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Maps of geographical consequences of paradigm shifts – a Danish case

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Introduction

This report covers research carried out as part of the 7th EU research project PASHMINA regarding a case study covering the eastern Danish islands, including the Danish capital Copenhagen. The aim of this study is to assess the feasibility of GIS modelling and its integration with analysis of travel behaviour and local planning paradigms. Specifically, the work conducted here examines how the built environment, transport systems and travel habits influence particular travel patterns that push towards high or low carbon transport futures as outlined by the PASHMINA scenarios.

For more than 60 years, spatial planning has been utilized in Denmark to restrict and target the development of land use and settlements in terms of urban sprawl, transport infrastructure and areas for recreation and nature. The so-called ‘finger-plan’ (see next chapter) defines and separates these areas from each other and has been revised several times to accomplish changing policies and developments like increasing transport demands. Latest developments focus on congestion taxing, new public transport infrastructure and gap-filling of existing urban areas rather than urban sprawl and extension of urban areas. For the remaining case area, similar development plans exist for each municipality, developed and coordinated under a national Danish planning directive.

We have translated the narrations of PASHMINA’s scenario outlines and associated paradigm shifts into the real world context of the Copenhagen case area, outlining clearly distinct future development paths. Please note that the scenarios modelled are NOT concrete developments expected, but illustration of the potential/possible consequences of different policies and planning strategies selected and the associated development paths as a consequence of these.

The main focus of this report is on the importance of the spatial dimension in describing, analysing and evaluating development scenarios accessible via GIS-based modelling and mapping. As it is difficult to display maps covering large areas with a high degree of detail, we have chosen to place a selection of input indicator and resulting land use maps using an interactive WebGIS tool freely accessible to everybody at: http://gis.au.dk/pashmina.eu. This tool enables the reader to view and overlay the maps together with maps and transport infrastructure and other information (figure 1).

Figure 1 – The interactive WebGIS tool with maps of the case area (http://gis.au.dk/pashmina.eu)
Spatial and transport planning in Greater Copenhagen City-Region

This report considers scenarios for transport developments in future Copenhagen in the perspective of accessibility to transport infrastructure and planned investments and interventions within the transport area. Thus, its main focus is the potential mobilities and travels enabled and determined by accessibility relative to the travel patterns of the city-region.

The Danish contribution to WP 2 is a GIS based modelling of present and future accessibility patterns which represents travels as based on access to transport networks. Travels comprise commuting (travels between home and job)studies) modelled on the basis of the LUCIA model and potential demands for leisure activities. The LUCIA modelling complex includes road networks as well as rails and private and public transport. Access is represented as time used at different locations and thus pictures accessibility according to urban densities. Hence, the modelling represents potential mobility and options for movements as based on location of dwellings and multimodal transport infrastructures.

Thus, from a mobility point of view, travels are determined both in relation to time consumption and in relation to location of dwellings, leisure and jobsstudies. In a future perspective, the accessibility based modelling will thus depend on infrastructure and spatial planning initiatives in the near and medium term. These can be estimated according to city-region specific principles for spatial planning.

The potential mobilities are translated into statistically based actual travels through the national travel survey that determines the travel modes, distance travelled, purpose(s) of travel and location of journey according to socio-demographic data. This provides information on e.g. car ownership, general distribution between modes of travel, etc.. The actual travels are thus based on accessibility, location and culture (tradition and habits).

In this document we make use of a pragmatic concept of city-region, based on the EC conception of regions which can host 500,000 to 5 mill inhabitants and which may or may not correlate with administrative boundaries. For city-regions it is defining that the city in its regional context is functionally coherent and e.g. provide a common labour market, and further, that it offer a common experience of place for its inhabitants (Massey, 1994). This means that for city-regions, the city is often the centre of growth.

Planning in Denmark

Denmark has a population of app. 5.4 mill inhabitants and covers an area of 43,098 km2, including more than 400 island and a coast line of 7,300 km. Residential areas cover 20 per cent while the remaining 80 per cent is used for agriculture, forests, water and wetlands, coasts and other nature. The two main islands, Zealand to the east and bordering Sweden, and Funen between Zealand and the Jutland peninsula to the west, are connected by bridges and tunnels. Approximately half the population lives on each side of the Great Belt connection between Zealand and Funen.

Spatial planning is in Denmark under the authority of the Ministry of Environment. The present Planning Act builds on a planning reform of 1975 and the major administration reform of 1970. It came into force in 1992, with amendments since. Local authorities have traditionally had a strong role for spatial planning in a decentralised system of planning. This system has however changed since a major reform of local government entered into force in 2007. With the reform, the number of municipalities was reduced from 275 to 98, with 20,000 as the minimum number of residents, and 14 counties merged into 5 regions. This reform further rearranged the tasks allocated to each planning level.
On the one hand, the reform led to increased centralisation of planning and the Minister for the Environment is now responsible for upholding national interests through national planning and has taken over a number of the former regional level planning responsibilities. The role of the regional councils is reduced to preparation of a strategic plan for spatial development in each region and to management of hospitals. On the other hand, the 2007 reform also pushed decentralisation, and now the local level municipal counties are responsible for comprehensive land-use regulation at the municipal and local levels and they produce legally binding plans and guidelines for property owners. Thus, municipalities plan both town and country, and are the main planning actors for local and urban development and land use.

A division of the country into three zones is the basic principle for the planning system; urban, recreational and rural zones. In the urban and recreational zones, development is allowed in accordance with local plans. In rural zones, developments or any changes of land use for other purposes than agriculture and forestry are banned unless special permission is granted by municipal planning authorities. A second key principle of the planning system is framework control, signifying that the plans at lower levels must not contradict planning decisions at higher levels.

**Transport planning in Greater Copenhagen**

Located at the eastern Öresund coast of Zealand, the City of Copenhagen is the capital of Denmark and with approximately 1.9 million citizens Copenhagen is the largest city in Denmark. Over the past decades, Copenhagen and the rest of Zealand has been geographically and functionally integrated, and to a limited extend also the Malmö area in Sweden. Zealand and Malmö for example now provide residential areas for commuters as well as hosts small and medium-sized businesses that interact with business in Copenhagen. In this case study we thus consider all of Zealand as part of the Copenhagen city region.

Further, the **Finger Plan 2007** has been adopted as a specific planning directive to the Planning Act that covers Greater Copenhagen. The **Finger Plan 2007** sketches the implication of the Local Government Reform 2007 for the Greater Copenhagen area and connects this to spatial planning and transport planning for the rest of Zealand.

Since the late 1940s, spatial development of the Greater Copenhagen Area has built on a strong socio-spatial imaginary, presented in the **Finger Plan** (Local Plan Office for Greater Copenhagen, 1947 – see image to the right). The **Finger Plan** gained its name from its shape where the city centre forms the palm of the hand and where the train lines of an urban train system, the S-train system, with parallel main roads, each traces out a finger around which suburban development has taken place, with green spaces – or wedges – filling the areas between the fingers. Over the years, the **Finger Plan** has ordered the metropolitan area as a city-region.

The **Finger Plan** includes not only the relatively small Municipality of Copenhagen covering the centre part of the city with app. 0.5 mill citizens but in addition take in the Greater Copenhagen Area, and thus also covers 34 adjacent municipalities. This very powerful, spatial strategic plan is foundational for spatial planning in Copenhagen[^1], which makes it

[^1]: and further has its own office in the Department of City and Landscape, Ministry of the Environment.
In *The Finger Plan*, Copenhagen’s medieval city centre around the harbour and adjacent 19th century residential areas form the palm of the hand while the S-train lines (an urban train system) and major road infrastructures radiate as five fingers from the city centre, connecting to the five main towns of Helsingør, Hillerød, Frederikssund, Roskilde and Køge (Local Plan Office for Greater Copenhagen, 1947) and (Ministry of Environment, 2007). During the second half of the 20th century, urban development happened along these transport corridors due to stringent planning by local authorities.

**Four ring roads cross and connect the fingers.**

In the mid-1990’s, Copenhagen opened the city’s first Metro line and the extended metro system now runs across, along and extends the existing S-train system. The metro system is still under development and has added another ‘finger’ to *The Finger Plan*, namely one running south from the city centre to the southern parts of the city (previously left out of the urban train system), Copenhagen’s International Airport and the Øresund Bridge.
A second defining feature of the Finger Plan is the green wedges that fill in between the fingers and which since early 2000s have been supplemented by green belts across the wedges. The green spaces have been under increasing pressure and has decreased in area. Planning aimed Biodiversity, Natura 2000, climate change adaptation and the inclusion of green spaces in urban strategies (branding and place-making) appears however to reverse this. Thirdly, during the 1990s the influential principle of proximity to stations was included in Copenhagen. Accordingly, business developments and major housing areas must be located within a radius of 1000 m from a public transport station, with the most transport heavy businesses such as shopping centres in an inner ring and no more than 500 m from a station.

New neighbourhoods are developing along the new southern finger, as well as in the old industrial harbour area along the coast of Öresund and in Christianshavn’s old shipyard area. A second novel and highly profiled neighbourhood, Nordhavn, is in the early stages of development. The inclusion of this former industrial harbour area within the living city is enabled as most industries and sea cargo transport has moved out of the city. These developments have put pressure on the strategic planning of Copenhagen but have likewise created novel ground for redefinition of its development rationale. This puts major urban development schemes on the agenda for the present planning and investment in Copenhagen and potentially changes Copenhagen’s spatial layout. Significantly, these plans are based on urban transport systems in the neighbourhoods as well as in the surrounding territory. Since the launch of The Finger Plan, proximity to stations has been a central planning principle, strongly emphasised in the two most recent city plans (Municipality of Copenhagen 2005, Municipality of Copenhagen 2009). In 2007, the city published a strategic vision, The Eco-Metropolis – Our Vision for Copenhagen 2015, which has become a reference document for municipal policy and planning. The Eco-Metropolis basically presents a ‘green and blue city’ with ‘sustainability mobility’ and an international reputation as a climate friendly place as the backbone for presenting Copenhagen as a ‘seductive place’ (Sandercock, 2003:16) that attracts investments, new residents and secure flows, and articulates these as ways to create a pleasant and desirable place to live marked by economic growth.

Copenhagen’s urban transport has historically been marked by a relatively large share of biking2 (Municipality of Copenhagen (Københavns Kommune), 2008, UK-version). In 2007 the share of biking amounted to 36 per cent of study and work related travels, while busses with 32 per cent of urban transport have had a small share of urban travellers, compared to other European cities that have up until 70 per cent travels by public transport. The share of private cars resembles with app. 31 per cent other European cities. Walking does not make up a significant share of urban mobility in Copenhagen. Car ownership has been low in the city while this changed with economic growth during the 1990s and 2000; however, most Copenhageners use the car for longer trips and leisure and leave the car during weekdays. With high real estate prices during the 2000s and the opening of the Öresund Bridge in 2000, urban sprawl has taken in larger areas of the region, including most of Zealand and the Malmö area in Sweden. Commuting has thus risen such that about 710.000 cars daily enter Copenhagen (in 2005) and 10.000 people daily commute across the Öresund Bridge, intensifying automobility in the city (Kommuneforum 2007). These trends have stirred an increase in the use of private cars in Copenhagen. Following this, the Municipality of Copenhagen and the national government both consider management of congestion a major challenge for city planning; a challenge which will increase in the near future. In addition, Copenhagen has specified climate change mitigation as a major focus area, including for its branding and place-making. A central part of these efforts are to make urban transport greener.

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2 The aim in the strategic visionary document The Eco-Metropole is to increase the share of biking to 50 per cent study and work related travels, through improved (more, better and safer) biking infrastructure and enhanced feeling of safety.
and more sustainable. Concretely, this has pushed a bicycle policy, efforts to increase the share of walking and an emphasis on improving urban trains and extending the metro system. To a large extent, these green mobility efforts run in parallel with and enforce the congestion agenda.

**Planned transport interventions in Greater Copenhagen**

In d2009, a broad national coalition passed an agreement on ‘Green transport’ which included a number of changes of the transport infrastructures in Copenhagen city region. These new transport projects mainly concern road and rail and are aimed at managing increasing congestion, anticipated rinsing transport flows and lacking connections across the ‘fingers’. As more people commute across Zealand and mobility has increased in volume, and since the Finger Plan is structured around transport lines that radiate from central Copenhagen and connects to the main towns nearby, including outside Greater Copenhagen, improvements of the main roads between Zealand’s towns have been suggested for decades.

Hence, the following planned transport interventions and investments are either under construction or far in the decision-making process.

**In greater Copenhagen**

A road Harbour tunnel had been decided to ease access to the Öresund region.

An extension of the motorway in Ring Road 3 is being completed. The Ring 3 is one of the most congested roads in Denmark and further extensions on the distances where it is not a motorway is under consideration.

A new metro line, the Metro-ring, is under construction and will by its projected completion in 2018 add an inner ring to the urban train system, with 17 new stations.

A light rail is projected in Ring Road 3 which will connect the s-trains running along the fingers, from Lyngby north of the city centre to . As part of the metro city ring and of the construction of the Nordhavn development area, the metro system will extend to Nordhavn Road user charges have been debated for more than a decade and are very controversial among politicians and publically. The original plan was to establish charges in central Copenhagen (the ring would follow Ring Road 2 and circle the centre). The decision has due to the massive opposition been postponed and the government has appointed a commission to examine options and produce recommendations for controlling congestion, possibly including user charges, in Greater Copenhagen.

Bicycle policy is targeted in strategies and plans for Copenhagen. A range of efforts to increase the share of cycling from the present 36 per cent to 50 per cent by 2015 has been proposed and launched. These include a green cycle track system detached from the road network, dedicated cycle infrastructures such as a profiled pedestrian/cycle bridge across the harbour, cycle motorways with additional lanes and cycle services along the routes and without traffic lights, improved safety, profiling the city identity as a cycle capital, waves of green traffic lights for cycles, cycle parking and cycle compartments in urban trains etc.
The rest of Zealand
As part of the Transport Agreement of 2009, a proposal for establishing a Motorway Ring Road 5 from Elsinore in the north to Køge in the south is being developed. The Ring 5 and will connect Scandinavia to continental Europe via the Fehmern Bridge, and thus decrease transit traffic in Copenhagen. The ring was originally proposed in 1967 and has since been highly debated, mainly because it will pass through protected nature areas and partly because it is anticipated to cater mostly for transit traffic between the other Nordic countries and Europe.

![Map of Ny Ring 5](image)

**Figure 3 - Existing (green) and planned (red) highways around Copenhagen adding a fifth ring road**

Also, a motorway is under construction along the middle ‘finger’ which will up-grade the road connection between Copenhagen centre and the city of Frederikssund – the only one not presently serviced by a motorway. Extension of the motorway to Holbæk and of the Køge motorway that connects to continental Europe at present via two ferry lines and, in the future, the Fehmern Belt Connection, planned to open in late 2020, will link road and rail to Germany.

A new rail line Ringsted – Copenhagen will extend the present 1-track line. This connection services both regional trains, national trains and trains to continental Europe and is heavily congested.

At national level, the Fehmern Bridge has been agreed and will connect Germany and the southern tip of Denmark.
Figure 4 - Location of the Fehmern Belt link, planned construction from 2014 onwards.
Modelling PASHMINA scenarios

This report focuses on a Danish case-study, where the qualitative scenarios developed during PASHMINA were turned into quantitative land use predictions. These were used as starting point for land use change modelling in LUCIA (Land Use Change Impact Analysis), a GIS based Cellular Automata tool developed by Hansen (2007). The scenario narratives as illustrated in figure 5 have been translated into spatial data by creating spatial map indicator dataset, which will allow for detailed modelling of the narrative. A list of the most commonly used factors in Cellular Automata models has been published by Santé et al. (2011). This supported selection of a series of different datasets, created from the best available geographical- and registry data from Denmark. A range of different GIS techniques has been drawn upon in this process, ranging from network based vector analysis to raster based density and distance mapping.

![Figure 5 - The main PASHMINA scenarios and paradigm shifts](image)

The key scenario setup as it was created, based on the narrative that is illustrated in figure 5. The interpretations made to address the conceptual drivers, was based on Danish planning practice, to match the context of the scenarios with Danish planning implementation. The modelling period is from 1990 to 2040, based on the population prediction statistics, which currently only is calculated as official forecast until 2040 from Statistics Denmark. The baseline is considered a business as usual pathway, corresponding to the Pear scenario ‘Growth without limits’. As this is not a standstill but just another development path, this scenario has been modelled as basics for comparison with the other scenarios and potential shifts and anticipates the development occurring with limited or no restrictions by politics and planning authorities. Changes taking place due to other development paths can be analysed by comparing this scenario with the modelling of the two other scenarios Apple ‘Growth within limits’ and Orange ‘New Welfare’. A development like the one leading to Stagnation is not considered very realistic, mainly in the light of that the Pear scenario already covers a kind of ‘no change’ development. The main drivers and indicator maps used in the three scenarios can be seen in figure 6. (Fuglsang et al. 2012a)
Analysing mobility through accessibility
The following paragraphs will be dedicated to the description of the case region, in terms of population development, placement of centres and commuting patterns.

Population
As it can be seen in figure 7, the uneven distribution of centres also result in an population density that is much higher in the Copenhagen metropolitan area, than in the rest of the region. In order to investigate the development of both the land use through the modelling of scenarios, and the placement of individuals to estimate accessibility and mobility, a prediction of population development must be utilized.
From the statistical office of Denmark, we get the population development and prediction statistics towards 2040, which is the end year of the current series. It can be seen, that in 1990 where the
Furthermore, where from Copenhagen rise is area. Since commuting From figure series Maps Paradigm the people population that counts. most the seen parts areas to the is the most of higher the total of kilometres travelled, due to the fact that the population density here is much higher than the rest of the region. It is quite evident that in general, the population on the south and western parts of the region travel more kilometres in general, that in the metropolitan area. If an average for the entire region is calculated as can be seen in figure 9 on the left side, then it is even clearer that the main commuting mileage is conducted outside the metropolitan area. From the statistical office of Denmark, we acquired statistics on Parishes level, which can be considered NUTS 4 for Denmark. Here, the population is accounted for as day and night population, where the night-time population is the inhabitants of the district, while the daytime population is the people working in the district as well as those both working and living there. These statistics can be seen in figure 10. On the left are the night-time population which is somewhat evenly spread across the region, with a slight overweight towards the metropolitan area. On the right are the daytime population displayed, and here, the metropolitan area is clearly dominating, with by far the highest counts. This means, that there is a daily transportation of workforce from the western and southern parts of the region towards Copenhagen, making the overall commuting patterns one dimensional.
Figure 9 - Commuting patterns in terms of distance – commuters out from each municipality. Left above/below average - Right number of kilometres travelled pr. municipality.

Figure 10 - Daytime and night-time population in the case region. Source: DST.dk
Methodology

Several different methodologies has been applied in relation to the work conducted for this report. The base of the works has been the modelling of land use scenarios using the LUCIA cellular automata model. Furthermore methodology to model accessibility in public and non-public transportation modes has been developed, as well as implementations of population density algorithms has been conducted. In the following paragraphs the background of the modelling methodologies will be evaluated, to describe the theoretical background of the work conducted.

Scenario modelling

The Cellular automata (CA) model applied for the modelling of the PASHMINA scenarios, is the Land Use Change Impact Analysis model (LUCIA) developed by Hansen (2007), which is a raster based GIS application (Fuglsang et al. 2012b). The model uses data aggregated into grid cells, and processed as binary arrays. In our case we use a spatial resolution of 100 meter, in order to be able to reflect even minor changes in land use and urban development. The grid used for the calculations are equivalent to the standardized Danish grid network and the resolution of Corine Land Cover maps that form the basis for present land use maps at EU-level.

The model simulates future patterns of land use change based on two levels, being macro and micro level driving forces (Hansen 2007). The modelling basics can be seen in figure 11. The model uses the macro level drivers such as population growth predictions to determine the demand for new urban areas. Based on these data, the model then assesses the transition potential of each cell, based on multicriteria analysis techniques (MCA). Here each of the micro level factors is assigned a weight to which it is multiplied. Then all factors are summarized into one cell value. Based on these values, the cells with the best scores are most suitable for transition of a type of land use, and are then converted into new urban areas.

![Figure 11 - LUCIA model approach.](image)

Each cells transition potential is calculated from a set of factors such as suitability, accessibility and proximity, and a set of defined constraints containing zoning and protection status not available for urban expansion. (Hansen 2007). The model is calibrated against observed data from the Danish
Building and Housing register, to assess the uncertainty of the results. The calibration period is from 1990 to 2002. To assess land use changes according to the scenarios, maps reflecting these factors have been created and applied in the modelling. The LUCIA model generates statistically based indicators such as spatial autocorrelation based proximity that in our case favours new urban cells to be located adjacent to cells of equal land use. Other factors must be created by combining auxiliary map layers through GIS modelling before entered into the LUCIA model. The following paragraphs will explain the work conducted, creating some of the central factors for the modelling, making it possible to implement the scenarios in the Cellular automata (CA) model. The pear scenario is considered the ‘business as usual’ scenario in relation to forecasting of development and land use change in Denmark. The patterns in urban development observed in recent decades in Denmark are dominated by a sprawl like pattern, with very disperse development. From the storyline of the pear scenario we adopt the car dependency and the scattered urban pattern into the modelling, by making the car and motorway accessibility to be the main location factor alongside value of property. Finally, for planning zones, we create some much expanded planning zones, making development possible in a large variety of locations. The apple scenario can be considered as the planning scenario that current planners ideally aim at, when conducting the long term plans. Here the narrative dictates stricter planning zones, and less car dependency. Therefore we model planning zones in relation to the Danish planning concept ‘The fingerplan’, and the ‘closeness to stations’ principle. These dictate urban development in fingers leading in to Copenhagen, with green areas in between the fingers. The closeness to stations dictates that urban development must be placed close to stations, thereby facilitating use of urban transportation. Furthermore the dependency of cars must be lowered, so instead of focusing on car accessibility, the main accessibility driver is by public transportation. Finally the orange scenario in the narrative is described as a complete rethinking of planning practice. The goal is a large degree of urban densification, as well as a much less transportation dependent systems. The interpretation that was created, focus on societal changes to occur, where for instance the use of teleworking will become more used. This will reduce the influence of travel to work, making the travel to recreational opportunities etc. more important in the overall transportation need. Therefore the focus of placement of development is on a recreational distance indicator, urban density indicators, as well as job distance. Figure 6 (above) gives an overview of the chosen scenario drivers. (Fuglsang et al. 2012a)

**Accessibility modelling**

The concept of accessibility is a key element in urban, regional and transportation planning, and accessibility is generally considered as one of the most important determinants of land-use patterns. Accessibility can be defined as the ease with which activities at one place can be reached from another place through the transport network. Accordingly, accessibility is dependent on the spatial distributions of the destinations (centres of opportunities) relative to a given location, the magnitudes, quality and character of the activities found at the destinations, the efficiency of the transportation system, and the characteristics of the traveler (Fuglsang 2011). Accessibility is a relative quality assigned to a piece of land through its relationships with the transport network and the system of opportunities represented mainly by the facilities in urban centers. Thus we can state that all locations are endowed by a degree of accessibility, but some locations are more accessible than others (Garner 1967). For the modeling conducted in our study, a joined measure of accessibility in raster based grid format was suggested, that could be used to analyze accessibility in both public and non-public transportation networks. The modelling of transportation accessibility by different transportation modes is a complex task, requiring data from many different data sources, and a high degree of processing for them to be
Applicable. Data providers for the modelling tasks include Statistics Denmark, who provided population and workplace statistics, the Danish National Survey and Cadastre who provided road networks and road classification from the national topographic database KORT10, and finally MOVIA – the company responsible for the bus services on Zealand - who provided vector based digital data regarding bus routes and bus stops.

Based on the input of the different transportation elements, a raster based cost surface was created. The calculation utilizes a Cell Crossing Time (CCT) algorithm developed by [16] which determines the travel time value for each cell in the raster dataset. The calculation of the CCT is based on the following algorithm:

**Equation 1 - Cell crossing time calculation**

\[
CCT = \frac{C_s \times 60}{T_s \times 1000}
\]

Where CCT is the cell crossing time expressed by the cell size of the raster dataset \((C_s)\) and the travel speed \((T_s)\) derived from the network [Juliao 1999].

The algorithm for the analysis of job housing relations is based on the work of (Coffey & Shearmur 2001 ). Here the use of a employment / population ratio is discussed for identifying urban employment centres. The ratio is for our purpose then combined with the cost distance calculation into the following combined equation:

**Equation 2 - Calculation of employment centre weights**

\[
\sum \left( \frac{W}{P_i T_i} \right)
\]

Where the travel time for a given cell specified by the cost surface is \(T\) for the centre \(i\), \(W\) is the number of workplaces for the centre \(i\), and \(P\) is the population of the centre \(i\).

A central part of preparing the datasets for the CCT cost surface creation, travel speeds must be assigned to all transportation type datasets, in order to determine the speed of travel through which a cell can be passed. The corresponding values assigned to the different types can be seen in table 1 and 2.

<table>
<thead>
<tr>
<th>Object Code (from Kort10)</th>
<th>Road type</th>
<th>Transport Speed (km / h)</th>
<th>Cell crossing time (CCT) minutes / 100m</th>
</tr>
</thead>
<tbody>
<tr>
<td>2111</td>
<td>Highway</td>
<td>100</td>
<td>0,06</td>
</tr>
<tr>
<td>2112</td>
<td>Main roads</td>
<td>70</td>
<td>0,086</td>
</tr>
<tr>
<td>2115</td>
<td>Roads + 6m</td>
<td>50</td>
<td>0,12</td>
</tr>
<tr>
<td>2122</td>
<td>Roads 3 - 6 m</td>
<td>40</td>
<td>0,15</td>
</tr>
<tr>
<td>2123</td>
<td>Other roads</td>
<td>25</td>
<td>0,24</td>
</tr>
</tbody>
</table>

Table 1 - Road travel speeds
Table 2 - Applied drive speeds for the non-road based transportation forms.

To make the model as precise as possible, it was important to model the drive time of lines in relation to the stations. Whereas you can enter a car-based network at all nodes and lines, a public transportation network is limited to only permit entering the network at railway stations and bus stops. In order to model these elements, constraints where added along the lines of the transportation networks. The workflow of the cost surface creation is illustrated by figure 12.
Figure 12 - Creation of constraints for public transportation networks

Using a function that expands specified zones of a raster by a specified number of cells a one-cell buffer was applied to the raster datasets representing the public transportation network, and these buffers where given the value 999. The resulting raster where then processed using conditional statements ensuring that the buffers where combined properly, maintaining the correct information from the original raster dataset. Next, the stops and stations had to be added to the layer, enabling entry to the transportation network. The stations from all three networks where converted into raster, and a two cell expand was applied to cut the holes in the constraint layer using a conditional statement.
Figure 13 - Calculation of public transportation accessibility

Figure 13 shows the procedural approach of the modelling task as it was created for the public transportation accessibility. Similar methodology was applied to the non-public transportation modes, however here, no constraints approach was implemented, since the network connectivity here is not refined to entry/exit points. The basic results of the modelling can be seen in figure 19, where the accessibility surfaces of 2010 for the case region can be seen for both public and non-public transportation.
Scenario results

The three different scenarios was then set up as projects in the LUCIA model, based on the drivers and weights that was assigned. Each calculation of a scenario from 1990 to 2040 took about an hour and 45 minutes to complete. The model produces several different outputs such as land use maps pr. Year, land use change maps pr year, and demand maps. The land use change maps of the simulation period can be seen in figure 14 and 15, together with a combined map of the three scenarios. Table 3 gives a comparison of the three scenarios with regard to the new urban areas created. Of a total of 255,55 km2 new urban areas approximately half of the areas are different between the three final land use maps for 2040, i.e. Apple 51,37%, Orange 58,43% and Pear 49,01%. New urban areas common to all three scenarios occupy 13,68% or 34,96 km2 and the remainder are areas where two maps overlap.

<table>
<thead>
<tr>
<th></th>
<th>New urban area</th>
<th>Only one scenario</th>
<th>All scenarios</th>
<th>Pear</th>
<th>Apple</th>
<th>Orange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total [ha]</td>
<td>25555</td>
<td>51,37</td>
<td>13,68</td>
<td>22,19</td>
<td>100,00</td>
<td>12,77</td>
</tr>
<tr>
<td>Apple</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>25555</td>
<td>58,43</td>
<td>13,68</td>
<td>15,13</td>
<td>12,77</td>
<td>100,00</td>
</tr>
<tr>
<td>Pear</td>
<td>25555</td>
<td>49,01</td>
<td>13,68</td>
<td>100,00</td>
<td>22,19</td>
<td>15,13</td>
</tr>
</tbody>
</table>

Table 3 – Map overlap of urban development according to the scenarios modelled.
Figure 14 - Modelling results of scenarios. Right the apple scenario left the pear scenario.

Figure 15 - Modelling results of scenarios. Left the orange scenario, and right a comparison of all three scenarios.
Population prediction mapping

Based on the scenario maps of urban development, maps of predicted population densities were calculated. The maps were calculated using the dasymetric mapping framework which will be described in detail in this chapter.

Knowing the spatial distribution of population is needed for analysis of people's interaction with their local environments, in the case of this study, their accessibility and mobility. Representing data in different areal units requires interpolation from the initial source units to target units. Using GIS, this can be achieved by dasymetric mapping (Wright, 1936). The methodology of this method is to transform data aggregated to one spatial scale to another scale in order to represent the underlying data distribution more realistically (Ural et al. 2011).

For the dasymetric mapping tasks in this study, the areal interpolation technique is applied. This method can be described as the transfer of data from one set (source units) to a second set (target units) of overlapping, non-hierarchical, areal units (Maantay 2007).

In order to establish the land use class weights, year 2000 was used as base year. Here the Corine 2000 land use dataset that was used for the cellular automata modelling was used as reference, and combined with the Danish central persons registry for year 2000. By this calculation, the population density of the different land use classes within the municipalities was calculated, and used as baseline for the population distribution for the scenarios. In figure 16, the population density map of the pear scenario as it was calculated for 2000 can be seen on the left, and the development as the scenario predicts for 2040 on the right.
Figure 16 - Population maps of the Pear scenario. Left year 2000 and right year 2040

Figure 17 - Population maps. Left the apple scenario in 2040, right the orange scenario in 2040
Hotspot identification

Based on the population density maps of the three scenarios, a hotspot development map was created (figure 18). We calculate the population density of only the new pixels for each scenario, and sum those up to one map. Based on this map, a hotspot analysis using the Gertis Ord-G was created, identifying the areas where population density growth is largest between the three scenarios. The areas with the high red colours are the hotspot areas, where population development are expected to occur, no matter which scenario is enforced in the coming decades. So despite the scenarios being modelled with significant difference in terms of drivers, it will have an impact on the population in these locations. Based on this knowledge, we can focus on the mobility in these areas, since it is here that the population is going to evolve, and transport infrastructure and mobility improvements are specially required.

Figure 18 - Hotspot analysis of scenario population development
Current accessibility landscapes

![Accessibility landscapes 2010](image)

**Figure 19 - Accessibility landscapes 2010. Right by public transportation, left by car**

**Future road traffic development**

Work conducted for the infrastructure commission on behalf of the government in 2007, have analysed and modelled the future development of traffic on the Danish road network. The research was conducted by The Danish University of Technology (DTU), predicting the development of average daily traffic amounts (ADT) and congestion patterns. In figure 20 the development in their low-growth scenario can be seen. In 2007 two scenarios was created, one with high growth that amongst others was calculated based on continuing low fuel prices, and one with low growth based on high fuel prices. Therefore I a scenario was to be selected from the report today, the low growth scenario is most viable, since fuel prices has risen almost 20% since 2007.
It is quite clear from figure 20 where the number of hours with more than beginning congestion is measured in hours, that the road pressure is to rise dramatically in the coming decades, posting severe mobility challenges for car based transportation. The conclusion of the report is, that major investments are to be made into the road network, if congestion problems are to be solved alone by extending capacity. In Denmark this means, that by 2030, a total of 500 – 800 kilometres of four-lane motorways must be constructed, in order to cope with the intensifying capacity build-up on the roads. (Danmarks Transportforskning, 2007)

**Transportation landscape of 2025**

Besides the investment in the extension of capacity on the existing networks, several new infrastructure projects are proposed for the case region, ranging from motorway projects, to light rail and metro construction, to extend the mobility of individuals in the region. Some of the projects will likely never become implemented due to political issues, while others are already well debated both by politicians and in the media. We have selected five suggested network improvements that is likely to be constructed within the period towards 2040.
In figure 21, the lines of the five proposals can be seen. The Ring 5 road project is probably the most debated one in Denmark currently. It is to connect and channel traffic from Germany to Sweden around Copenhagen when the Fehmern-belt Bridge currently under construction opens. Alongside the Ring 5 road project, we have selected a project extending the capacity and travel speed from Slagelse to Næstved, improving the connectivity of the network around Næstved, which is currently not directly coupled to the motorway network.

Besides the two road projects, three projects of public transportation improvements have been selected for analysis. First the Metro cityring, which is currently in its construction phase have been selected, alongside a light rail project on Ring 3, which has been passed and is to be constructed in the coming years. Finally an improved train connection from Ringsted to Copenhagen has been included, which is currently only a vision project that still is to be passed.

In the following paragraphs, each project will be evaluated in terms of accessibility and mobility improvements, in order to access the consequences of implementation of each project.
Impact analysis of new infrastructure

Slagelse – Næstved

Figure 22 - Impact of the Slagelse - Næstved road project. Right by percent increase, left by affected area

Ring 3 light rail solution

By 2011, the proposal for a light rail solution following the ring 3 around Copenhagen was agreed upon by the politicians, to be constructed during the next decade. Thirteen municipalities has agreed upon a frame, for establishing the 28 kilometers of ligh rail from Lundtofte and Lyngby over Herlev to Glostrup and Ishøj. The price of the implementation is estimated to 3,75 billion Danish kroners, and it is expected to begin operation by 2020 (Letbaner.dk 2011)

The proposal was inspired by similar rail projects in northern Europe, for instance the Tvärbanan in Stockholm, which one year after being operational has achieved 28.000 daily passengers.

The proposal will double the existing capacity of busses by 6-12 departures pr. Hour in each direction, and it is estimated that the maximum capacity of the solution is 24 departures pr. Hour – all without significant disturbance of the general traffic (Letbaner.dk 2003)

The passenger potential of the solution is by multiple Danish sources estimated to be around 60.000 individuals pr. Day, being equivalent to many of the existing S-tran connections around Copenhagen (Enevoldsen & Kejser 2008).

The traffic in Copenhagen has been increasing with rapid pace in the last decades, making the demand for new infrastructure improvements ever more important. The traffic across the fingers around Copenhagen has increased by 40% from 1995 to 2005, and on the ring 3 road stretch, the daily amount of hours with congestion has increased from 2 to 5 hours since 1993. (Enevoldsen & Kejser 2008).

The upgrade of the public transportation network outside the ‘main’ S-train network will release pressure on the existing stretches, as well as maintain and increase an high percentage of
commuters by public transportation. Based on planning strategy incorporated around the proposal, it is estimated, that by 2018, there will be established 12,000 new workplaces and 5,000 new inhabitants in the areas directly in contact with ring 3 (Enevoldsen & Kejser 2008).

In figure 23, the accessibility implications of the ring 3 proposal can be seen. It is clear, that the proposal has a intensive synergy effect with the existing S-train connections, making the cross-finger commuting become much more effective, improving the mobility of individuals in an area extending all towards Roskilde. It is also seen, to what extend the perceptual increase in accessibility is distributed, with an improvement of total public transportation accessibility by over 5% as far away as 10 km from the actual track itself. Combined with the hotspot mapping of the cross scenario result, it is clear that this proposal creates mobility improvements in the area around Copenhagen, which is predicted by the modeling to grow rapidly in the coming decades, making it a solid investment that will attempt to release road pressure, and optimize the public transportation potential.

![Figure 23 - Impact of the Ring 3 light rail project. Right by percent increase, left by affected area](image)

**Ring 5**

The plans of developing an outer ring road around Copenhagen has been debated in the last 50 years. The first political debates regarding this project was undertaken in 1967, where the legal groundwork for the connection was created. The creation of the transportation corridor was not only intended to solve the internal congestion problems in the Copenhagen metropolitan area, but also improve the general infrastructure and mobility in the entire Zealand area, and function as an important transportation vein connecting the Øresund-region (Ramböll 2010)

In conjunction with the road traffic ring 5 project, there is a proposed trainline connection planned to follow the path of the road, making it an infrastructure improvement that will affect both the public and the private transportation means.
The Ring 5 line is subdivided into 17 segments, and for each segment, the daily traffic load is modelled. The line segments will have between 55,000 and 25,000 daily trips pr. Segment, with the highest loads being on the road stretches close to the central Copenhagen infrastructure veins (Rambøll 2010). It is estimated that about 6% of the traffic on ring 5 will be cargo transportation, which is identical to the other highway lines around Copenhagen (Transportministeriet 2010)

Based on modeling, it is shown, that the implementation of the ring 5 project will have a substantial effect on the other main highway connections to Copenhagen, reducing the load of up to 15,000 on the stretches mostly affected (Transportministeriet 2010)

<table>
<thead>
<tr>
<th>Morning Rush-hour</th>
<th>Basis (min)</th>
<th>Ring 5 (min)</th>
<th>Improvement (min)</th>
<th>Improvement %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Køge - Helsingør</td>
<td>70,8</td>
<td>54,8</td>
<td>16</td>
<td>22,60</td>
</tr>
<tr>
<td>Roskilde - Hillerød</td>
<td>52</td>
<td>46,6</td>
<td>5,4</td>
<td>10,38</td>
</tr>
<tr>
<td>Frederikssund - Greve</td>
<td>51,5</td>
<td>49,7</td>
<td>1,8</td>
<td>3,50</td>
</tr>
</tbody>
</table>

Table 4- Travel time improvements. Source: (Transportministeriet 2010)

In table 4, the consequences of the proposal in terms of mobility are displayed. On selected stretches, the travel time improvement will be above 20%, reducing the travel time from over an hour, to just under 55 min. In figure 24, the accessibility impact of the Ring 5 proposal is shown. Since the proposal is still being debated, the lining of the proposal is not yet completely in place. We have selected to model just one of the six scenarios that are currently being proposed. We have selected the one that is currently accepted as the most likely political solution, but can still be changed.

It is clear, that the creation of this infrastructure improvement will have a major influence on the case region, creating accessibility improvements for a substantial part of the area. The improvements can be measured towards both Holbæk and Næstved, and even though the effects with this distance is not that great, it can still be measured. The area where the improvements are above the 3,5 that is the lowest travel time improvements that are estimated, are covering an area from Roskilde and Køge, and covering a substantial part of the north eastern Zealand region.
In terms of individual mobility and accessibility increase, the number of individuals that will be able to reach selected cities has been calculated. It can be seen in table 4, that the Ring 5 project will mostly improve the longer commuting trips. Within the zone where new individuals will be able to reach the centres within 20 minutes are small if at all existing. It is only in 3 of the selected 6 towns, where individuals not able to reach the centre within 20 minutes, will be able to after the implementation of ring 6. In the centres of Køge and Allerød on the outskirts of both Copenhagen and the line of Ring 5, the improvements are massive with 30 and 40 minutes travel time, due to the fact that the channelling of the line here is significant. It can however be debated, that Ring 5 might only insignificant way produce new commuting to those centres due to their placement.
**Ringstedbanen**

The track between Copenhagen and Ringsted are today the most used railroad track in Denmark. The capacity is fully used, and it is becoming more and more of a bottleneck for transportation in and out of Copenhagen by train. By establishing this new track, capacity will increase both for goods and passenger traffic, enhancing the stretches significance. The line is included in the European transportation network, connecting Scandinavia with the rest of Europe.

<table>
<thead>
<tr>
<th>Reduction based on Implementation</th>
<th>Number pr. Year (Count)</th>
<th>CO2 (Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>101658</td>
<td>18197</td>
</tr>
<tr>
<td>Vans</td>
<td>83614</td>
<td>24</td>
</tr>
<tr>
<td>Trucks</td>
<td>33337</td>
<td>26</td>
</tr>
</tbody>
</table>

When analysing the mobility and accessibility effects of this new track, it is clear that it is primarily an extension of capacity project. The areas where the improvements are localized can be seen in figure 26. The improvement that is gained from this new rail line, is first a result of a minor reduction in travel time to stations with some of the new locations, but mostly it is comprised of the increase in travel speed from 180 km/h to 225 which is estimated speed of the new line. Therefore, the improvement in accessibility is in the direction of the track from the western part of the region towards Copenhagen. Accessibility extending away from the new track is only increased minimally, since the accessibility here is not increased by much, an by the fact that the old existing track serves identical purposes in terms of accessibility.
Cityring

In 2005 the municipalities of Copenhagen and Frederiksberg agreed with the government about the creation of the metro cityring, which is currently under construction, and is to be open for business in 2018.

The main mobility impact of this project at is its described in the background analysis that was conducted regarding the construction of the line is, that it will mean that a lot of individuals will exchange their end of trip bus commute with the metro. overall it is estimated that the track will mean a total increase in number of public transportation trips by 35.000, primarily individuals that was previously travelling by bike or car. This means that not only will individuals formerly travelling by bus have their mobility improved in terms of transportation demand, but it will also facilitate an increasing shift towards public transportation for a large group of individuals. The total number of travellers is estimated to be about 280.000/day (Ministry of transportation 2005).

In the direct hinterland of the track, it is estimated that it will account for more than half of the total public transportation traffic in the area after its completion. It is also estimated that the metro cityring, which reaches areas of Copenhagen previously mostly accessible by slow busses, will mean an increase in the traffic with the S-train and regional train systems, since the connectivity and accessibility to larger areas of Copenhagen will increase (Ministry of transportation 2005).
Figure 27 - Impact of the cityring metro project

In figure 27 the direct measurable impact of the cityring can be seen. The effect in our analysis is generally low. This is because there are elements in the Centre of Copenhagen that is not handled effectively in our model.
Examples of combined impacts

Figure 28 - Impact of two road projects. Right by percent increase, left by affected area

Figure 29 - Impact of three public transportation projects. Right by percent increase, left by affected area
Discussion and conclusions

Accessibility modelling

![Accessibility modelling](image)

**Figure 30 - Connectivity of development hotspots related to existing (roads & railway lines) and planned transport infrastructure (lines)**

Danish transportation infrastructure towards 2030

In the report about the future transportation infrastructure of 2030, the infrastructure commission determine that:

*Mobility is an important element in the companies ability to compete – and thereby also for the Danish society. Effective transportation systems can assure that goods can be produced where it is least expensive and at the same time best. Production and distribution of goods becomes simpler and less expensive, because quick and reliable paths to the consumers are secured. At the same time, high mobility ensures, that the companies can attract the right amount of skilled labour required (Infrastrukturbeslutningen 2008)*

Mobility is an important issue for citizens’ ability to act and interact with society. To some extent all individuals are in daily contact with the transportation system, and it is estimated, that an average
household spend an average of 15% of income on transportation, which is more than is spend on food. As welfare increase, so does the amount of traffic. Citizens does not necessarily select jobs close to home, but instead they acquire car number two, and commute over longer and longer distances (Infrastrukturbnsen 2008).

The central visions of the Infrastrukturbnsen is:

- Mobility of individuals and goods are to remain at top international level.
- Well-functioning transportation systems secures high degree of mobility in society
- Public transportation is a solid alternative to motorized transportation
- Cities, airports and transport centres are linked together by effective infrastructure
- A decoupling between rising transportation needs and CO2 emissions.
- Significant improvement of traffic safety.
 (Infrastrukturbnsen 2008).

Knowing the political agenda and the goals for the forthcoming decades, it is possible to analyse our scenarios in relation to how they oblige to these visions. First we can perform an analysis of the transportation infrastructure in relation to the placement of the new urban areas of each scenario. We calculate simple Euclidian distance for each pixel towards infrastructure. We focus on the long distance mobility contributions of trains and car transportation, since it is shown earlier, that the general commuting distance in most cases are to long to do effectively by bus, why individuals must and will seek the high speed solutions. Therefore we use the train and metro networks stations as access point to public transportation, and major road elements as non-public transportation mean.

![Average Euclidian distance to infrastructure](chart.png)

**Figure 31 - Long distance commuting potential of scenario**

In figure 31 we see the result of the calculation of general accessibility. in all scenarios we have a distance over 2,5 kilometres to main road stretches. This distance when travelled by car is not a that great distance, since travel to get there is simple and easy by car – granting fast access to the main roads and much greater travel speeds. For public transportation, the distance to stations is much more important. In the pear scenario the average distance is above 3500 meters, which is a significant trip if individuals must do it by bus or by bike. Implementing the closeness to stations
principle in the apple scenario enforces that development must happen near stations, which greatly reduce the average travel distance to trains in the apple scenario. The orange scenario presents another approach to placement in space in relation to transportation. This will in case of our modelling result in an slight decrease in rail travel distance from the pear scenario, but a larger reduction in the car travel distance from 3500 metres to about 2500 meters.

In our scenarios, the apple scenario presents clearly the best mobility improvements for the public transportation users. But since many individuals resort to car traffic for commuting still, then the balanced strategy of the orange scenario will have the greatest overall impact on mobility of the future, if we look isolated at the accessibility of major transportation services.

![Public transportation accessibility score](image)

**Figure 32 - Accessibility scores of scenarios**

If we increase the level of detail in the analysis and include the busses in the calculation of public transportation infrastructure as was calculated, the scenario comparison then show a different picture. The calculation where the accessibility is weighted as a function of distance to centres and workplaces, the orange scenario is then the worst performing scenario of the there. The apple scenario which dictate urban development in relation to centres and in areas with good public transportation coverage naturally has a low score in the indicator. But where the orange had a good general distance accessibility relation in figure 32 it is now scoring high. This means, that the orange scenario places the pixels in areas with a relatively low distance to the infrastructure, but with less focus on placement in relation to jobs and centres. This actually show, that the scenario has been modelled according to the implementation plan, that states that the scenario should pay less attention to work commute, but favour other travel types.
Figure 33 - Development of public accessibility score from 2010 to 2040

If we look at the scenarios in context towards 2040 with the implementations that we have modelled, then we can realized how they improve the accessibility by public transportation score in the future. From an overall perspective, none of the public transportation implementations that we have analysed is directly new infrastructure, it is an extension of existing capacity or change in type. This can be seen from figure 33 where the overall accessibility score of the three scenarios are compared. For the pear scenario, the land use development will despite of the new implementations rise, meaning that the accessibility will fall as a result of the development. The orange scenario is stable in relation to the accessibility, whereas the apple scenario has an improved accessibility score of about 10%.
Conclusions
The modelling of land use, settlements and urban sprawl related to transport modes, infrastructure and accessibility is a way to analyze future scenarios by modelling different future pathways. We have chosen the Eastern part of Denmark covering both the Copenhagen Metropolitan region and some remote, sparsely populated areas for this case study. By using spatial data of different scales coupled with relevant socio-economic data, this work has explored and tested the understanding of land use change relation by modelling the often complex local and regional factors determining the allocation and placement of new housing areas.

Urban development and its inherited localisation of places for living, working and recreation often is driven by neighbourhood relationships. Explained in a simple way by an example, this so-called spatial autocorrelation assumes that urban sprawl takes place close to existing urban dwelling sites, but keeps away from noisy and/or polluted areas like heavy industry or transport infrastructure. Furthermore, administrative limitations like planning zones, nature protection areas and political demands may determine that new urban areas should be placed in the vicinity and with easy access to public transportation, mainly rail transport.

Computer based spatial GIS models have been increasingly used to simulate complex urban development and their spatial autocorrelation. Empirical data like land use maps and demographics covering a longer period of time can be used to reveal spatial autocorrelation patterns occurring in the past up to present time and thus enable calibration of Cellular Automata (CA) models in order to generate realistic urban development patterns. Such models are capable of assisting urban planners to predict the future outcome of actions and policies applied. It is therefore of great significance that policies consider accessibility and social aspects of transport patterns as well as economic impacts. Specifically, accessibility to main transport infrastructures, proximity of work, shopping, recreation and housing facilities to main transport systems and established transport behaviour patterns may be addressed through policies aimed at sustainable urban spatial development. These must rest on a combined understanding of the spatial landscape of the region\city-region and of specific trends in transport behaviours and chose of transport mode.

To carry out this case study, the narrative PASHMINA scenario lines for potential paradigm shifts in the transport and environment nexus have been translated to spatial map indicators and assigned varying priority and weight when included in the land use development model. The outcomes of the three scenarios are clearly distinct in terms of travelling distances and population distribution in the area, leading to different possible accessibility and thus possibility to chose more environmental friendly and public transportation. Furthermore, it has been demonstrated that political decisions and spatial planning should favour more dense and/or agglomerated urban development (Apple and mainly Orange scenario). In the apple scenario, closeness to public transport (mainly rail) already is favoured. The Orange scenario focus is laid on urban densification, mainly in suburbs and villages. This enables and enhances the possibilities of establishing new public transport infrastructure as many people then will live close to these. On the other hand, scattered places of living (Pear scenario) and working places leads to a demand more private, individual transport by car.

Other publications about the Danish case study (reports, policy briefs and peer reviewed scientific articles) will be published on the projects home page: http://www.pashmina-project.eu/
References

Danmarks Transportforskning (2007): Langsigtet fremskrivning af vejtrafik - Indikation af fremtidige problemområder. IT og Telesyrelsen
Municipality Forum for a Congestion Charging Scheme in the Capital Area (Kommuneforum om trængselsafgifter i hovedstadsområdet) (2007): Congestion Charging in the Capital Area (Trængselsafgifter i hovedstadsområdet), København: Kommuneforum


Transportministeriet (2010): ”Trafikberegninger for Ring 5 i hovedstadsområdet” Notatnummer: 1100881-001
