places in Europe.

In 2008, 420 MW of Concentrated Solar Power was installed worldwide, the main part of it in the USA (SEGS, operating since the 1980s). But also in Spain 270 MW are under construction, almost fully realised by parabolic trough plants. 5800 MW of CSP is planned for 2012 and 11 GW are already in different project advancement phases across the world (half being in the USA, a quarter in Spain, the rest in Middle East and China). In a very long term perspective, a global link of electricity networks could supply the EU with sustainable solar electricity from North Africa and the Middle East using high-voltage direct current (HVDC) “electricity highways” (DESERTEC Concept).

Sources:

24 Source : Global energy and CO2 database, Enerdata
25 REN21 Global Status Report, 2009
26 http://www.desertec.org/
Solar power density of centralized photovoltaic is around 25 MW/km², accepting that about 1/3 of land area is wasted. CSP power plants have currently a power density in the 20 to 50 MW/km² range, depending on the implemented technology.  

### 4.2.3.1.3 Solar thermal Energy

Total installed surface of solar thermal collectors is around 210 Mm² worldwide and 25 Mm² in the European Union. Main used technologies are flat-plate and evacuated tube collectors (over 80% of the market) while over 17% of collectors are made of unglazed plastic, mainly used on the North American market for swimming-pools.

The global potential of solar thermal electricity generation is estimated by Tzscheutschler (Tzscheutschler, 2005). According to the analysis of Tzscheutschler Europe has only a minor potential of suitable areas (0.02 Mio. km²) for constructing solar thermal plants. The technical potential for electricity generation in Europe is highest in Spain respectively Italy (ca. 1600TWh respectively 500 TWh). Especially because of low radiation more less only the south of Europe (Spain, Italy, Portugal) is suitable for solar thermal electricity generation.

### 4.2.3.2 Wind energy

Wind energy has quickly become an industrially developed power technology. Global wind electricity generation reached 230 TWh in 2008, mainly in the EU (over 50% of total wind generation). Wind installed power has increased by 27%/year on average, pulled by fiscal incentives like preferential feed-in tariffs or the establishment of green certificates markets. The EU is leading the wind offshore technology market with over 1 GW (the entirety of the installed power worldwide in 2007) and more than 90% of capacity concentrated in three countries (UK, Denmark and the Netherlands). Off-shore wind technologies are still less mature than on-shore ones. Their higher installation and maintenance costs tend to slow down its development even if other advantages are huge (potentials, social acceptability, load factors etc.).

Wind energy density is strictly connected to wind farms configuration and their spatial arrangement. Today’s average rated power density on-shore is around 5 MW/km², whereas in best case, regions can reach nearly 10 MW/km². Current wind off-shore projects reach an average power density of 10 MW/km² for specific rated power of turbines ranging from 3 to 5 MW. It depends on the average turbine spacing which

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27 Analyses of the SolarPACES project database show that the average power density is around 20 MW/km² for solar tower, and 25-50 MW/km² for parabolic trough systems. [http://www.solarpaces.org/inicio.php](http://www.solarpaces.org/inicio.php)
29 Source : Global energy and CO2 database, Enerdata 2009
in turn depends on the average turbine density, depending itself on the average turbine size. The average turbine spacing is evaluated at around 8 numbers of rotor diameters, but it may vary a lot according to local condition: However, also till 2050 there will not be more than two to three wind turbines per km$^2$ on average and the average rated power should remain at the same order of magnitude of what we know today, because size effect globally compensate the spacing effect.

There are also many urban wind energy concepts (rooftop or building integrated), with systems of a few kW of power able to supply a building. But integrating such systems in a urban configuration is still far from being easy, although demonstrators have already proved its feasibility (Miles, 2006).

The wind energy onshore and offshore potential for Europe is pointed out by the EEA (European Environment Agency, 2009d). The estimated potential described through full load hours is shown in

Fig. 28.

**Fig. 28 Distribution of full load hours in Europe**

4.2.3.3 **Biomass resources**

Biomass can be used for various energy purposes: either directly in final consumption through combustion or transformed in second energy carrier like biofuels or electricity. In 2008, biomass represented almost 10% of primary energy demand at the world level and 6% in the European Union. In Europe, a third of the

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30 See [http://www.4coffshore.com/windfarms/](http://www.4coffshore.com/windfarms/) for a detailed wind off-shore project database
biomass is used as energy input for power-plants, a third is used in residential, tertiary and agriculture sectors (over 90% for households only) and almost 20% is used in Industry. Finally, 10% of the biomass supply is used in the transport sector, as biofuels. At the world level, two third of the biomass is used in residential, followed by industry (16%), the electricity sector (7%) and transports (4%)\textsuperscript{31}. More details about the biomass resources and their potentials are provided also in the following sections.

The question about how much bio-energy can be produced in Europe without harming the environment is the main topic of an EEA report (European Environment Agency, 2006b). Bio-energy from agriculture, forest and waste is analysed within the mentioned report. Furthermore an outlook for future (2020 and 2030) bio-energy potential is given within the report. The environmentally compatible current potentials for European Union countries can be seen in Fig. 29.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{bioenergy_potential.png}
\caption{Current total bio-energy potential (MtOE)}
\end{figure}

Source: According to numbers of (European Environment Agency, 2006b)

4.2.4 Renewable Energy Harvesting and Land Use

The required land to collect renewable energy sources represents currently around 9% of total European land area, mainly due to the production of first generation biofuels and the exploitation of forests. Land-use for energy purposes could grow up to
15% of total surface by 2050 (14% in 2030) in a reference case as illustrated by the RECOVERY scenario (EnerFuture scenarios, cf. Land use patterns and energy infrastructure). In a carbon constraint scenario (RENEWAL), land-use for renewable energy production would possibly reach 18% by 2050 (16% in 2030), representing a doubling of the current allocated areas.

Table 4 Surface requirements for renewable energy collection in the EU-27 below provides an insight about the European land-use from various energy sources and technologies in the two scenarios. The main development would clearly come from biomass: forest residues and the development of short rotation crops (SRC).

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>S1 - Recovery</th>
<th>S3 - Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2020</td>
<td>2050</td>
<td>2020</td>
</tr>
<tr>
<td>Solar on roofs (PV and thermal)</td>
<td>1000 * Ha</td>
<td>22</td>
<td>135</td>
</tr>
<tr>
<td>Solar power plants</td>
<td>1000 * Ha</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Forests</td>
<td>1000 * km²</td>
<td>326</td>
<td>414</td>
</tr>
<tr>
<td>SRC</td>
<td>1000 * km²</td>
<td>155</td>
<td>217</td>
</tr>
<tr>
<td>First gen. Biofuels</td>
<td>1000 * km²</td>
<td>126</td>
<td>48</td>
</tr>
<tr>
<td>Wind energy</td>
<td>1000 * km²</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td><strong>Total renewable energy supply</strong></td>
<td></td>
<td><strong>Mtoe</strong></td>
<td>212</td>
</tr>
</tbody>
</table>

In RECOVERY, 21% of European forests are supposed to be exploited for energy purposes by 2050, against 27% in RENEWAL. The European Environmental Agency has calculated that 20% of forests areas would be classified as highly suitable for bio-energy production and an additional 51% would be moderately suitable, (European Environment Agency, 2007)\(^\text{32}\). This comparison tends to prove that a larger renewable energy supply will be possible in the future, especially from forests. Grassland areas will be the preferred land-type for developing renewable supply, mainly for energy crops (SRC) but also for wind energy generation. In RECOVERY, over 30% of grassland surface could be used to harvest renewable energies by 2050, and the ratio could reach over 40% in RENEWAL. This is not without questioning about the probable constraints and risks this may induce, issues that are investigated in the next sections.

The question is: how can we produce the requested amount of renewable energy at the lowest possible cost to satisfy with the visions of post-carbon societies? The answers can be substantially different across the various land use types. Each land use type, defined in Table 5, will have specific implications for the energy infrastructure due to different potentials for renewable energy harvesting across Europe:

\(^{32}\) The EEA calculates this ratio on a EU21 zone
The technology vs. land-type matrix presented below (Table 5) shows how renewable technologies can be implemented on various land-types. Practically, the possibility to build renewable capacities also depends on many other factors like the nature of the soils, the vicinity of a power network or other industrial activities, the accessibility of the zone, the presence of mountainous areas or water bodies… The deployment of some technologies allows to maintain the primary use of land (wind energy and in some cases biomass), while other technologies necessitate dedicated areas, and as such, a complete reconversion of the initial land-use (this is especially the case of solar power plants and in some way biomass).

### Table 5: Renewable energy sources and land-types

<table>
<thead>
<tr>
<th>Sub-type</th>
<th>Solar</th>
<th>Wind</th>
<th>Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 static countries with &gt; 60% natural land</td>
<td>x</td>
<td>X</td>
<td>x</td>
</tr>
<tr>
<td>1.2 static countries with &gt; 40% agricultural land</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>2 static urbanised countries</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>3.1 moderate urbanising countries with &gt; 60% natural land</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3.2 moderate urbanising countries with &gt; 40% agricultural Land</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>4 moderate urbanising countries</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>5.1 rapidly continuous urbanising countries with &gt; 60% natural land</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>5.2 rapidly continuous urbanising countries with &gt; 40% agricultural Land</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>5.3+5.4 rapidly continuous urbanising countries (urban area dominated)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 rapidly discontinuous urbanising countries</td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

Large X indicates first best options while small x indicates second best options to collect diffused renewable energy of the given land-type.

Exploitation of renewable energy on a given area may necessitate a complete land reconversion from its primary function. But there would also be relative complementarities between energy production and other ways of land-use. Solar power density is greater than wind energy density. But solar power plants also cover at 100% the requested areas and finally prevent from multi-use of land, unlike wind machines. This is why every situation requires a detailed evaluation of the total advantages and drawbacks in an integrated land-use perspective.

Renewable technologies can be used on several land-types. We would prefer speaking of first-suited or second-best technological options for a given land-use type, which generally depends on many factors (}
Table 5). For instance, solar technologies are generally adapted for built-up areas (=urbanised and urbanising countries) and marginal sunny regions like deserts. But as solar plants require 100% of land, it cannot be considered as the best option for countries dominated by agricultural or natural land including forests. On the contrary, wind energy is well suited for agriculture and natural land areas because it allows for multi purposes land-use. It seems also possible in built-up areas but is almost excluded in forests or mountainous areas, which roughness deteriorates the average load factors. Biomass may be largely produced from existing forests as it is. But grasslands would be often technically adapted areas to produce bio-energy, as they offer least competition with other uses. It is still possible to produce bio-energy on agricultural land, but there may be hard competition with crops and livestock products as experienced with the first generation bio fuels.

There are possible complementarities between energy production and other uses of land, as illustrated with two examples. First, there may be complementarities between wind energy and agriculture. The mandatory spacing between wind turbines is currently around 100 to 200m, which makes land available for other uses within wind farms, like farming or keeping cattle. Moreover, agricultural areas often have low roughness thanks to few obstacles, which implies a good average system capacity factor. Furthermore, wind farms can be designed with an optimal size and layout in such areas. Another possible co-benefiting case refers to first generation bio fuels production and animal feeding. Disregarding the negative sides which will be discussed later on, one positive aspect of first generation bio fuels production is the valorisation of by-products like the press cakes used for animal feeding (for instance in sunflower oil production). An additional example would be the valorisation of agricultural residues for energy purposes.

One common feature of diffused energy sources is that their capacity size is proportional to the land surface they cover. Large production rates require large areas to be collected, which explains why amounts of renewable energy cannot be collected in compact cities or urban cores. Following this characteristic, most of new and renewable technologies are land-intensive (basically all, except hydro technologies, geothermal technologies and wind-offshore, among technologies described later on).

Wind Energy has achieved a high penetration rate in some countries and accounts for 19% of the electricity produced in Denmark, 11% in Spain and 7% in Germany. All of this countries belong to rapidly urbanising countries, which shows that other factors are more important here than the land use characteristics of the country.

Within each country, the settlement appears in different urban forms as shown in Fig. 13. In a post-carbon society, the urban form decides on the potential of reducing energy dependency from rural zones and re-balance energy patterns:
The types II and III (urban cores, medium to small towns) have large energy efficiency potential and possible ways to reorganize their networks; they have clearly low renewable energy supply potentials because of a lack of free space. On the contrary, type I and IV urban areas (sparse developments and suburbs) will certainly maintain a larger energy demand, mainly due to an uncompressible need for mobility, but they have larger opportunity to catch diffused renewable energies.

**Type II and III settlement forms**

With a growing population on a limited earth surface, there will surely be a densification of human settlements in cities in the next decades, which is also true at the European level. There used to be a dramatic deficit of energy supply in urban areas, because of a lack of resources. In compact urban areas, renewable energy can mostly be collected on available roof areas, using solar panels (thermal collectors or photovoltaic panels). Buildings configuration is often multi-flat in these zones, which implies that their roof to floor areas ratio is rather small. Thus solar energy supply is usually not sufficient to cover the basic energy needs of buildings. In dense cities, buildings may also use low thermal geothermal or heat pumps technologies for space heating and cooling. However, these technologies are not completely autonomous and require other energy supply, mainly electricity, which in turn could be produced thanks to solar PV.

**Type I and IV settlement forms**

Larger free spaces in sparse urban areas would enable to collect more renewable energy on roofs (solar energy) and from unused areas. However, all kinds of energy network solutions are more difficult to implement on sparse urban areas in contrast to compact urban areas. Indeed, the profitability of such networks is directly linked to the potential market which is weak in sparse zones. Smart-grid technologies would finally ensure a better management of energy networks, in particular thanks to the possible development of electric cars that they would enable, in synergy with on-site energy production.

Some cities are ahead of the curve than others like the city of Växjö in Sweden, which makes part of the C40 group.\(^\text{33}\) It generates over 50% of its energy from renewable sources (solar, geothermal, biomass) produces one fifth of its electricity locally. However 37% of its renewable energy supply comes from biomass which is not produced on-site and still is supplied from countryside. It is then clear that full renewable energy autonomy is a target really difficult to reach for cities.

\(^{33}\) [http://www.c40cities.org/bestpractices/renewables/vaxjo_fossilfuel.jsp](http://www.c40cities.org/bestpractices/renewables/vaxjo_fossilfuel.jsp)
4.2.5 Problems and risks of land use for energy purposes

Depending on the land use subtype, there are various problems and risks.

4.2.5.1 Competitions with agricultural use
The role of land use issues depends on the kind of the considered renewable energy: As already shown, the constraints of wind energy and solar on-site energy production will be limited to economic and societal ones. Their future deployment will mainly depend on their technical and economic potential. On the contrary, centralized solar power (CSP or PV) and especially energy production from biomass will face major constraints to their development, related to land-use issue. They are supposed to develop on competing land-types, usually devoted to other uses and functions.

The more serious land-use competitor of renewable energy production is of course cropping and stock farming. Today, main land-use is clearly dedicated to agriculture purposes. At the World level, agricultural areas represent 38% of total surfaces, 32% of which is constituted by arable land and permanent crops, the remaining 68% being permanent pastures and meadows. The share of agricultural areas in the European Union is higher but slightly decreasing over time. It reaches 45% of total land surface, while it was around 53% in 1970. France and Spain account for 15% each of the total European agricultural area, followed by Germany and the United Kingdom (9% each) and then Poland (8%), Italy and Romania (7% each).

Unless to the rest of the world agricultural areas will probably not expand in Europe and there may remain potential unused arable land in the future. Today, arable land is estimated to be 50% of total surface. Moreover, 21% of soils have no major constraints with great disparities between countries: 54% of soils without constraints in France and only 3% in Spain.

In future, a larger usage of land for renewable energy production may appear as one on the possible contribution to combat climate change. In this new context, the equation to supply the various growing needs in a sustainable way will be difficult to solve. Indeed, large-scale use of land for energy purposes is already controversial. It is feared to roughly compete with the more traditional agricultural use to the detriment of the environment. Other land-types than agricultural will be investigated to produce renewable energy. Those are unused arable lands, natural grasslands (also including shrub-lands), marginal lands... (Van Vuuren, Bellevrat, Kitous, & Isaac, 2010).

4.2.5.2 Risks of degradation of natural land
The European Common Agriculture Policy (CAP) should reflect multiple objectives beyond the primary role of farming. According to the European Environmental Agency, farming and rural land management should also perform a complex set of

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34 For FAO land-uses definition please refer to http://www.fao.org/waics/aeostat/agicult/landuses-e.htm
35 http://www.fao.org/ag/agl/terrrastat/
36 Hydromorphy, Low CEC, Aluminium Toxicity, Vertic Properties, High P fixation, Salinity, Sodicity, Shallowness, Erosion Risk
functions for society (European Environment Agency, 2009b), including the provision of a range of environmental benefits and the maintenance of rural assets. Several risks for environmental sustainability are clearly identified. They are mainly associated to bio-energy production, and relate to biodiversity, water resources and soils quality as listed below.

- Risks for biodiversity

Global forest areas are declining by 0.2% on average each year for 20 years\(^{37}\). On the contrary, European forests are expanding (at less than 0.1%/year) and sometimes suffer a lack of global management and maintenance. But an intensive exploitation of forests, triggered by high valorisation of forestry products may induce unsustainable outcomes. First generation bio fuels have been accompanied with risks of deforestation and risks for biodiversity because of intensive implementation way. This was particularly the case in Indonesia with palm oil production and Brazil with sugarcane production. Lately, deforestation has occurred at a pace of 0.5%/year on average in Brazil.

Short rotation crops used for bio-energy production would probably use massively clones or GMO, with the associated potential risks for biodiversity. Intensification of farming activities is also a great threat for biodiversity on all agricultural areas. This is why the European Union has adopted in 2009 a directive related to good environmental practice for bio fuels production.

EU Member States have agreed to generate 10 percent of their fuel for transport from renewable sources by 2020, with a large proportion expected to come from bio fuels\(^{38}\). Sustainability criteria were also provided by the Commission but a recent publication (Al-Riffai, Dimaranan, & Laborde, 2010) calculated that only 5.6% of the target could be met with first generation bio fuels, within a certain environmental viability. By end of 2010, the European Commission will publish a report on indirect land-use change due to bio fuels.

- Risks for water resources

Global water stress in Europe is meant to remain quite stable over time or could even improve in the next 20 years (Alcamo, Heinrichs, & Rösch, 2000). However, water scarcity or resources depletion due to agricultural activity and bio-energy development may become a great threat in some regions like in southern Europe (Iberian Peninsula, Italy…). In addition, global climate change may potentially amplify this phenomenon in the long-term, once again especially in southern European regions ((Alcamo, Flörke, & Märker, 2007) and (Lehner, Czisch, & Vassolo, 2005)).

The pollution of underground water associated to the intensification of agriculture and the development of bio fuels (nitrogenous pollution of water) also questions the sustainability of the production system. It is thus necessary to study carefully, at the


\(^{38}\) Renewable Energy Directive 2009/28/EC
regional level, the potential impacts of bio-energy development on future water resources.

- Risks for soils degradation

Degradation of land due to agricultural activities is not a monopoly of emerging countries. Instead, the European Union has demonstrated that it is good also in this field, with 36% of degraded areas according to the FAO, 36% of which is due to agricultural activities (against respectively 26% and 35% at the World level)\(^{39}\). Intensification of farming activities to the detriment of more traditional environment-friendly agriculture has accelerated degradation of natural areas over time. This has been particularly the case in Eastern Europe (mainly in Bulgaria and Romania).

An extensive land-use for energy purposes may amplify soils degradation, in particular through intensive farming. This might be true also in Europe, and both land conversion and yields increase must take care of soils quality. Moreover, the removal of agricultural residues, used for energy uses, may accelerate soils degradation if the loss of nutriments is not replaced by additional fertilizers.

4.2.5.3 Risks for markets and food supply

For instance, large scale use of biomass for energy purposes is controversial, and the recent food crisis has attracted much attention to this topic. The UNEP (United Nations Environment Programme, 2009) proposes several explanations to the recent increase of food prices: competition for cropland from the growth in bio fuels, low cereal stocks, high oil prices, speculation in food markets and extreme weather events. According to Cooke (Cooke & Robles, 2009), the fluctuations are not directly due to economic fundamentals of demand and supply on food markets, but they were caused by financial activities and/or speculative behaviours. Nevertheless, it has become clear that the signal sent to the global economy reveals a risk for potential tensions on food market fundamentals.

This is why it has become crucial to study carefully the food price market formation, assessing future global supply and demand for food (Van Vuuren et al., 2009). The average diet will play a central role in the evolution of global food requirements, while the evolution of yields will determine the capacity of countries to meet their national demand. It is still not clear today what will be the necessary trade and dependencies between regions, and as a consequence what will be the future stress on food supply (in relation with water availability and areas devoted to agriculture).

\(^{39}\) http://www.fao.org/ag/agl/agll/terrastat/
According to Dornburg (Dornburg et al., 2008), biomass for energy purposes cannot be really decoupled from food production, because they both require land, which is ultimately the limiting factor for expanding bio-energy production. However, they propose various ways to weaken the link between food and bio-energy, through technological development, agricultural intensification, agricultural reorganisation and the use of new biomass sources.

First generation biofuels have shown a direct competition between energetic and food products, because they are based on “food” crops like corn, ethanol, rapeseed or sunflowers palm oil biodiesel. There have been clear correlations between food prices and the development of biofuels production in some countries. Around 30% of maize production dedicated to ethanol production in the USA, with impacts on food prices in the region. Second generation biofuels will also compete with food supply, but at a second-order level because the output itself is not in direct competition (International Energy Agency, 2010). ActionAid calls for a severe limitation of biofuels production stressing the potential risks for global food supply. They report that the food crisis in 2008 pushed 100 million people into poverty, a third of them directly linked to biofuels expansion (Actionaid, 2010). The report warns against possible food shortages by 2020 because of industrial biofuels, evaluating an extra 600 million people could be pushed into hunger by that time horizon. Food prices could rise by up to 76% if all biofuels targets are met.

Some efforts have been made in models to tackle the food-energy nexus, and its possible impact on future land price. But generally speaking, interactions between energy and food supply should be carefully analyzed. The European food security policy (CAP) have to be considered, taking into account the potential risks for long-term stability of food markets, at the European level but also at the global scale.
4.3 Cities and Energy

4.3.1 Heat demand of cities
To understand the heat demand of settlements it is necessary to start from a bottom up approach. With this in mind the energy demand of buildings as well as the behaviour of people and the general city framework have to be examined. In general heat means here low temperature heat which is used for space heating, hot water generation and low temperature processes.

In general it can be said that the heat demand will become less important in the long term perspective. The reasons are the construction of low energy houses as well as the refurbishment, modernization and rehabilitation of the existing building stock. Because of promises due to the Kyoto protocol the states adopt regulations for the construction of new buildings with the target to save CO₂ emissions. Low energy houses (<50kWh/m²*a heating demand) as well passive houses (<15kWh/m²*a heating demand) are state of the art buildings. The question is how fast construction and demolition is going on and in which extend refurbishment takes place. Next to the building properties which influence the main part of the heat demand global warming will reduce the demand for heat for the most places. In the next part a general approach for estimating the actual and the future heat demand of cities is presented.

First the current building structure of a city should be worked out which can be very time consuming. To understand the building structure it is essential to have an idea about the energy needs of separate houses. Therefore a physical model of a house is presented in Fig. 31.

Fig. 31 Physical heat model of a building

Because of the temperature difference Δt between outside and inside there is a permanent heat flow. If it is outside colder than inside the flow is directed to the outside. Next to these transmission losses there are losses resulting through ventilation. On the other hand there are solar and internal profits. These profits are in general not enough to keep a constant inner temperature so that an additional heat source (heater, furnace) is necessary.

\[ Q_{\text{heat}} = Q_{\text{trans}} + Q_{\text{vent}} - Q_{\text{int}} - Q_{\text{solar}} \]
To estimate the transmission losses you have to know the overall coefficient of heat transmission (u-value) as well as the geometry of the building to know the transmission surface. In the next part the focus is on the residential building sector. The base areas of buildings as well as the geographical position and therewith the positional relationship between the buildings should be obtainable by local authorities. Data about the height of buildings is in general more difficult to obtain. Sometimes databases with the number of storeys are available. Occasionally additional inspections, surveying and mapping is needed. Often these data isn’t complete, accurate and or actual. The best starting position is given if laser-scanning data about the region of interest is available. It is possible to generate a digital surface model out of these data. By this time it is possible to get the data of 4 Points at 1 square meter with an accuracy of 15cm related to location and height of the points. Therewith it is in general possible to detect a dormer, chimneys and the kind of roofs. Because of the difficulties gaining access to the needed data it is nearly impossible to compare different European cities due to their heat demand. Here it would be helpful if not only land-use data for the European Union would be available but also 3D models of different cities.

In Fig. 32 an example of a middle European city with its base areas of the buildings is illustrated. In general the following estimations about the heat and cooling demand will refer to that same city. The city population is about 150000 people.

Fig. 32 Example of a middle European city
In the left part of Fig. 32 the complete city is mapped. On the right part of Fig. 32 a zoomed in part of the city is mapped. Here the different buildings are recognizable. With it the area, perimeter, location and topology of the buildings is known. The grid cells which can be seen have a length of 250m. On the strength of data protection regulation the calculated energy demand of individual houses will be aggregated to such grid cells.

It isn’t possible to know all u-values for the different components of the different houses. To get estimations for such u-values it is our proposal to use or develop a typology of buildings at best specific for the region of interests. The typology groups buildings due to age classes and types of buildings (e.g. single family house, multifamily house, multistory building etc.). The assumption behind that is that buildings which are constructed in the same time span are build in a similar way with comparable materials and that these buildings have typical component surfaces. Hence they should have typical u-values.

Data as sources for our example city came from the local energy supplier the national statistical office as well as city departments. Within the city departments information from a building survey and mapping were available which contained information about building area, number of floors, gross floor area, coordinates, classification of gross floor area (twenty different classification classes) as well as other planning relevant attributes.

First of all the buildings were classified due to the belonging to the residential or non residential sector. Further variables like heated gross floor derived from the building survey data have been calculated. The typology of buildings consisted in our case of 24 types (8 age classes combined with one and two family houses, small multifamily houses and large multifamily houses). Small multifamily houses were defined as houses with 3-10 households, large multifamily houses with more than 10 households. The age of buildings was estimated by using data about water completion. Here it is assumed that the date of building construction equals the date of water completion. This assumption is accompanied by some inaccuracy. Nevertheless for newer buildings this age estimation method should give accurate results. It is the only method to estimate the age in a systematically way within reasonable time.

A validation of specific heat demand of building classes is essential because the heat demand of the whole city will be calculated out of this data. Every building of the city will therefore be assigned to one building class if no measured heat demand values are available. Because of the uniqueness of cities it is advisable not only to trust on values from literature but also to ask local experts who know the building stock as well as the reconstructions best. As result of the process every building is associated with a specific heat demand (expressed in kWh/m² a).
A geographical information system (GIS) was used to match information. That is necessary because the base areas are given as a geo-referenced polygon layer while other information like laser-scanning data or information about construction age of buildings are usually given as point data. A GIS can be used to calculate the transmission surface to the air respectively to neighbour buildings if existing, when data about the building heights are available. The heat demand of every individual building was calculated like mentioned due to the physical building model with typical u-values and typical inside and outside temperatures. The ventilation losses can be fixed to a constant value which can be found in literature. The internal profits can be determined depending on the number of persons living in the houses if such data is available. Otherwise average values have to be taken. For solar profits are just taken average values. At his point there are further possibilities to improve the procedure taking into account shading effects by other buildings, roof inclination and the orientation of buildings to south direction. The calculation was accomplished by using simply the office program Excel. Within the Excel model of the buildings different refurbishment options (windows/walls/walls, roof, basement/complete refurbishment) as well as inside and outside temperatures can be chosen. That means that different scenarios can be made. Climate change can be considered for the future in a simple way just by increasing the outside temperature. Changing behaviour can be simulated through influencing the inner temperature and the ventilation losses.

Fig. 33 Heat demand at current situation of the city
In Fig. 33 the recent heat demand of the example City is presented.

Fig. 34 and Fig. 35 show how the heat demand will develop if the building stock could be brought to low-energy respectively passive standard. The figures include the residential as well as the business sector. The number of inhabitants as well as the
square meter per capita within the residential sector was kept constant. The overall heat demand decreases to 58% in the low-energy case and to 40% in the passive case versus the current demand.

The generation of such heat demand maps for visualization is very important for city authorities and stakeholder, mainly because the heat demand (heat density) has a big effect on technologies which can operate in an economically way to fulfil the energy needs. Here it can be thought first of the district heating and the gas network system. Where and in which extent it is useful to have district heating in the future is one important question for cities today. In which areas a dismantling of pipeline-bounded systems has to be considered could be another interesting question. Such analyzes has to be seen against the background of long term investments in the field of pipeline-bounded systems and increasing maintenance and fix costs during the lifetime. The importance for developing the city energy infrastructure today to be best prepared for future changes see e.g. Reiter (Reiter, Botzenhart, Mühlich, Hamacher, & Reuter, 2009). Next to the pipeline-bounded systems it has to be thought about alternative technologies for heat supply (e.g. solar thermal, heat pumps). For cities it is a question where priority areas for different heat supply technologies could be determined.

Demolition and construction rates could be taken from national or local statistics. In general it is useful to calculate the future heat demand with different construction, reconstruction and demolition rates so that different scenarios can be distinguished. Average reconstruction rates are known by average lifetime of building components (e.g. roofs). In general refurbishment has to be constrained within the modelling process to get realistic results. Lower and upper bounds for refurbishment have to be implemented. Lower bounds can be taken from historical data. That means that there will be some minimum refurbishment independent from all influences. The upper bound has to be estimated somehow and is related to the available capital, workforce and willingness for refurbishment.

Furthermore it has to be mentioned that there are unknown developments which will influence the quickness of the transformation process towards a sustainable energy demand and supply (e.g. the gas and oil price will influence the reconstruction rates). Assuming different prices will lead to e.g. low- and high price scenarios.

See that not only the amount of reconstruction but also the location is important for good estimations of heat demand situation in future much more information and understanding of coherences is needed. Where reconstruction probably takes place (ownership structure, distribution of income)? In which extent income influences reconstruction rates and energy waste? In addition to that the recreation of buildings
was supposed as spread equally over the city area. So in this context some improvements of the process could be made in general.

**Fig. 36 Specific heat demand [kWh/m²] in dependence of construction-age classes**

In general next to the physical condition of the building envelope the behaviour of tenants influences the heat demand to a great extent. The underlying calculation of Fig. 36 supposed no differences of people behaviour. As it can be seen from the figure the energy demand of old buildings are overestimated and the demands of new and newest buildings are underestimated (red bars). That the energy demand of newer buildings is underestimated is often explained by rebound effects. People know that they are living in a thermo technical well-resourced flat or house and therefore they do not care so much about energy anymore. Resulting in that they waste energy or they just prefer to increase the average room temperature. Next to need of energy for space heating the hot water generation has to be regarded.
With enhanced refurbishment of the building envelopes the share of energy which is needed for hot water generation will be increase. See therefore the red and the yellow line in Fig. 37. The figure shows the share of hot water generation within the project raster-cells of the regarded city sorted in a decreasing way. For this graph it is supposed that the demand of water stays constant over the time-frame in each raster-cell. Furthermore the energy needed for hot water generation was set as constant. While the driver for space heating is the gross floor area in combination with the refurbishment status the driver for hot water consumption is the development of the population. The population was set constant with time so that the need of hot water doesn’t vary. A need of 850kWh per inhabitant and year was assumed for main residences to generate hot water (425kWh assumed for secondary residences). All in all this means that the question of how hot water should be generated will be an important question for the future.

Next to the residential sector the trade and the industrial sector of a city have to be recognized. Because we live more and more in a society dominated by service sector industry sector often doesn’t play a major part in cities today. If there are bigger industrial activities in the city these industries have to be regarded separately. It has to be found out if waste heat from industry could be used and how heat demand will be in future from industry perspective.

The estimation of the heat demand of the service sector is more complicated then the residential sector. There are different reasons for that. First of all there are different classifications of the service sector (e.g. WZ2008 in Germany, ÖNACE in Austria, NACE within the European Union and ISIC United Nations). There are not many publications writing about the energy needs of overall service sector. The reference units differ within the sector (e.g. in case of hospitals the interesting unit is the...
amount of hospital beds). However by default the energy demand is given per employee. That means that data about the number of employees at every job location is needed. For our estimations average numbers from literature were taken. In addition to that also statistical data and the building database were used to estimate the energy demand for hot water generation and process heating of this sector. Next to that this data was balanced with energy consumption data which was provided to us by Public Utility Company. Without such data provided by public utility the results for estimating energy demand in public service would be less accurate. Further problems are the determination of the number of storeys of buildings (e.g. warehouses - here laser-scanning data is even more valuable) and the determination of the proportion of service sector if a building is in mixed use (residential and services). So if there are flats and services in one building services are generally treated like residential use.

Recommendation
Laser scanning data are essential to design a 3-D picture of cities. A common European effort to produce and collect laser scanning data from the whole of Europe would be rather helpful for many kind of energy analysis.

4.3.2 Cooling demand of cities

Cause of general global warming cooling will likely play an increasing role in the long term perspective of most cities. Even without the aspect of global warming the demand for cooling increases because of comfort aspects in the residential and non residential sector. The cooling demand is in general treated like the heating demand. Due to the difference of determined outside and inside temperatures the cooling load can be calculated.

Fig. 38 Cooling demand of the city
In Fig. 38 the cooling demand for the city is presented for the case that the average air temperature increases by 2 degrees from the today situation. Therefore the average hourly temperatures for the city region within a whole year provided by the next local meteorological office were increased by 2 degrees. This simplified practice has to be in general improved by a better understanding on the local climate and city climate itself. Therefore city climate models should be helpful. Nevertheless a rough estimation of the needed cooling load can be appointed with that way. Cooling is seen as necessary if the daily mean temperature exceeds 22 degrees. As it can be seen from Fig. 38 the highest cooling demand matches the areas of high heating demand and district heating system. District cooling could be an interesting alternative to meet the demand. Next to the decentralized district cooling it is possible to cool buildings with centralized technologies. These are in general absorption, adsorption or compression chillers. In case of district cooling the Nordic European countries are the forerunner. There are existing district cooling systems e.g. in Stockholm and Helsinki. Especially for cities situated at the sea or river having the advantage to uses water resources at least partly for deliver cooling. Helsinki district cooling began in 1998. The Baltic Sea is used from November till May as a cooling source. Another example for district cooling is Stockholm which began in 1995. Because of increasing demand for cooling with increasing intensity of solar radiation solar refrigeration is another solution to satisfy the cooling demand. At the moment solar cooling isn’t very important in Europe. There are lots of different technologies to use sun energy for cooling (e.g. solar electric, thermo-mechanical, sorption refrigeration options). According to (Kim & Ferreira, 2008) solar thermal systems with absorption followed by solar thermal with adsorption seems to be the best solutions at the moment according to performance and investments required per kW cooling. New concepts like electrochemical refrigeration which is under investigation for its feasibility currently could enter the market in the long term perspective.
The potential for cooling sources in Europe is seen higher as 500TWh by (Euroheat & Power, 2006). At this natural cooling has a potential of 260TWh, residual cooling of 30TWh and industrial cooling of 260TWh. The total cooling market is estimated by 500TWh in 2020 (EU 15). The today market share of district cooling is given by the authors with 1-2% (2-3TWhc). So all in all the cooling market in Europe will increase in future whereby it is not so clear which technology will be used in which extent to fulfil the needs.

4.3.3 Cities and Climate

In Fig. 39 it can be seen the heat island effect by reference to one city example.

Fig. 39 Heat island of Atlanta
(Surface temperature – Landsat image – 28th of September, 2000)
The figure at the beginning of this part should show that the settlement has a big influence on climate. As you can see it is possible to have temperature differences of up to 8 degrees between urban core areas and surrounding suburban or natural landscapes. This it can be imagined has an influence for the heat and cooling demand of the settlements.

In general climate isn’t understood here in a narrow scientific understanding. It means here more or less air temperature respectively temperature change. Less evaporation as well as materials (mass, albedo) of settlements which store energy leads to increasing temperatures within the city. There is a positive correlation between the degree of sealing and occurring temperatures within settlements. In addition to that the reflection of long-wave radiation is often reduced due to the existence of increased gases like CO₂ which also increases the city temperatures.
Last but not least the anthropogenic generation of heat within the buildings leads to the recognizable heat island effect.  

![Fig. 40 Temperature differences for different European Cities](image)

In Fig. 40 the correlation between the city size measured as the number of inhabitants in million people and the maximum temperature differences between the core city and its surrounding is presented for different European cities. The triangles in the graph mean just small cities.

![Fig. 41 Variables of urban heat balance](image)

Fig. 41 illustrates the general variables influencing the urban heat balance. As it can be imagined the city has partly an influence on the albedo and the advective transport due to sealing and construction location of buildings. Further the planning of green open space has an influence on the heat balance.

A summary about recent heat island research in Europe without regarding research based on remote sensing techniques is made by Santamouris (Santamouris, 2007).  

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40 more information about the heat island effect is available at the U.S. Environmental Protection Agency (http://www.epa.gov/heatisland/)
Study cases from south, mid- and northern Europe are discussed within this paper. The appearance of urban heat islands during the year differs with location. In Madrid the main appearance of UHI (urban heat island) is at summer time, in Izmir, Adana and other cities the UHI appearance is distributed more less equally over the year and for example in Lisbon UHIs are observed most often in wintertime. The maximum heat island temperatures are observed under anticyclone situation with totally clear sky and low wind by different studies due to (Santamouris, 2007). In contrast to Fig. 40 Santamouris points out that there is apparently no relation between UHIs and city size. Furthermore the energy impact of heat islands, the impact of UHIs on natural and night ventilation potential as well as the research on mitigation techniques are discussed in the mentioned study. To single out just one result of research the author stresses the impact of urban temperatures on cooling. For the case of Athens the peak cooling load of a reference building almost doubles determined a set point temperature equal to 26 degrees.

Next to energy questions urban heat island influences also human health. Johnson (Johnson, 2007) mentions heat related morbidity. According to Johnson 700 people died in Chicago (1995) from hyperthermia. Because of that experiences Chicago has built cooling centers in locations where they are believed to be needed.

4.3.4 Cities – Energy system modelling
Without explicit mentioning in the preceding paragraphs energy models of cities have to be used to come to estimations about future energy structure. Models can be distinguished by the general approach (top down or bottom up), the time and the geographic scale as well as the mathematical theory behind the model. In Fig. 42 a general classification of energy models can be seen.

As it can be seen from the figure there are different possibilities for modelling on the local scale. Due to the given date, the spatial resolution and the general questions linked to the energy structure the bottom up approach is adequate for giving answers. So the idea is to start from the inhabitants and the separate buildings (bottom). The aggregation of the buildings (building stock) and the development of the number of inhabitants will then give an idea of energy needs.

To get ideas about the development of energy needs of cities system model generators could be used. In our context we use the model builder TIMES which is made for creating energy system models from local to global scale. TIMES is the acronym for The Integrated MARKAL-EFOM System. The time resolution can be chosen relatively freely so that it can be used for short, medium or long term time frames. The overall idea is that the created model minimizes the total costs of the energy system. Because of implementing framework details like the need of CO₂ certificates TIMES could be seen also as a top down approach. The possibilities and

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Fig. 42 Classification of model types

Source: (Kemfert, 2003)

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Further information about TIMES (TIMES documentation) can be drawn up from http://www.etsap.org/index.asp
limits of TIMES can’t be discussed in this document. For further information about TIMES the ETSAP internet page is recommended. Here it is the target to explain the general procedure dealing with cities and energy system TIMES model.

The model topology can be described by a reference energy system. So the first step of modelling the energy sector is to determine a reference energy system.

**Fig. 43 Example of a reference energy system (RES)**

Reference energy systems have to be read from left to right. The vertical lines stand for commodities included in the model. Processes are drawn as rectangles. The topology of the processes is given through the horizontal lines (commodities enter and leave processes). At the very right in the RES the drivers of the model can be found (in this example the number of residents. As processes there are different technologies for heat and cooling supply implemented. Each technology is characterized through different costs (investment, maintenance and operating costs). Learning and further improvements in technology can be implemented through varying costs and increased efficiency. Next to the energy supply technologies there are different processes describing reconstruction processes for buildings.

The resumed approach of getting a heat demand projection is illustrated in **Fig. 44**.

**Fig. 44 Linear model city energy needs**
Like mentioned in the heat demand part the building stock gives the bases of the model. A physical building model is needed to estimate the heat and cooling demand of the building stock. In general drivers of the model have to be determined. That could be e.g. the development of the inhabitants which have a need for living space. The development of inhabitants has to be given to the model (perfect foresight models). Different developments could be regarded as different scenarios. The most important variables are the variables for the energy prices (price for pellets, gas, oil...). In dependence of the different price scenarios the model will chose different supply technologies. Furthermore the amount of reconstruction will vary with these prices. That again means that the demand for heat will be different. So the model has in general the freedom to decide for technologies or reconstruction. Next to this technical parameters have to be given for the processes. It is possible to examine which influences political guidelines would have (e.g. implement given CO\textsubscript{2} reduction targets for the future which have to be fulfilled or set a lower bound for the minimum use of solar thermal technology).

After presenting the relation of urban form and heating respectively cooling with introducing how future energy demand/supply can be estimated with the help of energy system models now the next part will present the relation between urban form and transport.
4.4 Cities and Transport

4.4.1 Transport and urban form

Transport is the most important part concerning energy and urban form. The importance of transport and mobility for European urban environment is described e.g. in (Commission of the European Communities, 2007) or (Commission of the European Communities, 2009). A wide spread form means that large distances have to be overcome to fulfil people’s needs. Also compact structures can increase transport because of lacking green open space, so that people move to the surrounding for recreation purpose. In tab. 1 the travelled distances in dependence of city sizes are shown.

<table>
<thead>
<tr>
<th>Urban Area</th>
<th>Car</th>
<th>Bus</th>
<th>All modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner London</td>
<td>45.3</td>
<td>12.0</td>
<td>110.5</td>
</tr>
<tr>
<td>Outer London</td>
<td>113.3</td>
<td>8.9</td>
<td>166.6</td>
</tr>
<tr>
<td>Metropolitan Areas</td>
<td>70.6</td>
<td>16.9</td>
<td>112.7</td>
</tr>
<tr>
<td>Other Urban over 250,000</td>
<td>93.6</td>
<td>11.2</td>
<td>141.2</td>
</tr>
<tr>
<td>100,000 - 250,000</td>
<td>114.8</td>
<td>8.6</td>
<td>160.5</td>
</tr>
<tr>
<td>50,000 - 100,000</td>
<td>110.4</td>
<td>7.2</td>
<td>154.5</td>
</tr>
<tr>
<td>25,000 - 50,000</td>
<td>110.8</td>
<td>5.7</td>
<td>151.0</td>
</tr>
<tr>
<td>3,000 - 25,000</td>
<td>133.4</td>
<td>7.2</td>
<td>175.7</td>
</tr>
<tr>
<td>Rural</td>
<td>163.8</td>
<td>5.7</td>
<td>211.0</td>
</tr>
</tbody>
</table>

Source: (Fulford, 2008)

Using rail, walking and other possibilities for overcoming distances are left out in this table. It can be seen that public transport gets less important with decreasing population (population density). Newman and Kenworthy (P Newman & Kenworthy, 1989) found out a statistic correlation between settlement density and the demand for fuel per person. Nevertheless cities with similar settlement densities (measured as people per hectare) in the USA and in Australia have a really different fuel consumption per person. That can be explained through different fuel prices. Due to the European Commission the passenger transport (measured in passenger kilometres) increased in the following way distinguished by mode within the EU-25 and a 10 year timeframe (1995-2004).

- Cars (+17.7%)
- Bus & Coach (+5.8%)
- Air (+48.8%)  
That makes clear why transport sector should be in focus within the sustainability research. Transport energy use is affected by land use as well as transport system. In addition to that transport energy is related to such different fields like air pollution including fine particles, car dependency, trip distances, travel time, accessibility or transport system design.

According to Wegener (Wegener, 1999) there is a growing consensus that simple explanations about coherence of settlement structure and transport services are not sufficient. There is a less consensus about how energy optimal city should look like. Wegener cited Schmitz who argues that from view of transport no ideal city is known and that terms (e.g. de-central concentration and construction of development axes in the regional context) are more less keywords which have to be contents wise strengthened and proven.

The influence of urban form and socio economic factors on the development of the ecological footprint was worked out by Muniz and Galindo (Muniz & Galindo, 2005). As the area of interests they have chosen the metropolitan area of Barcelona. They focused on commuting which has a share of 30% of all trips in the area of interest. Urban form is described by population density, distance to city centre and distance to the nearest transport axis whereas socio economic factors are measured by average household income and job ratio. As a result of that work it can be pointed out that ecological footprint is in absolute value in the satellite cities and commuting areas of satellite cities higher than in Barcelona and the first ring. In addition to that also the growth rate within one decade (1986-1996) of ecological footprint was higher in the satellite city commuting area as for example in Barcelona. Furthermore a result of the study is that density mainly affects the proportion of trips made by car whereas the accessibility has a higher impact on the trip distances. As a conclusion the authors mention that the urban form (net population density, accessibility) has a greater capacity to explain municipal ecological footprint variability than social factors like family income.

Barcelona is often taken as an example for a real compact city. An example for an extreme sprawled city is Atlanta. A study researching on urban form and household activities was made by (Lee, Washington, & Frank, 2009) for the Atlanta metropolitan region. The activities were grouped into subsistence, maintenance and discretionary activities within this study. The authors found significant relationships between urban form and time spend on maintenance and discretionary weekday and weekend activities. As a conclusion the authors mention that reducing time consumptive and energy intensive travel requirements can be achieved in part through more heterogeneous and balanced urban forms where activity opportunities can be more efficiently interwoven in space.
Reducing the energy need in transport sector through intelligent urban planning is import. However a higher potential for energy saving respectively CO\textsubscript{2} saving is likely given by substitute fuels or increased automobile technology. The potential of renewable energy of a certain area (lower fraser valley) for the transport sector was examined by Poudenx and Merida (Poudenx & Merida, 2007). They came to the result that 40 till 60 per cent of the renewable resources would be needed to transform the private vehicle fleet away from gasoline consumption under their given assumption for the area of the valley. However the authors mention that if there would be a switch to renewable resources the change of ridership to most efficiency modes (in the study case that are mainly trolley busses and the skytrain) would increase the success because of the general reduced fuel consumption and emission. Here is a feedback to urban form because public transport services are linked to a certain dense of cities which is needed to guarantee economically operations.

Urban planning is important. However transport energy planning is not a part of transport planning. The common used four step method for planning doesn’t implement energy constraints according to (Saunders, Kuhnimhof, Chlond, & da Silva, 2008). Because of these lack Saunders, Kuhnimhof, Chlond and da Silva developed a software tool which implements an energy specification. The tool is intended for use within existing local government urban planning frameworks.

4.4.2 Best practice examples – reducing CO\textsubscript{2} Emission in city transport sector

There are a lot of improvements cities could do to reduce CO\textsubscript{2} emission mainly through promote walking, cycling and the use of public transport. Examples of bike cities will be mentioned as good illustration for improving city transport. The cities of Greifswald and Münster are the capitals of bike use in Germany. For daily routine 44\% of the Greifswald and 38\% of the Münster inhabitants are using the bicycle. So reaching one third till 40\% is a practical target. Nevertheless it has to mention that these cities have the advantage to be university cities and therefore the cities have a young age structure of inhabitants. In addition to that students are often not motorized. In the case of Greifswald 95\% of the inhabitants are living within a 3km radius. The average travel distance as related to internal traffic is 2km. With distance to the core city bicycle use decreases. That means that people are willing to use the bike if an appropriate accessibility as guaranteed. According to (European Commission (Ed.), 2007) 50\% of car trips are less than 5km, 30\% are even less 3km. That clarifies the potential of bicycle use. To promote cycling is therefore especially a good opportunity for smaller cities. To reach accessibility big cities have to be organized in sub-centres. That is a challenge for future city planning process. The numbers for Greifswald are taken from Steingrube (Steingrube & Bördlein, 2009).
European scale the people in the Netherlands and in Denmark are using the bicycle most often. According to the EEA (European Environment Agency, 2008) the cycling rates in the year 2000 range from 20km per person and year (Spain) up to 936 km per person and year (Denmark). For comparing some more known cities in Europe Pucher (Pucher & Buelher, 2007) ascertain that the cycling modal share in Berlin is 10% however Copenhagen reaches 20% and the share in Amsterdam is even 37%. It’s needed to have plans how cycling should develop within the city. Copenhagen e.g. has 3 targets they like to reach until 2015 (increasing the percentage of commuters which use the bike to work/education up to 50%, ensure that 80% of cyclists feel save in traffic and reducing the seriously injured cyclists by 50%). On step for promoting cycling within Copenhagen was the establishing of green waves. Therewith it is possible for cyclists to surf on a green wave with a speed of 20km/h during rush hour. According to a Forbes document London has an average speed of 19km/h, Berlin of 24.2 km/h.

Next to best practise bicycle cities there are of course lots of different other ideas how to improve/develop city transport systems. Out of those ideas only the idea of car sharing will be pointed out here. Referring to car sharing two cities should be mentioned, the city of Austin (USA) and the city of Ulm (Germany). Ulm has about 200 Smart Fortwo cars which can be easily localised and leased every time by using telephone or internet. Car2go was launched in Ulm in March 2009. Special at this project is that the car can be parked everywhere within the city after leasing it. A further advance is the simple price structure which is depending only on time for leasing (the price includes cost for fuel, cleaning, taxes etc.). In Austin the same concept was established.

Related to the transport sector one item should be mentioned which concerns the whole city. It is the lightning/street lightning concept of cities. It is an important topic firstly not from the potential of saving energy (refurbishment has a much higher potential therefore) but it can be influenced (especially street lightning) by a great extent through the city administration. So good lightning concepts can save energy, money and light pollution can be reduced. Wien can be seen as a good example concerning public lightning. The city has a master plan which has a timeframe up to 2018 for further lightning development. To name just a few numbers Wien has 2850 km lighted ways and streets. There are 227000 lamps (total connection load 14MW) which consume 56000MWh. Since 2008 first prototypes of solar and LED lamps are tested within the streetlight concept. Ann Arbor (USA) is a city which changes their

42 http://www.forbes.com/2008/04/21/europe-commute-congestion-forbeslife-cx_po_0421congestion.html (last visit 08-03-2010)
43 see http://www.car2go.com/?selection=new for more information on car sharing concept of the mentioned cities
44 see http://www.wien.gv.at/verkehr/licht/beleuchtung/oeffentlich/
street lights to LED technology (50%-80% saving of energy in this context)\textsuperscript{45}. Further advantages are that CO\textsubscript{2} emission could be reduced by 2200 tons a year and that there annual savings due to maintenance costs.

4.4.3 Using Multi Agent Systems for mobility estimation

This part focuses on the simulation of urban activities. A first important question which has to be answered is question on which scale/ on which resolution the simulation should be implemented. In general if mobility is modelled it raises the question if space, time-horizon and status of modelled objects are to be implemented discrete or continuous.

Modelling approaches could be:

- classical craft models (differential equations)
- driver craft models (behaviour of drives is considered)
- cellular automata

Because of the interest to model urban mobility (city scale) it is useful to take a multi agent system for simulating. There is no concrete city which will be modelled. Therefore also the population is freer to model. The basis for modelling can be an artificial city which is divided by a chosen grid. The city then will be filled by residential location and places of interest. Therefore it is advisable to use a geographic information system for feeding the multi agent system. Within the multi agent system the residential locations will be filled with agents. The agents in case of energy and city research could be in general inhabitants, owner of houses, energy supplier and so on. For the current approach agents will be a compromise between individuals and households. In general the agents are individuals. Nevertheless the agents belong to a household so that mobility of part or whole household (e.g. family trip) can be easily implemented.

The first step of simulating process is to generate a plausible population structure for the city. Here it is later interesting to analyze cities with different population structures (especially different age structure but also other distinguishing variables are in principle conceivable). Next an activity model has to be known. Time-budget data can be helpful in this context to learn more about activities (when, where and how often activities take place by the different population classes). The potential targets for activities are given by the point of interests coming from the GIS. Point of interests could be e.g. such different places like hospitals, supermarkets, parks, schools or cinemas. When activities take place is given through different circumstances. Here

\textsuperscript{45} see http://www.c40cities.org/bestpractices/lighting/annarbor_led.jsp
the model has to be implemented in a way that additional variables could be implemented in an easy way. The activity time is depending on the day (weekend or weekday) but also on status, age and interests of the agent. Next to the agents the households have to be modelled. In relation to mobility the existence of cars or bicycles belonging to the households are with utmost interest. The last step is choosing a mode. Therefore also the availability of public transport has to be considered. With that information simulation in principle can start. Because of the general approach of mobility without having a real city in background the mobility will take place on raster cell level and not on street level. So distances will be described through the Euclidean distance plus a certain additional term taking into account that beelines are in most cases not possible within the city. Furthermore it has to be mentioned that the private transport can be modelled in that way. The not to be neglected part of trade transport has to be taken into account using additional approaches which we have not defined today. All in all it is the target to simulate the mobility of city inhabitants using artificial cities with artificial agents taking into account different urban forms which means in this context different city sizes with different distributions of living places as well as of point of interests.

4.5 Examples of good practices: urban schemes with decarbonised transport and energy system

4.5.1 Munich: decades of experience on integrated urban planning

The MOLAND project\(^\text{46}\) studied Munich urban development between the decades 1955 and 1990 when the population increased of 49%. Munich represents the only urban area, out of 24 cases studied by the project, where the growth of the built-up area was lower than population growth, and where two third of the residential areas built after 1955 are densely populated.

Much of the Munich success depends upon the decision after World War II to rebuild the city centre following the pre-war patterns and style and to combine it with an increase of green urban areas and the construction of traffic ring around the historical city. The city reacted to 1960s pressures for new housing and transport solutions by adopting far sighting solutions, i.e.:

- Developing the first urban integrated plan, providing guidelines for municipal activities concerning town planning, economy, social and education issues;
- Creating a discussion platform between citizens and city planners, and establishing an independent city department to strength the links between research and stakeholders regarding planning activities;

• Reinforcing the participation of neighbourhood communities, mainly rural, in the consultative body ‘Munich Regional Planning Association’ with the aim of balancing regional development.

In the 70s and 80s, Munich urban development vision become less clear, however, the solutions adopted have proved to be crucial to create a high quality environment. Especially, attention was displayed on balancing economic, social and environmental interests and on promoting the inward city’s extension through the re-use of large brownfields vacated by industry, military and public infrastructures. The city preserved large green areas and limited the new road development, placing strong emphasis on public transport.

In the 1990s, a new integrated urban planning was developed, the so called ‘Munch Perspective’ aiming to make the city ‘compact, urban and green’. This strategic plan covers all sustainability aspects, and it is coherent with the previous policies of regional cooperation, brownfield development in the inner city instead of new greenfield developments and the implementation of mixed land use (residential, commercial, services). The public transport network has been continuously improved, together with the promotion of cycling and walking as alternative ways of transport.

4.5.2 Copenhagen: urban development along the railway

<table>
<thead>
<tr>
<th>Municipality characteristics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size: (km²): 88,25 km²</td>
</tr>
<tr>
<td>Number of inhabitants: 503,699 inhabitants</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Climate Change Targets and Indicators:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Total CO2 eq. per capita, including electricity use: from 6.65t in 1990 in 2005 to 4.91t in 2005</td>
</tr>
<tr>
<td>• Citizens connected to district heating (%): 97% of the city.</td>
</tr>
<tr>
<td>• CO2 per capita from transport: 1t in 2007</td>
</tr>
</tbody>
</table>

Copenhagen has a long tradition of integrated urban planning: the first regional plan was developed in 1947 in order to avoid uncontrolled urban growth from industrialisation. The so called ‘Finger Plan’ described the urban structure shaped as a hand and restricted new urban settlements along the existing railway lines. Since then the Regional Plan and the Municipal Plan (1993) have always placed a focus on compact development, land and transport integration and improvement of sustainable energy production. The ‘Metropolitan Milieu’ Plan reinforces these policies and set the goal of reducing by 2015 20% of the 2005 level of carbon dioxide emissions.

47 The case study is based on the information contained in the Copenhagen Application for Green Capital Award and in the Copenhagen SURBAN case study contained in the European Academy of Urban Environment at [http://www.eaue.de/](http://www.eaue.de/) (European Academy of Urban Environment, 2007).
As it is shown by the high population density, the city has been developed in a very compact way. Around 80% of new districts are constructed on brownfields, using a mixed land use approach through the decentralisation of public services and activities. Transport policies include measures to improve the public transport with the extension of the metro lines and the upgrading of the public fleet, with 50-60% of new low emissions buses. The use of private car is discouraged through the implementation of parking policies and the extension of environmental zones while the use of walking and cycling is favoured by upgrade of the cycling paths. In particular, city of Copenhagen has established the goal of having 50% of commuters to use the bicycles by 2015. As regard sustainable energy production, Copenhagen has established an extensive district heating network and promote the use of cleaner fuels in CHP stations.

The city has actively participated to many projects direct to expand renewable energies technologies and applications, among them:
- In Middelgrund wind farm Project,
- in Valby and Kalvebod a solar cell projects,
- In Amager, a geo-thermal plant project combined the creation of an Environmental centre.

Two programmes include awareness raising activities. The first is the “Solar City Copenhagen” programme, establishing a cooperation among all the stakeholders in order to promote the development of solar cell and solar heating installations. The second is the “Copenhagen Environmental Network”, a voluntary forum that gather together 500 enterprises wishing to take an active role in improving the environment.

### 4.5.3 Freiburg: Vauban and Rieselfeld Projects

**Municipality characteristics:**

- Size: (km²): 153,07 km²
- Number of inhabitants: 219,430

**Climate Change Targets and Indicators:**

- Electricity consumption in the city from renewable sources: 3,7% in 2005 target 10% in 2010
- Targets: CO₂ emissions by 25 % by 2010, (goal presumably not reached) and 40% reduction of CO₂ by 2030.

Freiburg is internationally known for its strong municipal energy policy, and for a long tradition of integrating environmental considerations into transport and built environment planning. Another aspect that distinguishes the city's planning policies is the high level of civil participation: in 2005, citizens were invited to form 19 working groups to discuss every potential construction areas of the Land Use Plan 2020. The
discussion outcomes have been used by the City Council to reorient its decisions. As for the case of Vauban, land planning is seems to be used for raising environmental concerns and promote sustainable lifestyle among citizens.

Two Freiburg districts – Vauban and Rieselfeld - provide emblematic examples of sustainable urban developments.\(^{48}\)

The Vauban project started in 1993 in an area of 38 hectares and aimed at creating housings for more than 5000 inhabitants and 600 jobs. The city administration owned the land but the turning point has been the adoption of a ‘learning while planning’ approach: the administration set basic ecological standards and then allocated the plots to private builders and co-housing groups. This process has led to the establishment of citizens’ (Building Co-operatives) and developers’ groups (Citizen’s Building Stock Corporation) that worked together in order to achieve the most environmental and cost effective solutions. The Forum Vauban facilitated the participatory process and the formation of co-housing groups while the Genova Housing Association assisted low income citizens to be part of the projects. The high participatory process created a strong community, characterised by high interest on adopting sustainable lifestyle.

All Vauban Buildings are low energy standard, 50 are passive houses and 100 units with ‘plus energy’ standard. Solar panels and photovoltaic cells are commonly used and the district is estimated to be one of the larger ‘solar district’ in Europe. A co-generation plant operating with wood chips and natural gas provides hot water and 65% of the district’s electricity. The water management system increases the rainwater infiltration and reduces the run off.

One of the primarily goal of Vauban district was to create a ‘car free’ and parking free district with parking slot placed outside of the site and with the prohibition, in many cases, of building parking spot even on private property. Residents who join the car sharing, receive one year free pass for public service.\(^{49}\) The district has been connected to the inner city through a tramline, two line buses and a suburban train. In addition, the Council has created a ‘car sharing’ system and the whole city is provided with an extensive bicycle path (500km in total). Vauban has been designed to create a ‘short distance district’, where services such as schools, shops, farmer’s market, business and shopping centres are easily accessible by walking or cycling.

The construction of Rieselfeld was started by the City of Freiburg in 1994 in a area of 70 hect., previously hosting a sewage field. The district is surrounded by 250 hect. of natural reserve area. The urban development was carried out with a participatory


\(^{49}\) 40% of residents do no town a car. If you choose to own a car you must buy a parking lot in multi-storey park on the outskirt of Vauban for the value of €18.000
process as for the Vauban case, and it was mostly financed by the sales of city owned plots. The project has created 4,500 flats with low energy standard, 1000 new jobs and good public and private infrastructures.

Municipal guidelines requested standards for buildings with a maximum energy consumption of 65kwh per square meter and imposed the obligation to connect all structures to the district heating network fed by combined heat and power plant and the use of renewable energy sources such as solar energy, wood pellet and heat pump. The water scheme provides for a separate collection of surface water and a complete recirculation of the water after the purification process.

Attention has been paid in favouring pedestrian and cyclist: the district is connect with a tramline since 1997, a general speed limit of 30km per hour is enforced and many “streets for letting children play” have been created.

The project has successfully implemented a mix land use: integrating living and working space and attracting a large number of shopping, social and cultural facilities. However, buildings have generally one parking spot per household.

4.5.4 Stockholm Projects of Hammarby Sjostad and Royal seaport

| Municipality characteristics: |
| Size: (km2): 209 km² of which of which 21 km² consists of water area. |
| Number of inhabitants: 795 163 citizens. |
| Climate Change Targets and Indicators: |

- Targets: reduce the GHGs down to 3.0 tons CO2e per capita until 2015 and the step towards is to become fossil fuel free city by 2050
- CO2 eq. per capita, including electricity use: from 5.4t in 1990 to 4.0t in 2005
- CO2eq per capita from transport: from 1.6t in 1990 to 1.3 between in 2005.
- Citizens percentage connected to district heating: almost 70%.
- Share of renewable used for production of district heating is about 70%.

Stockholm is showing to European cities the pathway to become ‘post carbon cities’. It has been among the first cities able to make strategic commitments for reducing co2 emissions, to effectively plan a long term strategy and to implement a rage of measures embracing energy production and consumption. Most importantly, while most of cities are currently setting targets, Stockholm has already achieved the goal of reducing greenhouse gas emissions from 4.5 to 4.0 CO2e for the period 2000-2005. The reduction is the result of integrating climate considerations and of
adopting a wide range of programmes in all relevant areas (electricity generation, transport, buildings and land planning)\(^50\).

Stockholm land use policy aims to build the city inwards by directing city’s developments to reuse former industrial areas often contaminated.

The ‘Hammarby Sjostad’ project has demonstrated the key role of integrating environmental targets from the very start of the planning process. The project started in 1995 with the idea of expanding the inner city, while converting an old industrial and harbour area into an environmentally friendly neighbourhood. Indeed, even if the district is located outside of the inner city, the design is intentionally urban rather than suburban in terms of street width, block sizes, density and mix land uses. In 2015, Hammarby Sjöstad will have 11,000 residential units for 25,000 people and a total of about 35,000 people will live and work in the area. The city’s authority has driven the project’s development by purchasing the land and drawing a master plan in consultation with Birka Energy and the Stockholm Water Company. The distinct feature of the ‘Hammarby Sjostad’ is the creation of interconnected infrastructure systems for water, waste and energy, with recycling of energy and materials flows, reducing the amount of energy and resources needed for their operation (ref. ‘Hammarby Sjostad Model’ figure below).

When completed, the Hammarby Sjöstad will produce half of the energy consumed from local sources, and the entire heating supply will be based on waste and renewable energy. Many apartments have solar panels incorporated in their fabrics and all of them are linked to the city district heating while district cooling is offered to offices\(^51\). Sewage from the apartments is converted into heat energy and biogas for the use of district heating plant and public transport vehicles. Solid waste resulting from the processing of sewage is composted and used in forestry. From 2003, Hammarby has opened its own pilot sewage treatment centre. To facilitate recycling process, waste is collected through the ENVAC system: a network of underground pipes to central point of collection. Surface water is treated locally.

The extension of the tram infrastructure and the creation of a new road have been central to the district development. The area is now connected to the underground network by tram service whose extension will allow a direct connection with the inner city. Public transport is guaranteed by three bus lines and a free ferry service and car sharing service. A city survey in 2005 reported approx. 66% of residents own a car with similar average with the inner city and that half of all the car are parked in private garage. The area is characterised by strong network of safe (frequent use of speed restriction and zebra crossing), well lit and easily accessible streets and public spaces. In order to reduce noise pollution, the road alongside the development has been lowered by two meters.

\(^{50}\) Stockholm Action programme in Climate Change, Stockholm Green Capital Award Application, the Hammarby Sjostad’ web site http://hammarbysjostad.se/ (Stockholm (City administration)); the Royal Seaport web site, http://www.stockholmroyalseaport.com/ (Stockholm (City Development Administration)) and the CABE case study http://www.cabe.org.uk/case-studies/hammarby-sjostad

\(^{51}\) District heating connection with exhaust air systems: 100, of which 20 kWh electricity/ m² UFA. District heating connection with heat extraction systems: 80, of which 25 kWh electricity/m² UFA
In order to promote the district culture and social life, the Master plan has included the building of a church, four schools, nursery, culture and sport centres. And then financial incentives have been introduced to attract shops and services in the area. Recognising that technological improvements could be offset by unintended citizens behaviours, the city administration has established the ‘Glasshouse one’: an educational centre to encourage environmental friendly lifestyle.

The city of Stockholm has started in 2009 a new project on sustainable urban development in a brownfield area. The Royal seaport district covers an area of 660 acres, which in 2025 will host 10,000 new apartments and 30,000 new work places. The area is located 2,1 miles from the inner city, and it will be connected by biogas bus services, city tram, and subway. The project aims to be a global showcase of environmental technology and creative solutions for transport, buildings and energy conservation. The goal is to achieve a fossil free district by 2030, with residents and workers producing less than 1,5 carbon emission per person.

**Fig. 45 City of Stockholm Hammarby Sjostad Model**

4.5.5  London: the Royal Albert Design Project

**Municipality characteristics:**
Size of municipality (km2): 609 square miles (1,579 square kilometers),
Number of inhabitants: 7,512,400 within Greater London (2006),
London metropolitan area: between 12 and 14 million;
Climate Change Targets and Indicators:

Targets of reduction Co2 emissions by: • 22 % of 1990 levels by 2015, 38 % of 1990 levels by 2020, 60 % of 1990 levels by 2025.

2006 Total CO2 emissions: 47.5 MtCO2
2006 CO2 emissions per person: 6.2 t, CO2 per year
Even if London per person CO2 emission is lower than the national average of 8.7, the carbon footprint of the city is very high.

The mayor of London is currently canvassing comments on the Draft Mitigation Climate Change and Energy Strategy and aims at finalising the document for the end of 2010. The comprehensive strategy sets the ambitious target of making London among the first “post carbon” cities by drastically reducing the CO2 city’s emissions by 2025. The strategy is built upon 15 policies shortly introduced by a ‘vision’ and described in detail through cross cutting actions and programs. In particular, the strategy is focused on:

- The economic reforms necessary to attract low carbon investments
- The ways to increase the demand of low carbon services and products (procurement, research and behavioural changes)
- the initiatives to promote the employment and training opportunities for green jobs
- the infrastructure needed to upgrade energy production and distribution,
- the initiative to facilitate retrofitting of old buildings and construction of new low energy buildings
- the measures and investments to support sustainable transport.

The Royal Albert Design Project has been recently designed by the Climate Clinton Initiative as one of the 16 worldwide large scale urban project that demonstrate cities can grow in ways that are 'climate positive'. Climate positive indicates the real estate developments that strive to reduce the amount of on-site CO2 emissions below zero. The London Development Agency (LDA) owns the Albert Bain site at the eastern end of the Royal Docks, adjacent to Gallion Reach Docklands Light Railway station. The site has been recovered from brownfield land with the goal of creating a mixed use community with more than 1,000 new housing and commercial units. The Albert Basin project aims to be the first LDA carbon zero development at Gallions Park through the use of:

- Building Specification stricter than the 2006 regulations in order to achieve a 40% carbon cut. Buildings are requested to respect the code for sustainable home (CSH) level 4 and beyond.

52 The full Strategy text is available at: http://www.london.gov.uk/priorities/environment/climate-change/ climate-change-mitigation-strategy (London (City administration), 2010)
- Energy supply from Combined heat and power (CHP) able to provide zero carbon energy supply.

The project is also an instrument for demonstrating that the early provision of low carbon infrastructure, before site development, is both economically and environmentally advantageous to developers.

Much of the project’s attention is now concentrated in designing and financing a Albert Basin ‘Low carbon Energy System’ consisting of a Energy Centre generating heat and electricity, and of an area wide District Heating distribution network. The network would comprise pipes to each of the development sites area. The aim is to deliver ‘low carbon heat’ to the new developments by allowing developers to link up to the network for a fee, thereby meeting their renewable obligations. The end consumers are initially developers with whom LDA is negotiating land deals and ultimately with the new and existing occupants. Developers will be mandated to utilise the low carbon energy system and existing occupiers would be strongly encouraged to connect.

A large part of the apartments will be sold at an affordable price, the Albert Basin is part of the ‘London Wide Initiative’ that promotes low cost home ownership scheme for key workers living and working in the capital. In 2009, 428 apartments have been already constructed around the Royal Quay, mixing riverside apartments, commercial propriety and open space for children. The focal point of the project has been the Grande II Hotel, originally build in 1880s, that has been fully refurbished.

The Royal Albert Basin Project\textsuperscript{54} is part of the Thames Gateway Development and Investment Programme which includes five urban developments where 10,000 new homes will be build by 2016. The LDA is the largest landowner of area, with more than 600 acres, facing the challenge to create an exemplary environmental region at the cutting edge of new zero carbon technologies.

Fig. 46 Draft Mitigation Climate Change and Energy Strategy - London 2025 a day in the life

\textsuperscript{54} More information on the Project: http://www.lda.gov.uk/server.php?show=ConWebDoc.410
(London Development Agency)
4.5.6 Alessandria: Concerto al Piano Project

**Municipality characteristics:**

Size: (km²): 204 km² (78.8 sq mi)  
Number of inhabitants: 93,922

Since 1998, the ‘Urban Neighbourhood’ convenant is one of the main financial instrument for urban rehabilitation in Italy. The model is aimed to catalyse public and private financing the social and economic regeneration of more deprived city’s districts. The CONCERTO AL PIANO (2007-2010) project\(^{55}\) has tested the legal and financial problems connected with the inclusion of sustainability measures into ‘Urban Neighbourhood’ convenant. The City of Alessandria has indeed aimed to develop a Zero Fossil Fuel Settlement to be used as benchmark to define and improve local building regulations. The project has been developed in the same district where was carried out in 2001 the ‘Photovoltaic Village’ Project, which installed a grid of photovoltaic (PV) systems in 192 flats and some public buildings\(^{56}\).

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\(^{56}\) Initiative developed in the framework called HIP-HIP (House Integrated PV - Hightech In Public)
The project CONCERTO AL PIANO follows a comprehensive approach including policy and demonstration aspects. The policy initiatives include the organisation of workshops with policy-makers and developers as well as awareness raising campaign targeting the citizens. The demonstration part, whose basic financing was provided by the Ministry of Housing and Infrastructure, was related to the realization of:

- The eco-refurbishment of 300 social housing units and the extended energy retrofit for the buildings of the district. The plan foresees to supply resources for energy/building retrofit of 48000 m2 equivalent dwellings.
- The construction of a "new eco-village" formed by 104 dwellings which also feature a social-elderly house, a health centre and a kinder garden.
- The setting of a system to monitor the effectiveness of the measures realised.

The building construction and retrofitting exploits a ‘micro –climatic’, innovative design with extensive adoption of PV modules. The works are carried out following high energy standards incorporating eco-insulation of triple size compared with the normal standard, and the district’s energy is powered by polygeneration and solar energy (biomass heating + cooling + electricity). The project was completed with measures in the field of mobility such as the extension of bicycle lanes and the promotion of PV recharge facilities for electric bikes. The water and the waste infrastructures are being upgraded in order to support the use of rainwater for irrigation, reduction of water flows, use of grey water and to promote a better waste management.

4.5.7 Totnes: Transition Town Initiative

Totnes, situated in the south east of England, has a population of approx 8,000, thus its challenges in decarbonising its structure are hardly comparable with cities challenges. However, the experiences gained by this town in active citizens participation is an important sign and has been taken up by others bigger city’s districts. Totnes has joined the ‘Transition Town Initiative’ in 2006 and has published a Energy Descent Action Plan (EDAP) in 2008. The Transition Initiative\(^{57}\) has the main objectives of supporting practical actions to reduce citizens carbon emissions and of building town’s resilience in term of food, energy, employment and economics.

The Energy Descent Plan aims to create a collective vision on how the towns could look like in 2030 and to figure out the pathways to become less resilient on oil. It is drafted by groups of citizens articulated by sub-themes (i.e. Building & Housing, Education, Energy, Transport etc) and it represents mainly a powerful instrument to raise awareness and promote sustainable behaviours and projects. In some cases, the citizens experience has gained support of the local authorities that have endorsed the Energy Descent Plan.

\(^{57}\) Transition Network web site: [http://transitiontowns.org/TransitionNetwork/TransitionNetwork](http://transitiontowns.org/TransitionNetwork/TransitionNetwork)
and Transition Totnes website: [http://totnes.transitionnetwork.org/](http://totnes.transitionnetwork.org/)
(Transition Network) (TTT Ltd)
The Transition Network now includes initiatives in 170 towns, situated mostly in the UK, and it represents an example of bottom-up approach regarding the promotion of sustainability measures in transport, housing and food production. The movement is deeply rooted in local culture and needs, and it has been able to elaborate a global vision and to communicate and networking with different realities.

4.5.8 Brand new eco-cities: Dongtan and Tianjin from China

China is living one of the biggest migratory movements from countryside to cities and it is estimated that from now to 2020 will build 400 new towns to accommodate more than 300 million people.

The city of Dongtan, in Chongming Island near to the Shanghai, should have been a model of sustainable zero emissions city with a planned population of 25,000 by the 2010 Shanghai World Expo. However, the project didn’t proceed due to legal claims about corruption addressed against the city’s Mayor, the project main investor. All the references to Dongtan were indeed removed from the Shanghai World Expo website. However, the city’s master plan developed by Arup - tendered out in 2005 by the Shanghai Industrial Investment Corporation – provides a blueprint of a “new post-carbon town”. The city is planned to be ecologically friendly, with zero-greenhouse emissions transit and complete self sufficiency in water and energy together with zero energy buildings. The energy demand should be covered by biomass (organic waste and rice husks) and renewable energy produced by both windmills and by photovoltaic. The project promotes green transport allowing to electric vehicles and favoring the use of public transport, bicycling or walking inside the district.

Attempts to build ‘eco-city’ are currently undergoing near the western shore of the Bohai, on the north east of China and one of the most polluted seas in the world. A new settlement, Tianjian Eco-City58, is planned to be built in over 350 hectares hosting more than 350,000 people. The idea underpinning this initiative is to create a ‘scalable and replicable’ project, which can be disseminated in other parts of China or even in India and other developing nations.

Taking stock of the lessons learned from the experience of Dongtan, the new project aims to find a right balance among economics, user – friendliness and environmental concerns. The environmental targets have been significantly reduced and, at the same time, consultation and awareness raising activities have been stimulated, aiming to change residents’ behaviour.

The new district will use 20% of renewable energy from wind and geothermal power, and strict energy standards for construction are adopted. In order to achieve a 90% cut in car journeys it is planned to build a capillary light railway line and walking and cycling facilities. Furthermore the zoning should ensure the presence of schools, clinics and shops within a walking distance. More than 60% of waste will be recycled.

58 The case studies is base on the information contained in http://www.tianjinecocity.gov.sg/ (Tianjin (administration)) and the article J.Watts “China teams up with Singapore to build huge eco city”, the Guadina june 2009, http://www.guardian.co.uk/world/2009/jun/04/china-singapore-tianjin-eco-city
and domestic water should be kept below 120 litres for person each day, with more than half supplied by rain capture and recycled grey water. More green space, approximately 12sq metres, shall be available for its residents.

4.5.9 Abu Dhabi: Masdar a clean technology hub

Masdar project\textsuperscript{59} is driven by ABU DHABI future energy company, fully owned by the government of Abu Dhabi through the Mubadala Energy Company. The ideas behind the project is to create zero carbon, zero waste and 100\% renewable energies-powered community that serves as clean technology research hub, designed to rival silicon valley, in the centre of global oil and gas industry. The city will be a hub of innovation, products developments and light manufacturing in the field of renewable energies and sustainable technologies. Cross cutting technologies are being experimented in the areas of energy and water conservation, waste management, smart grid technologies, transportation and renewable energies generation. The city’s construction is then seen as a showcase of sustainability business.

The city, that aims to be self sufficient, will be constructed from the scratch in five and half kilometres and is designed to host 50,000 people, 1,500 businesses and 40,000 daily commuters. The city goal is to attract business by offering cluster advantages to leading multinational companies in the clean tech sector as well as small and medium size enterprises and entrepreneurial start up. The Masdar Institute of Technology will be the centre of city’s R&D activities.

The Master Plan is planned analysing traditional Arab cities infrastructures and takes into consideration the challenging city’s geographic location, near the heart of the desert. The buildings will have to be ‘carbon neutral’: passive features have been included in order to reduce building energy and cooling loads with the aim to have peak load of less than 45kwh per mq\textsuperscript{2} and to reduce of 50\% of CO\textsubscript{2} compared with the business as usual construction. Studies have been conducted on sun angles, wind patterns, streets widths, building density and height and even the city orientation was studied in detail in order to facilitate the use of renewable energies.

To be 100\% renewable energy, the community will indeed mainly relies on solar and biomass conversion complemented by other renewable sources such as geothermal, wind and hydrogen which are currently under consideration. The Master Plan foresees also the plantations of different trees species useful for producing biofuels. Masdar will be built as compact, pedestrian city recalling the traditional Arab city’s centres with the target to be ‘zero accident’ city. The goal is to reduce car use by 95\% 10 years after the conclusion of the final phase. Vehicles will be left at the district’s perimeter and people will have either to walk or use a uniquely designed transportation system to get around. The city is planned to be fully accessible and will comply with the American ‘Disability Act Accessibility Guidelines’. The pedestrian level will be constructed six meters above the ground which will allow the Personal

\textsuperscript{59} The case study is based on the information provided at :http://www.masdarcity.ae/en/index.aspx and ESRI UK

‘Masdar City: the world first carbon-neutral city’ (ESRI UK, 2009)
Rapid Transit (PRT) network to be build on the ground. One of the technologies being evaluated is the six person drive-less vehicles that runs on batteries charged with clean solar power. Masdar will be connected with the immediate neighbours and the nearby airport through the Light Rail Transit and the Metro systems.

The community has the targets of reducing through behavioural changes and policies:

- water consumption from 180 l/c/d to 146 l/c/d;
- waste production of 30%.

The City has also the target of recycling 80% of the water through recover and reuse of rainwater and condensate other water steam. As waste, the biological waste will be transformed in fertiliser, the industrial waste will be minimized through recycling and re-use.

The City Plan includes an impressive number ‘sustainability policies’: improvement of indoor and outdoor air quality, adhesion to ‘dark skies’ campaign for fighting light pollution, even measures to avoid fugitive odour and dust. As for the quality of life the district proposes to have a ‘sure and innovative’ with lower incident rate than other UEA average and more religious and recreational activities than UEA average. Businesses and employment opportunities are strongly supported.

The planning has exploited cutting edge technologies: the geographical information system (GIS) built on ESRI GIS software has been used by planners to increase energy savings and reducing carbon emissions during the building and operation and maintenance phases.

The modelling helps to track costs, schedules, carbon emissions and has been also used to calculate where it would be better to place critical infrastructural centres (energy production, recycling transports). The Building Information Technology will provide a 3D CAD based representative model of all the city’s constructions: location and interrelations of all gas pipes, electrical cables, clean and wastewater network and transport infrastructures. This control will be integrated with a computerised management system able to visualise the overall energy and water consumption of the city, which will enable the single residents to easily know their own consumption.

5 Conclusion – energy flows and urban form

![Fig. 47 Energy and urban Form](image)
Urban form has a big influence on energy flows within the cities. It influences the energy demand side as well as supply side. The urban form itself is influenced by variables like living standard or population development (see Fig. 5 – relationship within the urban form).

At the demand side all energy relevant sectors are affected. The transport sector with the demand for fuels due to changed distances which have to be bridged is affected as well as the cooling and heating sector because of influenced city climate. The electricity sector will be influenced by the use of different technologies. Electric cars will enter the markets most likely in the future. Furthermore technologies like heat pumps would increase the demand for electricity in a greater extent.

The Heat demand will lose importance in time because of increasing refurbishment standards. Low-energy houses as well as passive houses are available for a few years. It raises the question whether all buildings could be brought to such standards and if so within which timeframe. Here it has be mainly thought of historic building stock which is often under protection. Due to reconstruction-cycles it seems to be not unrealistic that nearby low-energy standard could be reached within the residential sector of the whole cities next fifty years. Whether ventilation and waste heat recovery with fresh air pre-heating (passive standard) will be accepted from a wide range of inhabitants isn’t so clear at the moment. During 1998 till 2001 CEPHEUS
(Cost Efficient Passive Houses as European Standards) was a first European project where passive houses were build and evaluated in different European countries. Nevertheless passive houses aren’t wide spread today. Due to the mentioned increasing building standard as well as expected increase of temperatures because of global warming heating will be not so important but cooling. To operate economically technologies like district heating or district cooling need a certain amount of demand within a certain area. Because of decreasing heat demand district heating seems to be a transitional technology in the long term perspective in most cases. The demand for cooling increased the last decade and will be increasing in the future. At the moment district cooling has a low market share within the cooling market in Europe. Nevertheless this is an interesting option for the future. To keep such technologies as possible alternatives it is necessary to reach a minimum density of buildings. However the density shouldn’t be too high because different reasons like the heat island effect. The most important field is the transport sector. Increasing distances means that more fuel will be consumed. The more sprawled a region is, the less competitive the public transport is in general. Therefore it has to be avoided that a city gets too unattractive using public transport services. However the best opportunities are given through the development of new technology and an appropriate use of modes (car sharing; bike and ride; kiss and ride…). Planning is most important also for the field of energy. Here it is important that people find destinations within relatively small distances. Few traffic city structures have to be the target of city planners. Inappropriate building decisions lead to increased traffic. In general density, diversity and design have to be taken into account for good planning praxis. People are in general willing to use a bicycle within three kilometres distances. So accessibility is a main factor for choosing mode. Promoting the use of bicycles is so especially interesting for small cities or urban districts. Nevertheless also bigger cities like Odense or Copenhagen implemented successful bicycle strategies.

The transport sector is in general the most difficult part concerning energy and urban form. Remote placed little settlements have in general a higher transport demand than settlements being nearer to a core area. However an “ideal” city form from transport perspective isn’t known (Wegener, 1999). The price for fuel, the availability for cars, the competitiveness of public transport and other variables are influencing the demand for fuel and therefore also influencing the transport demand. In the end the price for fuel it’s maybe a better indicator for estimating fuel consumptions as the settlement density which influences the urban form. All in all there has to be much further research on transport to come to quantitative states concerning urban form and transport demand.

From scientific point of view the relation between energy flows and urban form is because of its multidimensional and complex nature difficult. Things are done but it is still much to do. Theoretical described qualitative states have to be transformed and
examined to work also in a quantitative way. The data basis isn’t as good as it could be. Take the example of land-cover data. In the CORINE project the cover of countries as well as the spatial resolution, the recording period and the file types differ within the two years where data is available for free. Time series of free satellite pictures from urban settlements would be a good basis for analyzing the change of urban form (here often images from commercial satellites have to be used). Furthermore available laser-scanning data would be helpful to analyze the 3D component of the urban form. Last but not least data based on grids like it is available e.g. from Austria are helpful. However every national statistical office supplies data differently. Data based on a grid is so available only for a few countries in Europe.

Recommendation

The research on urban form linked to energy questions which deal with future energy demand as well as energy supply is important. On the European scale it is difficult to get adequate data as basis for research. Therefore research focuses on individual cases and neglects the general view. To improve research better data bases are necessary. A first step is the improvement of the CORINE land-use data. However it would be desirable to get more information about the settlements. The 3D forms of cities would help to estimate energy needs (so laser-scanning data from example cities are useful). The connection of land use data with population density and energy balances would be ideal. Also political and administrative regions need to be easy identifiable in GIS systems. This would offer the easiest way to make connect land use information with general statistical information.

6 References


energy demand and economy. Bilthoven: Netherlands Environmental Assessment Agency.


