LAHDEN AMMATTIKORKEAKOULU
Lahti University of Applied Sciences

HELSINKI CITY PLAN 2016 CLIMATE CHANGE IMPACT ASSESSMENT – EMISSION SCENARIOS FOR 2035 AND 2050

LAHTI UNIVERSITY OF APPLIED SCIENCES
Master's Degree Programme in Environmental Technology
Sustainable Urban Planning and Climate Change
Master’s Thesis
Autumn 2015
Johannes Lounasheimo

Lahti University of Applied Sciences
Degree programme in Environmental Technology

LOUNASHEIMO, JOHANNES

Helsinki City Plan 2016 Climate Change Impact Assessment.
Emission Scenarios for 2035 and 2050.

Master's thesis in Environmental Technology, 119 pages, 7 pages of appendices

Autumn 2015

ABSTRACT

The purpose of this study was to examine the effects of the implementation of the new Helsinki City Plan on the greenhouse gas emissions of the city. The main question is, how large are Helsinki’s emissions in the target years of 2035 and 2050. The starting point is the city’s current annual emission monitoring produced by HSY, and the Climate Swing scenario tool. The study also addresses how the future emissions of Helsinki comply with the emission reduction targets of the city, what is the role of urban planning, and what are the strengths and weaknesses of Climate Swing as a tool for master plan emission assessments.

An essential part of the scenario analyses are the underlying general trends and assumptions. Much of the research data was collected from previous scenario exercises carried out in Helsinki. The research methodology combines the narrative scenario of the City Plan’s vision 2050 with quantitative parameters that are entered into the Climate Swing tool.

In order to demonstrate the emission trends, two scenarios were constructed: the “More people” scenario describes the effects of the intensive urban growth that is expected in Helsinki. The “Less emissions” scenario exemplifies a situation where the City Plan is implemented as planned, and a range of emission reduction measures are carried out decisively up to the year 2050. The impacts of the City Plan itself were also assessed separately.

The key finding of this thesis was that the emissions can be decreased to a level where Helsinki’s emission reduction targets are almost met. By having an effect on the new construction, energy renovations and mobility, the City Plan enables 33 % lower emissions compared to the scenario of mere growth. Including other measures, the total reduction would be almost -90 % in 2050. The Climate Swing was originally not designed for master plan assessments, but with some additional calculations it can very well be used for such purposes.

Keywords: climate change, greenhouse gas emissions, master plan, urban planning

CONTENTS

1 INTRODUCTION

In September 2013, The Intergovernmental Panel on Climate Change, IPCC, released the first part of its Fifth Assessment Report, focusing on the natural scientific background of climate change (IPCC 2013). The report confirms the facts about climate change. Greenhouse gas emissions resulting from human activity are undeniably causing global warming, and the average global temperature threatens to rise to up to five degrees by the end of the century. The projections for sea level rise have also been revised upwards. Limiting global warming to tolerable two degrees, compared to the pre-industrial times, requires drastic emission reductions, and the vast majority of known fossil fuel resources must be left unused (see chapter 2.1).

A binding and universal agreement on climate, applicable to all countries, should be adopted in the United Nations's COP21 climate conference in Paris in December 2015[1]. The agreement will be implemented from 2020, but local emission reduction measures are needed even before that. Furthermore, the local and regional scale is where the low-carbon activities take place also in the future, when the national objectives and policies have been ratified.

Rapid urbanization puts special pressure on sustainable urban planning, even in Helsinki and Finland. The great challenge of humankind is to establish sustainable urbanism controlling climate change, and ensuring the quality of life of the city dwellers in the conditions of growing populations. The role of cities, urban form and planning are discussed in chapter 2.2.

Long-term land use plans guiding the development of urban structure have been prepared in Helsinki approximately every ten years. The current master plan, the City Plan 2002, came into force in 2006. The new city plan is being devised in the City Planning Department so that the city council can make the final decision on it in 2016. At the end of 2014, the first draft of the plan was introduced,

---

[1] U.N. Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP21)

accompanied with an extensive impact assessment. An essential part of the impact assessment is effects on the environment and climate.

The new City Plan is based on intensive growth (see chapter 2.3). According to the master plan vision reaching out to the year 2050, there will be some 860 000 inhabitants and 560 000 jobs in Helsinki by mid-century. In addition, the plan includes a master plan map guiding detailed planning up to the year 2035, and an implementation program (Helsinki 2015a).

Tens of thousands of new inhabitants, the growing building stock and traffic directly affect the city’s greenhouse gas emissions and global warming. In the recent years, the emissions of Helsinki have declined even with the city growing. A similar development may continue also in the future when implementing the City Plan. The environmental policy of Helsinki has a significant target of carbon neutrality by the year 2050 (Helsinki 2012). The short-term goal is 30 percent lesser emissions by 2020 (Helsinki 2013a). The Plan should contribute to meet these objectives up to the vision year 2050.

HSY annually calculates the greenhouse gas emissions of the cities of the Helsinki Metropolitan Area. In 2013, the emissions of Helsinki were 2.9 million tonnes of carbon dioxide in total. This is over 20 percent less than in 1990. In the 2000s, the emissions have decreased by almost 13 percent. The majority of the emissions are caused by the heating of buildings, traffic and electricity consumption (Figure 1).

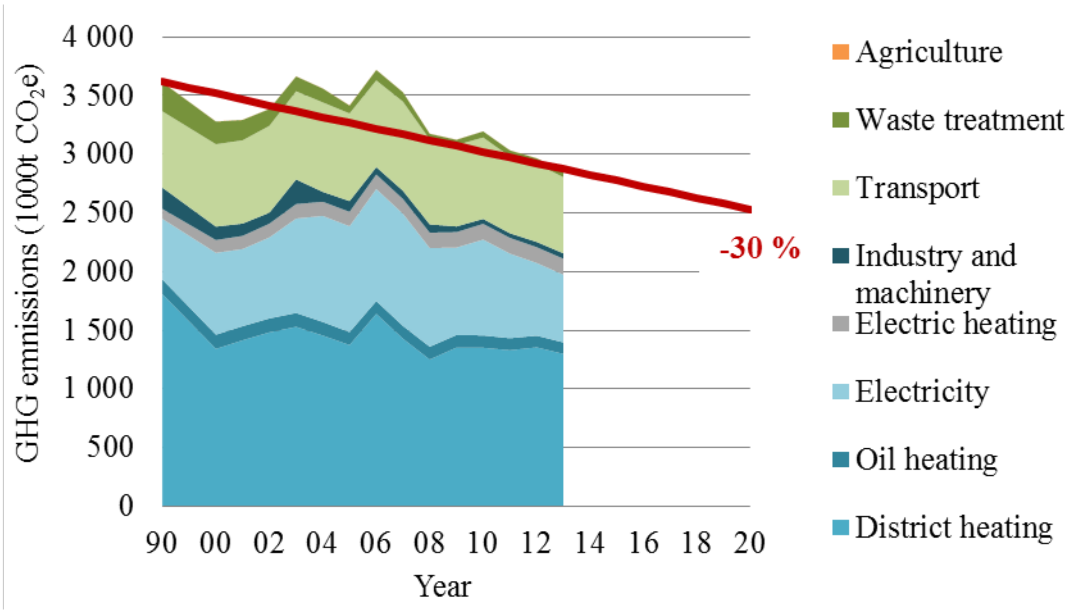

Figure 1. The greenhouse gas emissions of Helsinki (1000 t CO_2e) in 1990 and 2000–2013. The red line illustrates the emission reduction target of -30 % by the year 2020. (HSY 2015a)

When reviewing the climate impacts of the City Plan, it is essential to assess the greenhouse gas emissions of Helsinki in the targets years of 2035 and 2050. The scenarios presented in this study are based on the calculation methodology of HSY, and on the annual emission monitoring of Helsinki. The Climate Swing scenario tool has been used to support the assessment (HSY 2015b).

The Climate Swing scenario studies demonstrate the greenhouse gas emissions of the whole city in a given year. The impacts of the plan outside the city borders are not counted in the emission calculations. The future target is a densely built rail transport network city. Thereby, the community structure does not necessarily spread anymore elsewhere in the Helsinki region, which in turn lowers the emissions on a national and global level. Furthermore, the indirect emissions from producing the construction materials, or, for example consumption goods are excluded from this study.

The climate impacts of the City Plan are assessed also in ways other than the city level emission calculations, such as e.g. using the Keko B -regional ecocalculator for cities and municipalities (see chapter 2.3.1).

2 THEORETICAL FRAMEWORK

A megatrend is a major, often global, path of development that restructures our societies. It is a macro-level phenomenon or a wave of phenomena that, based on the actual development, is expected to sustain in the future (Rubin 2000). Stefan Hajkowicz futher defines that megatrends are gradual, yet powerful trajectories of change that our narrative of the future is built upon (2015). He adds rather dramatically that

> *[megatrends] will at some point express themselves with explosive force and throw companies, individuals and societies into freefall.*

The term was first popularized by John Naisbitt who analysed the major changes and developments taking place in the United States in the beginning of the 1980s (1982). Probably the most acclaimed study mapping the global megatrends, however, has been The Limits of Growth by Meadows et al. (1972). In addition to presenting trends based on current and past features of the society, the report was also one of the first to use scenario analyses as a research method (Swart et al. 2004, 140).

Dozens of megatrends have been identified by many authors[2] and institutions such as the Worldwatch Institute, European Environment agency and several management consultancy companies[3]. The most prevalent suggestions in these listings are

1. accelerating urbanisation,
2. resource scarcity,
3. digitalisation,
4. climate change and
5. demographic shifts.

According to a recent survey (Economist 2014), these five are also the ones that

---

[2] See eg. Glenn & Florescu 2015; Coutard et al. 2014.

[3] See e.g. Worldwatch 2015; EEA 2015; EY 2015; PwC 2015; KPMG 2014.

business, government and civil society leaders believe most likely influence their organisations’ big decisions. More importantly, these also affect each person’s everyday life as well as the planet itself. Although megatrends cannot be directly controlled, they can, however, be molded (Hajkowitz 2015). It is becoming increasingly clear that how we manage to influence the ongoing major development patterns, that in turn influence us, is crucial to the well-being of humankind.

The focus of this thesis touches two eminent megatrends, i.e. urbanisation and climate change. These are directly linked with other global phenomena, including demographic shifts and resource scarcity. In this broad context of planetary survival, reducing greenhouse gas emissions and sustainable urban planning play a decisive role.

The theoretical framework of this thesis is dealt with in the following chapters. Section 2.1 describes the alarming prospects of global warming, the cities’ position in the changing climate as well as their significance in the mitigation efforts. In section 2.2 the means of urban planning in reducing emissions are discussed more specifally.

2.1 Climate change – a critical outlook

In the light of latest, peer-reviewed scientific knowledge, it is clear that the growth of global greenhouse gas emissions should be overturned in just a few years. The later the emission trend starts to decline, the larger, more difficult and more expensive are the emission reductions required for preventing dangerous climate change going to be. The continuously high emissions consume the maximum allowed carbon budget (see Figure 2) and leave less room for manoeuvre in the coming decades.

Several countries, states, metropolitan regions and cities have announced ambitious goals and plans to cut greenhouse gas emissions. Many strive for a complete elimination of carbon dioxide emissions by mid-century. According to the IPCC's recent report (2013), the world's *greenhouse gas emissions* must be halved by the year 2050 and reduced by 2100, in order to stop global warming to two degrees Celsius above pre-industrial levels. In this case the *carbon dioxide emissions* should peak at 2020, and be completely phased out already around 2080 (Figure 3). Most of the proven resources of fossil fuels must be left unburnt (Figure 2).

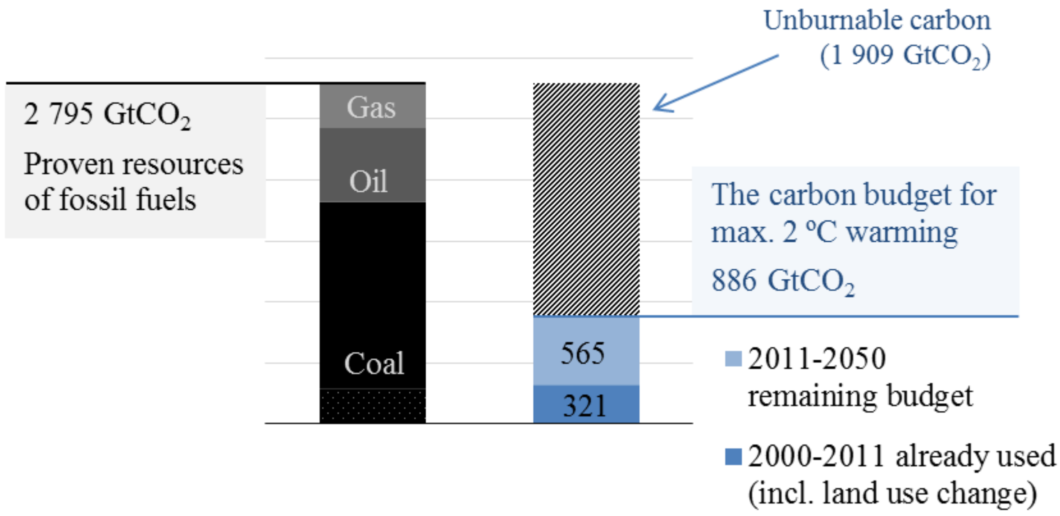

Figure 2. The proven resources of fossil fuels and the global carbon budget for limiting global warming to two degrees Celsius above pre-industrial levels (Carbon Tracker 2011).

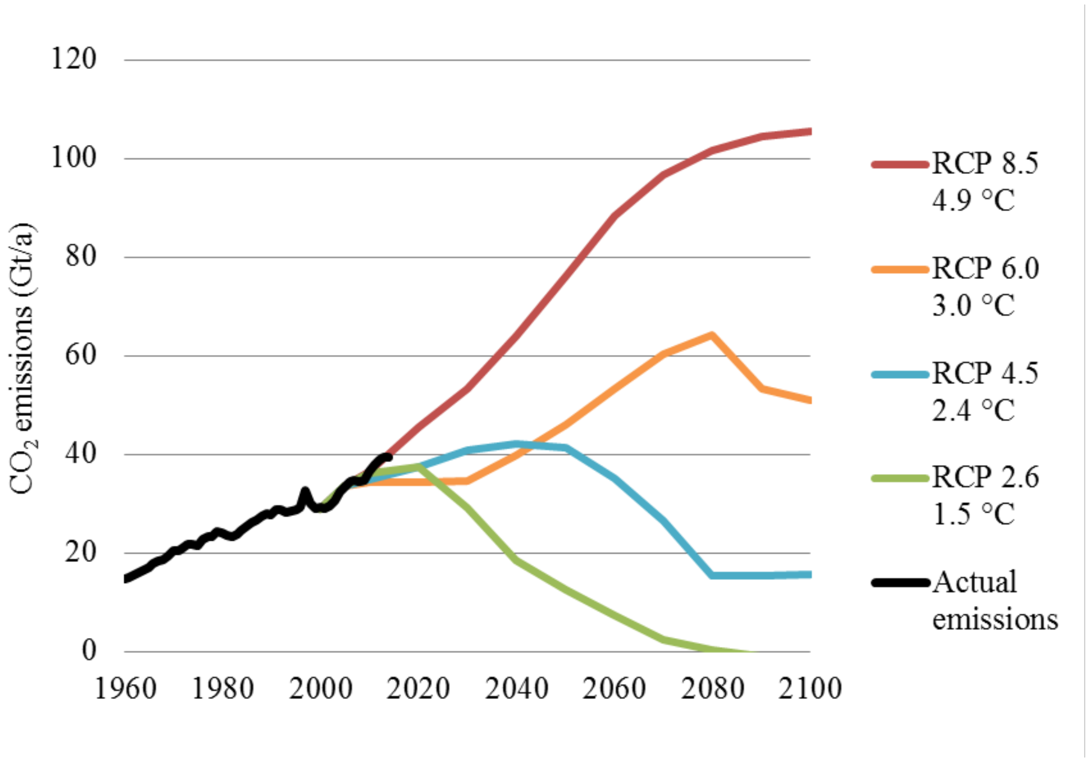

Figure 3. The carbon dioxide emissions from the use of fossil fuels and the land use changes (Global Carbon Budget 2014) compared to the IPCC's scenarios (IPCC 2013). In 2014, the emissions were predicted to have remained at the previous year's level (IEA 2015). The temperatures with each scenario indicate the change in global average temperature by the end of the century, compared to the pre-industrial era.

By mid-century the sustainable annual level of emissions would be approximately 1-2 tonnes of CO_2-equivalent per person, which means that the industrialized countries and the developed urban areas should reduce their emissions by 80-95 per cent. The carbon neutrality target of Helsinki seeks to address this challenge (Helsinki 2012).

The global average temperature is already 0.85 degrees higher than in the late 1900th century (Figure 4) and the consequences are clearly visible. For example in the United States of America, the following events have been discovered: extreme heat, heavy downpours, inundation, changes in the timing of streamflow, sea level rise, erosion, drought, increasing wildfire, insect outbreaks, tree diseases and increasing ocean acidity (USGCRP 2014). According to the U.S. Global Change

Research Program all this poses major threaths to water supply, infrastructure, agricultural yields, human health and the economy (2014). In Europe, heatwaves like the 2003 event which killed 70,000 people (Robine et al. 2008) are already ten times more likely than a decade ago (Christidis et al. 2015). The most evident proof of climate change already taking place is probably the decline of arctic sea ice. In the record year of 2012, the ice coverage was as much as 49 percent below the 1979 to 2000 average (NSIDC 2012).

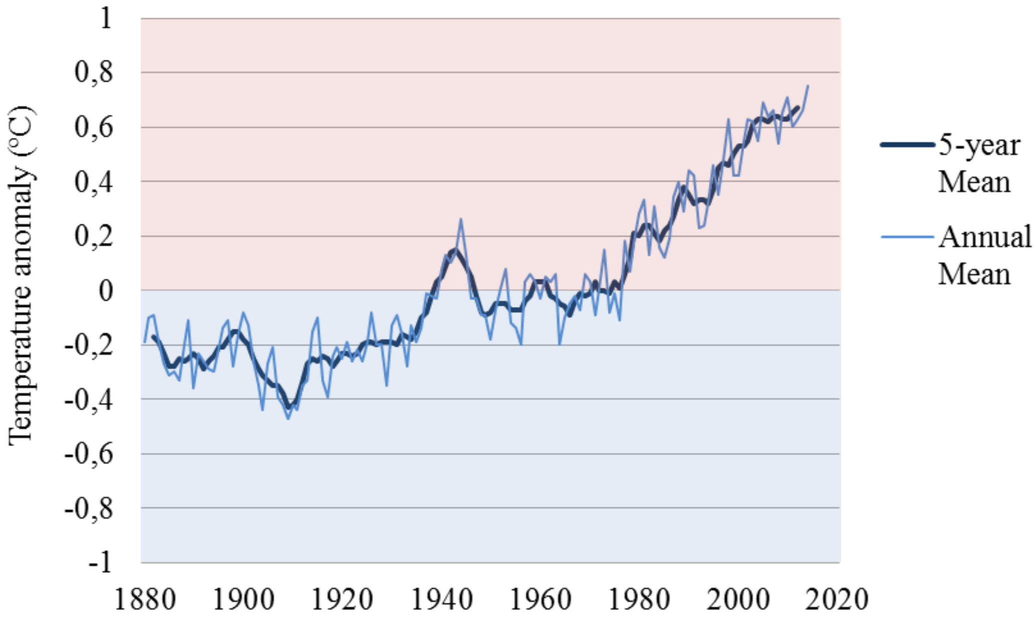

Figure 4. 1880-2014 land-ocean temperature anomaly compared to the 1951-1980 average (Nasa/GISS 2015).

The Paris climate conference tries to achieve a negotiation result that would efficiently contribute to keeping global warming below 2°C. However, more than doubling of the currently witnessed average warming would have very severe consequences. All the risks already recognized would be amplified, with one of the biggest being climate-change-induced migration as food and water security is reduced. The same applies to Finland and Helsinki. Other major impacts that are expected to multiply in the future are extreme weather events and sea level rise (IPCC 2014a).

The global warming is intensified in the northern latitudes because the melting snow and ice decrease the albedo effect[4] and increase the land area exposed to solar radiation. Also, the northern air is dry and thus susceptible to increase of water vapour and its warming potential. Mikkonen et al. (2014) report that Finland is already over two degrees warmer than in the 1900th century while the global average temperature has risen less than one degree. According to the Finnish Meteorological Institute, by the end of the century the IPCC's business-as-usual scenario RCP 8.5 (see Figure 3) implicates as much as six degrees, plus the already occurred two degrees, higher average temperatures for Finland (Ruosteenoja 2013).

According to a recent study, the national, voluntary emission reduction pledges, the INDCs[5] that countries have announced ahead of the COP21 conference, are enough to limit global warming to not more than a catastrophic 3.5 degrees above pre-industrial (Climate Interactive 2015). The amount of extra heat the Earth is about to experience, even with the national promises fulfilled, equals to how much temperatures were lower during the last ice age (Figure 5). While desperately waiting for more and more robust contributions from nation states, cities and other actors may take the responsibility for making up the difference between the current warming trend and a sustainable, livable future.

---

[4] The albedo effect is a measure of how much of the sun's energy is reflected back into space.

[5] In preparation for United Nations' COP21 climate conference, countries have agreed to publicly outline their Intended Nationally Determined Contributions (INDCs), i.e. what climate actions they intend to take and how much emissions they are ready to cut under the new international agreement.

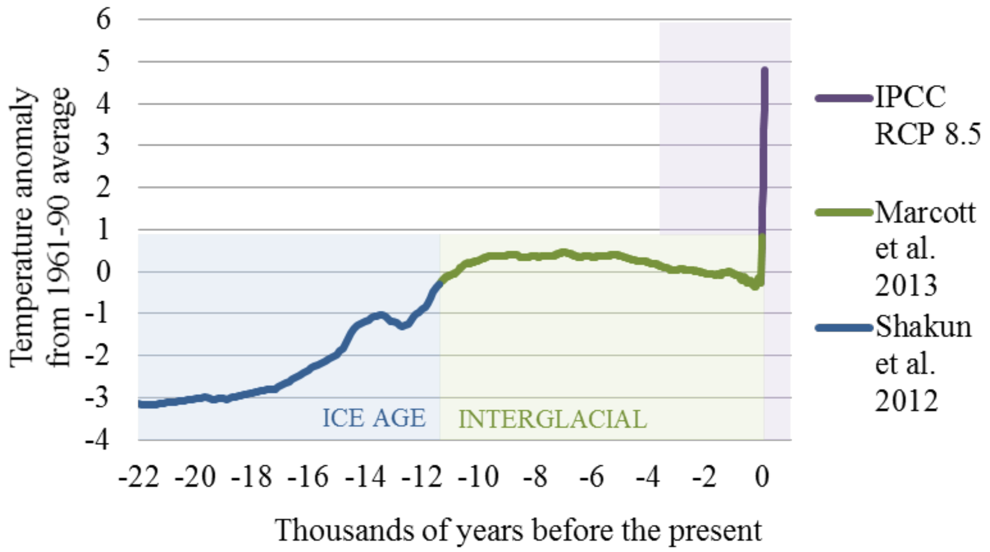

Figure 5.The change of global average temperature since the last ice age (Shakun et al. 2012; Marcott et al. 2013) and a possible future scenario up to the year 2100 (IPCC 2013).

At present we are not anywhere near the zero emission pathway. The global greenhouse gas emissions are at their highest levels ever (see Figure 3), and at this rate the global carbon budget will be spent in a few years (see Figure 2). Then at least the two degrees of global warming is locked in. However, China, the world’s biggest greenhouse gas emitter, has managed to turn its coal consumption to decline (Greenpeace 2015). Most likely this means that China’s CO_2 emissions peak as much as 15 years before the target year proposed in the country’s INDC. Also, Brazil recently came out with a new and rather ambitious commitment of cutting emissions by 37 percent in the next 10 years (UNTV 2015).

Even if the global emissions were cut completely today, the warming trend would persist, although a lot more gently, because of the long life-span of the already emitted greenhouse gases. Solomon et al. have found that as much as 40 percent of the 21st century’s carbon emissions remain in the atmosphere a thousand years from now (2009). This further underscores the alarming prospects of climate change that fundamentally mean two things: firstly, the urgency for mitigation measures taken at all levels of activity, from international cooperation to states, cities and individuals, is highly emphasized. Secondly, the adaptation capacity, and preparedness for the impacts of a changing climate must be enhanced already today.

2.2 Cities, urbanisation and global warming

In 2014, there were some *three thousand million* more urban dwellers across the world than in 1950, and the trend is expected to continue. According to the United Nations Department of Economic and Social Affairs the global urban population exceeded the rural population for the first time in 2007, and in 2050 the world will be 66 percent urban. (UN 2015). Besides climate change, rapid urbanisation is another prominent megatrend that is changing our world.

The role of the cities is constantly expanding. They are the economic, social, cultural, educational and political hubs offering the resources, opportunities, and interaction that the modern world is calling for. Manhattan-born economist Edward Glaeser writes that cities have the ability to create collaborative brilliance, produce new thinking, and speed innovation (2011). Nevertheless, the rapid urban growth engenders many negative externalities, such as pollution, congestion, security issues, and social degradation (Kourtit & Nijkamp 2013). Extensive energy use and greenhouse gas emissions could be added to the top of the list. IEA has estimated that already in 2006 about two-thirds of the world’s energy were consumed in cities causing over 70 percent of global energy-related CO_2 emissions (IEA 2008).

The World Bank has calculated that the collective greenhouse gas emissions of the world’s largest 50 cities, with more than 500 million people, are greater than any country’s emissions apart from the US and China. Those 50 biggest cities also make up for the second biggest economy in the world (2010, 18). The global economy and generation of wealth are evidently anchored to cities, which in turn facilitates sustainable market innovations and generates a huge potential for effective mitigation of climate change.

The economically productive cities may be the main reason for environmental degradation but they can also be the solution. Realising the potential, however, poses a great challenge to sub-national governance and city planning. Today’s decisions more or less lock in the futures of many growing cities as much of the infrastructure of the year 2035, 2050 or even 2100 is currently being built. Regarding the role of the cities, former vice president of Sustainable Development at the World Bank (2010) has stated that

> *sustainable development can only be built upon sustainable cities.*

In order to secure the prosperity and stability of our societies, mitigation of climate change should be policy priority number one at all tiers of governance. Nonetheless, as noted in the previous chapter, the global warming cannot be completely stopped anymore, meaning that adaptation to the gradual changing of climate and its consequences, as well as to the more unpredictable impacts, such as extreme weather events, has become an essential policy issue for the cities across the world.

Cities and metropolitan areas are more vulnerable to the impacts of climate change than less-urbanised areas because of their high density of built infrastructure and the dependency on complex networks of transportation, communication and trade (OECD 2010, 65). The risks for urban settlements include sea-level rise, tropical cyclones, heavy precipitation events causing flooding and landslides, extreme heat events and drought (UN-Habitat 2011, 65). These hazards may disrupt for instance the food distribution, energy provision, water supply, waste treatment, information technology, and sanitary systems of the city further triggering impacts on the city’s economy and public health. Ultimately, the impacts of climate change may trigger mass migration if the livelihood of people, particularly the food and water security, becomes threatened.

Well-designed, effective adaptation responses adds to the city’s resilience, the ability to absorb disturbances, and maintain and rehabilitate the vital functions of the city in the case of a disruptive event. In a resilient city, the government, businesses, organizations, households, and individuals have strong adaptive capacity including enhanced knowledge, institutional capacity, and financial and technological resources (UN-Habitat 2011, 130). Risks are recognized, vulnerability is reduced, and the adaptation measures are planned and options weighed in an integrative, cross-sectoral manner. Building resilience and preparedness is certainly a central topic in the field of sustainable urban planning. This thesis focuses yet on the other aspect of responding to climate change, the greenhouse gas emissions, and the mitigation measures in the context of a growing city.

2.2.1 Does density lead to sustainability?

The current megatrend of rapid urbanisation is historically not a unique phenomenon. Now it is only taking place on an unprecedented scale, mainly due to the massive population growth particularly in the developing countries. In the 19th century's Britain, for example, the urban settlements grew at an astonishing rate with the outbreak of industrialisation (Jenks & Dempsey 2005, 288). The overcrowding and the inadequate infrastructure led to slums, unsanitary conditions and people's health problems. In the 1840s, Friedrich Engels described Manchester as a 'Hell upon Earth', a place of filth, ruin, and uninhabitableness (1845, ch. 4).

The problems with excessive urban density in the early industrialized western cities were tried to be alleviated with legislative measures. The long-time ideal was towards *a less compact* urban structure. The concept of garden cities, for example, was first introduced by Ebenezer Howard (see 1902) for over a hundred years ago. Contemporary literature still sees urban sprawl, and the associated car dependency as the predominant characteristics of urban development (Lahti et al. 2012, 218). According to Seppo Lampinen (2015), the main reason is specifically transport planning based on passenger cars. This in turn stems from the tradition emphasising speed as a central factor for the efficiency of society and general well-being.

The dispersing urban form does not seem to support the principles of eco-efficiency and sustainable development, including greenhouse gas emissions.

According to a literature review made by Lahti et al. (2012), the line of thought seem to be universally accepted:

1. The urban fabric is scattered.
2. It is necessary to build increasingly expanding infrastructure.
3. More and more natural resources and energy is consumed in construction and maintenance of the infrastructure.
4. The distances grow.
5. Mobility and transport use up an increasing amount of non-renewable resources.
6. The growing motorized traffic growth causes urban segregation and isolates neighborhoods from each other.
7. The standard of services and the quality of life deteriorates in the large, sparsely populated suburban areas and in the outlying areas.
8. Services must be sought from increasingly longer distances, further increasing traffic.
9. Non-renewable and scarce resources are consumed more and more.
10. Harmful emissions are increased and global warming continues.
11. Ecosystems become more vulnerable and the ecosystem services (particularly clean air, water and food production) are jeopardized.

There is strong evidence that urban densities have been declining over the past two centuries. Angel et al. (2005) have studied changes in urban land cover between 1990 and 2000 using remote sensing techniques. They came to a conclusion that, with the observed decline of density, the occupied urban land is likely to triple when the population is doubled.

One of the first to question the decentrist view on spatial planning favouring sub-urban developments, and also strict zoning of city functions, was Jane Jacobs. She argued in her book The Death and Life of Great American Cities (1961) that the quality of life could be maximized, and the damage to the environment minimized by clustering of people, mixed uses of city blocks, and high pedestrian permeability. Later the emerging discourse on sustainable development had its implications also on urban planning. In Europe, this arguably culminated in the European Commission’s Green Paper on the Urban Environment (see 1990) introducing the concept of a ‘compact city’ (Welbank 1996).

Mike Jenks and Nicola Dempsey point out that the arguments for increasing urban density have remained the same in the past decades: a compact form allows for a mixture of building types and uses, the containment of sprawl, social and economic diversity as well as preserving agricultural land, and securing the proximity to facilities, transport and work. Further reasoning from the 2000s include sustainability and environmental issues, reduced car dependency and encouragement of walking, cycling, and use of public transport. (2005, 298-302)

In addition, Sirr et al. (2006) think that more efficient utility and infrastructure provision as well as revitalization of inner urban areas may be added to the variety of socioeconomic and environmental benefits of a compact city. It is also argued, however, that the reuse of urban land might lead to a lack of urban green space, increased air pollution, loss of biodiversity, and an overcrowded environment with social disparities and crime.

On the whole, there is a broad consensus on dense urban agglomerations’ favorable impacts on sustainable development (Jenks & Dempsey 2005). Bearing in mind the disadvantages of extensive urbanism, the link between density and sustainability is yet not simple and straightforward. Looking exclusively at greenhouse gas emissions, the connection becomes even more complex. A dense urban form does not implicitly mean low emissions and, on the other hand, low-density settlement patterns in the hinterlands may be more sustainable than the city centres they are surrounding.

In the urban complexity, there is a range of factors affecting the greenhouse gas emissions. The relationship between land use and emissions involves at least transportation-related emissions, buildings, landscape impacts such as deforestation, carbon sequestration by soils and plants, urban heat island effect, emissions from waste treatment, infrastructure impacts as well as electric transmission and distribution losses (UN-Habitat 2011, 54). Greenhouse gas emissions from industrial fuel use and processes, and agriculture would complement the assortment.

International air and marine traffic could also be added to the greenhouse gas emissions sources related to urbanism. The same applies to other so called scope 3 emissions (see GHG Protocol 2014), where the end product is consumed in the city by a citizen or an institution, but the carbon dioxide is physically emitted where the goods are produced, e.g. in a factory in China. Depending on the viewpoint and the scope of the greenhouse gas emission inventory, a city or a metropolitan region may receive quite different results when assessing its sustainability.

Typically the city-level emission inventories account only direct emissions produced within a certain geographically defined area. This scope 1 approach is derived from the UNFCCC’s national accounting standard. Also scope 2 may be used, as in Helsinki Metropolitan Area, meaning that the emissions from the use of grid-supplied electricity or heat are accounted whether or not they are occurring within the city boundary. Inventories including scope 3 emissions are rare, and the extent to which the indirect emissions are included is quite random, ruling out comparisons between urban areas (UN-Habitat 2011, 57).

The volume of the greenhouse gas emissions embodied in the goods consumed in the city is especially large in big and well-developed urban areas with high permeability of services and commercial activities. The scope 3 emissions would in such cities drastically increase the per capita emissions compared to the usual, more restricted approach (Dhakal 2008, 176-177). It is argued, however, that it is practically impossible to compile a comprehensive inventory of scope 3 emissions taking all the consumption of the citizens into account (UN-Habitat 2011, 57). At least the reliability and the relevance of the results should be carefully considered.

The benefits of urban density, in terms of greenhouse gas emission reductions, can most unambiguously be discovered in the community-scale assessments including the typical range of energy-based emissions. First of all, denser cities use less energy for transportation and cause therefore less transport-related emissions. The proximity of homes and work places encourages walking, cycling, and the use of public transport instead of private cars. Within compact distances, also freight can be delivered with less fuel.

David Satterthwaite has observed that doubling the average density decreases the per-household vehicle use, and the corresponding greenhouse gas emissions, up to 40 percent (1999). Later it has been argued that it is not the overall urban density *per se* that breeds eco-efficiency and lowers the emissions from transport, but the popularity and speed of public transport, the share of bicycle and pedestrian traffic, the compactness of the nuclear centre of the city and the limited number of parking spaces in the centre (Mindali et al. 2004). However, a dense urban form enables the establishment of a cost-efficient and attractive low-carbon transportation network.

Secondly, in addition to transportation impacts, spatially compact and mixed-use urban developments may have reduced per-capita consumption of heating, cooling and lighting resulting from smaller homes and shared walls in blocks of flats or town houses (UN-Habitat 2011, 54). Moreover, installing energy-efficient district heating and cooling systems may not be possible in the more sprawling areas, and also the distribution losses are bigger due to the lengthy transmission lines. On the other hand, with the late advances in low-carbon on-site energy technologies and energy-efficient housing, the supreme status of district energy networks and the cogeneration of heat and power is not so clear anymore.

Third benefit of density is the conservation of wilderness and fertile land. Although urban areas are globally expanding, compact development preserves biodiversity, and the carbon sink capacity of forests and soil outside of the city boundaries. The emission-reducing impact of restrained urban sprawl is indirect and challenging to measure precisely. Therefore it is usually not presented in city-level greenhouse gas emission assessments, although in this case the mechanism by which compact urbanism mitigates climate change is quite clear.

Kennedy et al. have studied greenhouse gas emissions of 10 cities across the globe. Combining the emissions with urban density gives a noteworthy correlation (Figure 6). The most sparsely populated city Denver has the greatest emissions while Barcelona being the densest stands out with the lowest per capita contribution to global warming. The research finds that Denver scored highest in the transportation sector, but also in emissions from the use of electricity, heat and other fuels (2009, 7298). However, adding Helsinki to the comparison reveals the complexity of the equation; Helsinki has almost as low emissions as the six times denser city of Barcelona (Figure 6).

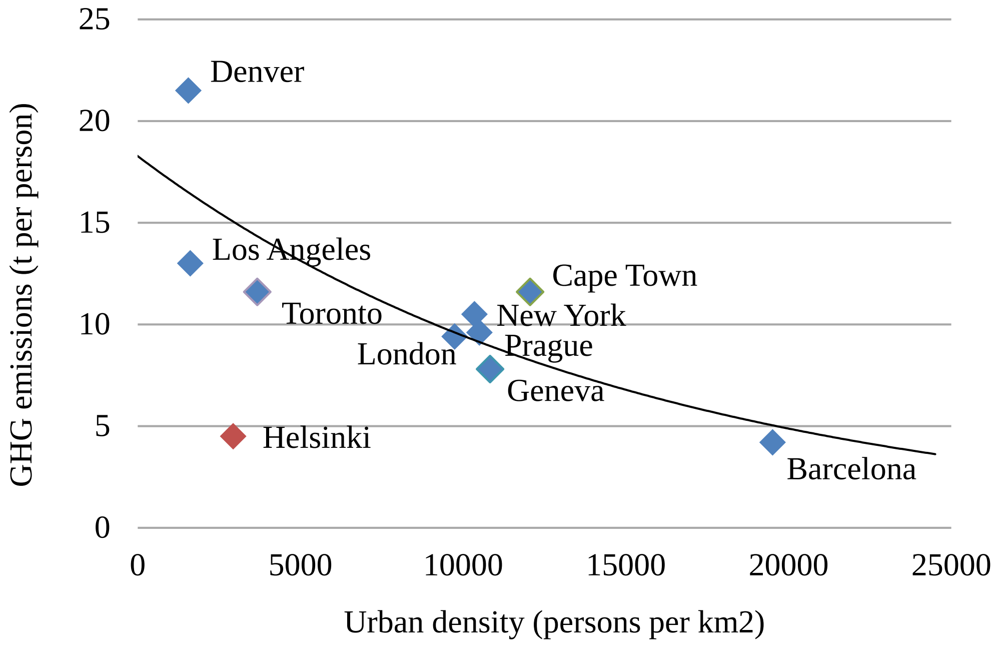

Figure 6. The greenhouse gas emissions of ten cities according to Kennedy et al. (2009, 7300) and the city of Helsinki (HSY 2015a) combined with population density.

The Organisation for Economic Cooperation and Development has achieved comparable, national-level results in terms of energy consumption. Japan’s urban areas are denser than Canada’s by a factor of five, and the electricity consumption per capita is only around 40 percent that of Canada. In Finland the amount of electricity consumed per person is more than double compared to four times denser Denmark (OECD 2012, 60).

There is a wide spectrum of factors with complex interactions affecting the greenhouse gas emissions. As discussed above, the urban structure does not determine the sustainability or climate friendliness of a city. Depending on what is measured and included in the emission inventories, however, the land use patterns and planning principles may offer substantial potential for reducing the urban greenhouse gas emissions.

Xuemei Bai argues that in service-oriented cities, such as Helsinki for example, the consumption-based, indirect emissions are more important than those of production (2007, 2; see also Dhakal 2008). In the high-consumption, import-reliant urban societies with little industrial activity this undoubtedly holds true. However, regarding the relationship between land use and greenhouse gas emissions, a total carbon footprint approach, taking residents' personal consumption habits, and all the scope 3 emissions into account, may be confusing.

In a recent study, Ottelin et al. (2015) analyzed the carbon footprints of residents living within three different urban forms in Finland. They found that the inner urban areas had less private driving, but the benefit was offset by high emissions from holiday traveling, and the consumption of commodities and services. The differences in lifestyle-based emissions were determined mostly by the income level of the residents. Lenzen et al. (2008) have also pointed out that wealth is the dominant factor affecting the personal greenhouse gas emissions. On a broader scale, the World Bank reports, not surprisingly, that rich cities use more energy and emit more greenhouse gases than poor cities (2010, 18).

Another key finding of Ottelin et al. was that the housing energy was actually lower in the outer urban and peri-urban areas, than in the inner urban areas because of the technological advances in the new building stock (2015, 9574). This further adds to the discussion about the sustainability of dense urban form, suggesting that the juxtaposition of urban and suburban areas should be reduced. However, the question is raised whether certain settlement patterns induce certain types of consumerism. It can be debated whether taking the citizens' lifestyles and consumption habits into account, also in other areas than in transport, is relevant in shaping local land use policies, or whether the issue should be included in a more holistic urban development scheme.

2.2.2 The means of spatial planning to reduce emissions

The main drivers of sustainable urban transformation include governance and planning, innovation and competitiveness, and lifestyle and consumption (McCormick et al. 2013). Hence spatial planning must be understood as an important part of effective climate change mitigation, among other sustainability goals, but not disconnected from overall development and other essential elements of change.

George Bugliarello (2010, 355-356) identifies challenges of sustainability policies, all of which concern also urban planning. Firstly, policies must be ambitious but realistic. Secondly, they must be flexible in the fast changing urban conditions, and thirdly, opposing policies should be eliminated. Climate change and urbanisation are setting new standards of ambition, and in the case of Helsinki and Finland the hierarchical system[6] prevents contradictory planning. The call for quick implementation and responsiveness poses yet greater challenges for urban planning processes.

Structures and systems built and maintained by humans have characteristically natural slowness in them (Lahti et al. 2012, 218). Lieven De Cauter (2000, 112) states that opposing change, and not having done anything to alter the 'predicament of mankind' known for decades is because of the inertia of the law of physics:

> *This inertia is not so much the inertia of being too passive, but […] of being caught in an acceleration that will not stop if there is no other body or force to stop it.*

Thankfully, the force is becoming stronger. With the raised awareness of the disastrous consequences of uncontrolled global warming as well as the impacts already felt, nation states, cities, businesses, and individuals are finding ways to hop off the current business-as-usual trajectory. In the quest for sustainability,

---

[6] The national land use guidelines steer regional plans that guide the local master plans, which, in turn, control the local detailed plans (ME 2015)

urban planning is recognised as a key method for governing and implementing the transformation (Wamsler et al. 2013)

It is just the slow structures though, that urban planning is most of all dealing with. For example, it is estimated that only up to 2 percent of the building stock is renewed each year (see e.g. Heljo et al. 2005). Large-scale investments in rail traffic are rare and costly, and a new master plan is devised in Helsinki as seldom as in every ten years or more. Nonetheless, spatial planning has several concrete means of affecting the city's greenhouse gas emissions. The impact can be either direct or indirect. At the master plan level, the latter is typically accentuated.

The impact on the emissions from transport is fairly straightforward mostly through modal changes but also changes in the need for transportation. In terms of emissions from other energy consumption, energy production, and construction, for example, the role of the master plan is first and foremost enabling. In addition, the new Helsinki City Plan is an important example of the big picture of urban development, and as such affects indirectly, but in all likelihood very strongly, the greenhouse gas emissions of the city.

In spatial planning long-term decisions can be made so that it is even possible to curb the emissions in the first place. On the other hand, decision-making may lead to a policy failure, so called carbon lock-in, which creates macro-level barriers to the diffusion of emission-saving technologies and practices (Unruh 2000).

Helsinki City Planning Department has collected master plan level actions to reduce emissions (Helsinki 2013d):

- Preventing resolutions that may hinder the emission reductions
- Ensuring adequate area efficiency
- Condensing and complementing the urban structure
- Determination of the physical boundaries of the city
- Sustainable design and allocation of services
- Introduction of public transport early enough
- Supporting renewable energy production
- Improving cycling and walking conditions

- Goal-orientated planning of parking
- Preferring construction that lowers the energy consumption and the greenhouse gas emissions
- Enabling regional or local energy renovations

In IPCC’s report ‘Climate Change 2014: Mitigation of Climate Change’ (2014b) a number of spatial planning strategies and policy instruments are identified, all of which are in line with the findings of Helsinki (2013d) listed above. *Urban containment* was already discussed in the previous section. *Balanced growth* emphasizes the co-location of homes and work places. The jobs-housing balance has been shown to reduce traffic congestion, emissions, and related externalities although there are many factors affecting the choice of residential location (IPCC 2014b, 958-959).

Urban regeneration, e.g. brownfield[7] redevelopments, and *infill development* are also on the agenda in Helsinki, and they will gain more ground with the new master plan (see chapter 2.3). Also, *transit oriented developments, TODs,* are found important in the Helsinki Metropolitan Area (see e.g. Helsinki 2013e; HSY 2015c). Besides face-lifting of stations and their surroundings, TOD can also refer to integrated planning of transportation system, housing and services, represented for example by the new master plan of Helsinki (see chapter 2.3).

Other planning principles that may reduce urban form-related GHG emissions are *new urbanism* complemented with *pedestrian zones* or *car-restricted districts* (IPCC 2014b, 960-961). New urbanism refers to compact cities that draw people together creating urban culture and a sense of community. This can be supported by planning that takes on features of traditional, pre-automobile neighbourhoods. Hass-Klau (1993) has observed that pedestrianisation and traffic-calming[8]

---

[7] an industrial or commercial site that is idle or underused, often because of environmental pollution

[8] slowing down traffic with speed humps, realigned roads, necked down intersections along with trees or other vegetation in the middle of streets

measures increase pedestrian flows, transit ridership, land values, retail transactions, and more intensive land uses, along with fewer traffic accidents.

Climate change mitigation oriented urban planning strategies lean on an array of policy instruments and levers, the effectiveness of which depends on the prevailing legal and political environment. The instruments include density regulations, sprawl-controlling instruments such as greenbelts or urban growth boundaries, affordable housing mandates affecting the jobs-housing balance, building codes regulating energy efficiency and building materials, parking standards and design regulations that can promote green roofs, walking, cycling or reduce urban heat island effect and impervious surfaces. (IPCC 2014b, 962-963)

The most of direct urban greenhouse gas emissions are from energy use in buildings and in transport. In Helsinki, for example, that share is as much as 97 percent (HSY2015a). A thorough example of taking energy efficiency, and thereby the mitigation of climate change, into consideration in the urban planning process is Skaftkärr in Porvoo where a specific *energy plan* was devised in a stakeholder project. The main conclusion was that the energy efficiency of districts can be significantly affected by spatial planning (Rajala et al 2010).

The planning of the Skaftkärr area aimed at small carbon footprint and sustainable construction solutions promoting energy efficiency. One finding was that already in the planning phase of the area, the most suitable and efficient low-emission methods of energy production should be explored. Also transportation systems and mobility, energy usage and building-specific energy solutions proved essential for low carbon urban form. Carbon balance assessments were found important, and according to Rajala et al. (2010) they should be generally incorporated in the planning process.

Besides the energy-related greenhouse gas emissions, the land conservation and carbon sequestering aspects of planning as well as the urban metabolism, e.g. choosing and recycling of building materials, should be considered. Moreover, urban planning plays a key role on the adaptation side of responding to the challenge of global warming (Wamsler et al. 2013).

2.3 Helsinki City Plan 2016

The master plan is a long-term plan of land-use and zoning that guides the detailed planning and other more specific planning. The master plan’s implications stretch over decades to come, particularly on how it steers the evolution of urban structure. The building of infrastructure, construction of buildings and other developments also need years to implement, so strategic and coordinated long-range planning is crucial.

The process ultimately leading to the city council’s approval of the new master plan of Helsinki, the City Plan, in 2016 started in the end of 2012. With the various steps of the planning process, the drafts, proposals, workshops, public discussions and political processes, the procedure clearly answers to the call for coordinated and strategic approach. The first draft of the City Plan was completed at the end of 2014. The scenarios presented in this thesis are based on the draft version and the associated material of the plan (see chapter 3.3.). The whole planning process is presented in Table 1.

Table 1. The process flow of the City Plan (Helsinki 2015a).

YEAR	OBJECTIVE	RELATED DOCUMENTS (Helsinki 2015b)	EVENTS AND DECISION MAKING
2012	Starting points and working programme	Supplementary material	Participation and assessment scheme
2013	Vision 2050	Annexes to the vision	Theme seminars and public GIS survey
2014	Plan draft, map presentation, plan commentary	Impact assessments, land use reviews and	Planning workshops

		reports, thematic vision maps	
2015	Publication of the draft	Impact assessments	Evaluation workshops, discussion events
	Plan proposal, map presentation, plan commentary	Thematic maps	City Planning Committee proceedings
2016	Revised proposal		City board and city council proceedings

The City Plan consists of a map presentation guiding the detailed planning up to the year 2035, an implementation program, and a strategic vision of the future state of Helsinki up to the year 2050 (Helsinki 2015a). According to the vision 2050 Helsinki will be a rapidly growing city with a highly efficient rail transport network. Commuter trains, metro, and light rail network offer fast connections between the expanding central areas and other parts of Helsinki. Urban density is intended in the developing centres, and along the transverse traffic routes and current entrance highways. Changes in mobility are desired. The vision (Helsinki 2013c) declares that

> *Urban spaces will be designed on terms that suit pedestrians, not vehicular traffic.*

The starting point for the City Plan has been a population forecast suggesting that there will be about 860 000 inhabitants in Helsinki in 2050. The intensive growth requires new plan reserve and thorough densification of the city structure. Previous master plan 2002 was largely based on project areas freed from the harbour. This plan reserve is currently running out, and there are few opportunities left for new developments, in effect only for supplementary construction.

Other figures determining the scope of the new City Plan are the target of almost 200 000 more jobs and as much as 23 million square meters of new floor area by the year 2050. Helsinki provides for the continuing trend of fast growth. In reality, however, the master plan steers the detailed planning, and creates chances for construction, for the next 15 years or until a new master plan is once again prepared (Helsinki 2015a). The long term projections are subject to change. For instance the maximum amount of new construction that the City Plan allows for may be revised. In the year 2050 there may be more or less new floor area than the currently envisioned 23 million square meters.

The vision 2050 narrative is composed of seven themes, all characterised by dense centres and sub-centres, mix of services and functions, public transport, and quality of life. According to the theme *Urban metropolis* there will be vibrant public spaces and more encounters between people. *Appealing living options* aims at varied styles of living co-existing in the city. *City of economic growth and jobs* emphasises the attractiveness, productivity and competitiveness of Helsinki. *Sustainable mobility* is principally based on walking, cycling and public transport. *Recreation, urban nature and cultural environment* suggests that the diversity of recreational areas and urban nature are essential appeal factors for Helsinki. In 2050, *Helsinki's seaside areas* form an active part of the city, and they can be easily reached by city residents. Finally, Helsinki is *international* and *part of the region*. The densely built, easy-to-reach, premium-quality urban environment attracts international companies and tourists alike. (Helsinki 2013c)

After the remarkable work on the vision 2050, the Helsinki City Planning Department published the more tangible draft version of the new City Plan, targeted at the year 2035. The draft was followed by the further processed plan proposal (Helsinki 2015c) that was presented to the City Planning Committee in October 2015.

The themes and ideas presented in the vision 2050 have been filtered and refined into the plan proposal's main map, the plan commentary report, and the supporting, legally non-relevant thematic maps[9]. The basic principles have remained the same. Land use and transport are tailored more tightly together in the new City Plan, with special emphasis on walking and cycling, and reachability by public transport, primarily by rail. The suburban station areas are turned into urban centres, and land use efficiency is increased in the current motorway-like surroundings. The preconditions for business as well as the network of green spaces are secured. (Helsinki 2015c)

In the new City Plan the reserve for housing is a bit larger than the population projection up to the year 2050 suggests. The plan should ensure sufficient supply of new homes keeping both housing prices and the labour costs reasonable. Not all zones reserved are, however, strategic ally prioritised. A central idea related to housing is that it can be combined with other activities. The plan notation ‘housing-intensive area’ depicts the objective of mixed-use urban areas. New office areas are not introduced in the plan proposal. (Helsinki 2015c)

The master plan is in general *strategic* by nature. The main map (Helsinki 2015d) is presented as a grid of 100 x 100 meter squares and only the primary purpose of use is indicated. Other regulations are verbal. Precise zoning, or for example the division into areas of apartment houses and detached houses, is no longer shown. Instead the plan defines the key priority areas of Helsinki’s future development. For housing-intensive areas also the different targets for block density are included in the plan regulations. The key policy instrument of the new City Plan is specifically *sizing* which enables accurate impact assessments and projections of future population and work places. Thus efficient planning of services and scheduling of transport investments is possible, and overall the city can be developed in a goal-oriented manner. (Helsinki 2015c)

---

[9] The Natura 2000 and other nature conservation areas in the *Urban Nature* map and the nationally significant landscape and cultural environments in the *Cultural Environments* map must be considered legally relevant (Helsinki 2015c). Other thematic maps of the plan proposal are *Recreational and Green Network, Public Transport Main Trunk, Road-, Street- and Cycle Lane Network, Seaside Helsinki, Technical Community Management* and *Inner City* (Helsinki 2015b).

2.3.1 Impact assessments of the City Plan

According to the Land Use and Building Act (Finlex 1999a) and Decree (Finlex 1999b) land use plan’s significant direct and indirect impacts on

- people’s living conditions and environment,
- soil and bedrock, water, air and climate,
- plants and animals, biodiversity and natural resources,
- regional and community structure, community and energy economy and traffic and
- townscape, landscape, cultural heritage and the built environment

must be investigated. Assessing the diverse effects that implementing a master plan in a city the size of Helsinki may have is a time-consuming effort. Therefore the impact assessment of Helsinki’s new City Plan was initiated already early on, hand in hand with the planning process. The majority of the work, including climate impact assessment, was done in the draft phase of the City Plan, based on the fast growth population projection, the key priority areas of the plan’s vision 2050 and the intended changes in land use. The assessments were complemented in the proposal phase. (Helsinki 2015c)

In total eleven separate assessment reports are annexed to the proposal, including Natura-assessment and impacts on nature, the city boulevards, reachability by rail, climate change as well as commercial, economic and social impacts (Helsinki 2015b). These reports, and the assessment work done with the preparation of the plan are summed up in the plan proposal.

The impacts of implementing the new City Plan of Helsinki can be concluded as follows (Helsinki 2015c, 144). The City Plan

- creates conditions for adequate supply of housing,
- densifies and defragments the urban structure of Helsinki,
- creates conditions for a rail network city and improves the reachability by public transport,
- enables the expanding of the inner city,

- enables the preconditions for business throughout the city area,
- increases the productivity of private and public sector in the future, based on high density of population and jobs,
- enables supplementary construction throughout the city
- creates conditions for maintaining the services in the current suburbs through potential supplementary construction
- enables diverse housing stock in Helsinki
- increases the urban living environment
- enables the service network development by addressing new urban centres
- enables the increase of walking and cycling
- maintains the green network city
- creates conditions for developing the seaside Helsinki
- preserves the nature conservation areas and important natural values and improves connectivity
- enables the preservation and the development of valuable cultural environments and
- enables the appropriate development of technical community management, the consideration of soil and bedrock constructability, and the prevention of harmful environmental health effects in the planning phases subsequent to the master plan.

The impacts of the master plan on climate have previously not been investigated to this extent. During the last master planning process merely the effects on the city’s greenhouse gas emissions were estimated (Helsinki 2002). With the new City Plan a similar, but a more comprehensive exercise was carried out, as presented in the chapters 3-6 of this thesis. Besides the Climate Swing scenario analyses, several other applicable methods for assessing the climate impacts were used. The different approaches were partly due to the multidimensional nature of the subject of evaluation, and also because there is not yet an established procedure for such an impact assessment of a master plan (Helsinki 2014a).

The City Plan’s impacts on the traffic volumes, passenger mileages, and the related emissions of Helsinki have been examined in the national Keko B -project, which aims at developing a methodology for assessing the eco-efficiency of planning (see SYKE 2015a). The methodology has been piloted with the draft of the new City Plan. The traffic assessment was based on the zoning analysis by the Finnish Environment Institute, where the urban structure is divided into pedestrian, public transport and car zones based on the location, and the public transport service level (see SYKE 2015b). The current zones of mobility were compared to those of 2050, allowed by the City Plan.

The key finding of the study was that in 2050 clearly a larger share of the city's residents would live in the 'intense public transport' zone due to the densification of the station areas and the conversion of motorways into boulevards. The 'car zone' diminishes substantially. In terms of greenhouse gas emissions per capita there would not be significant changes because a smaller share of the population would also reside in the inner city, the area of the lowest emissions. However, it is noteworthy that by enabling sizable population growth in Helsinki, the greenhouse gas emissions from transport at a *regional* level can be reduced. (Helsinki 2014a)

Locating a quarter of a million new inhabitants within the borders of Helsinki can be regarded as an enormous construction project causing ample emissions. The issue is therefore considered also in the climate impact assessment of the City Plan. The construction phase creates a strong peak in the life-cycle emissions of buildings (Säynäjoki et al. 2012). This could be avoided only by restricting construction in the first place, which is not relevant in the context of the new City Plan and the related emission assessments. Looking at the consumption-based, scope 3 emissions (see chapter 2.2.1) from construction, the focus should be on the building materials. However, the City Plan proposal does not include regulations regarding e.g. timber construction. It does reduce emissions from construction of new *infrastructure* by allowing a dense urban structure. (Helsinki 2014a)

The implementation of the City Plan implies that some of the green spaces in Helsinki are converted into built-up environments, affecting the carbon absorption capacity of the city. The urban forests are especially important in this regard. The outgoing carbon sinks, according to the City Plan draft, were estimated in the Keko B -project (SYKE 2015a). The results show that the suggested land use changes would reduce the amount of urban forests by 39 percent, equivalent to around 400 thousand tonnes of carbon (Helsinki 2014a; see also ILKKA 2014). The figures include also the Östersundom area which is subject to a separate master planning process together with the cities of Vantaa and Sipoo (see Östersundom 2015). The City Plan's impact on the carbon storage is therefore somewhat smaller, mainly because Östersundom has little existing infrastructure, and the planned changes there are substantial. It is also argued in the climate impact assessment report (Helsinki 2014a, 14), annexed to the plan proposal, that

> *…presumably the urban sprawl taking place more widely in the region would be more damaging with respect to carbon sinks, than building equivalent new floor space in the core area of the region.*

The Land Use and Building Act (Finlex 1999a) obliges that the National Land Use Guidelines must be taken into account and forwarded also in the municipal planning. Related to the quality of the living environment and the urban structure, the guidelines stress that land use planning should create conditions for adaptation to climate change (ME 2008). Adaptation is recognized in the City Plan but it is not covered in the impact assessments as a whole. It is simply stated in the plan proposal that the environmental hazards are recognized and efforts are made to prevent their impacts (Helsinki 2015c, 184). In addition, it is written in the plan regulations (Helsinki 2015d) that

> *Preparing for floods must be taken into account when planning near the sea or by the waterways. Stormwater management should be allowed for in the planning process and a stormwater management plan must be drawn up when significant land use changes are expected.*

The City Plan proposal's annex report on technical and economic planning (Helsinki 2015e) summarizes all the reports providing foundation for preparing for floods in the detailed planning after the master planning process. These include the city's flood strategies, reports on flood risks and management plans.

For example the guide for flood preparedness in construction (SYKE 2014) suggests that the lowest recommended elevation for seaside construction in Helsinki is 280 centimeters above the sea level.

3 RESEARCH QUESTIONS, METHODOLOGY AND DATA

This chapter outlines the thesis' research questions, how the study was conducted and what kind of research material was used.

3.1 Research questions

The main objective of this thesis is to find out how accomplished Helsinki is to respond to the massive challenge of climate change mitigation. In order to limit global warming below two degrees, and therefore withstand the inevitable impacts of climate change, the global greenhouse gas emissions should be decreased to almost zero level by the end of the century. The widespread view is that the developed western countries should lead the way in the mitigation efforts.

Cities are important players in the context of global warming. They are a big part of the problem but, as discussed in chapter 2.1, they must also be the solution. Helsinki represents the global urbanisation megatrend on its own scale. According to the new City Plan, Helsinki grows extensively in the coming decades. Currently the city is on a good track in terms of greenhouse gas emissions, but will the trend continue? What are the future emissions of the growing city, and will the city's climate targets be met?

The main research question of this thesis is:

- How large are Helsinki's greenhouse gas emissions in 2035 and 2050 when the new city plan is fully implemented?

Secondly, the study answers to the following questions that are related to the main research question:

- How do the future emissions of Helsinki comply with the emission reduction targets of city?
- What are the roles of city planning, energy production and other measures in terms of emissions?

Thirdly, the thesis discusses the usability of the Climate Swing scenario tool in the context of urban planning:

- What are the strengths and weaknesses of Climate Swing as a tool for master plan emission assessments?

3.2 Methodology

According to Michael Lee (2012) the future can be studied and understood as systematically as the past. Today humanity has such an accumulated, multidisciplinary bank of knowledge at its disposal that the future can be explored systematically. The sufficient understanding of time and history, systems, the causal factors, and the universal laws and principles provides the means for developing plausible forecasts. Lee (2012, 3) further argues that

> *Understanding the future would better prepare individuals, organisations and societies to face relentless forces of change. It would reverse stagnation in social, political and economic development arising from uncertainty of the future.*

This is especially true in the case of global warming. Humankind is undoubtedly not properly prepared for the impacts of climate change and, on the other hand, much more effective policy measures should be taken in order to curb the emissions to sustainable levels. Simple trend analyses would not paint an accurate enough portrait of the future because of the fast-changing political, technological and economic conditions in the field of climate change mitigation. Such extrapolations appear more objective than they actually are. (Gordon 2003, 3). The selection of a period for analysis, for example, can have significant impact on correct recognition of the trend. Therefore, it is justified to use scenario analysis for assessing the climate impacts of Helsinki’s new City Plan.

A scenario is a fuzzy concept with many different definitions by various authors. Dictionary definition of a scenario is *a sequence of events especially when* *imagined*, and *an account or synopsis of a possible course of action or event*[10]. Alcamo & Henrichs (2009, 15) propose the following definition:

> *A scenario is a description of how the future may unfold based on 'if-then' propositions and typically consists of a representation of an initial situation and a description of the key driving forces and changes that lead to a particular future state.*

Kosow & Gaßner conclude respectively that a scenario is a description of a possible future situation including the paths of development which may lead to that situation (2008, 11).

Scenario analysis is a broader concept, a procedure that covers the development of scenarios, comparison of scenario results and evaluation of their consequences (Alcamo & Henrichs 2009, 16). Key idea is to consciously present several alternative future developments and not rely on historical data.

Scenario analyses can be developed for a range of different purposes. Firstly, scenarios have a knowledge and communication function as they serve to deepen the existing understanding of contemporary developments and conditions. (Kosow & Gaßner 2008). They are powerful tools to think through our key considerations and assumptions, explore possibilities, and challenge conventional thinking (Greeuw et al 2000, 9). Secondly, scenarios may have a goal-setting, decision-making and strategy formation function. With the help of scenario analysis, it is possible to work out the actions to be taken, and evaluate decision-making processes. In this way, the scenarios serve to test the reliability and effectiveness of policies (Kosow & Gaßner 2008).The Helsinki City Plan's climate impact assessment of this thesis pursues to achieve both of these goals.

An intriguing aspect of this scenario exercise is that the City Plan can itself be seen as a scenario. Particularly the plan's 2050 is a goal-oriented, conceptual future of Helsinki (Helsinki 2013c). By nature it is a *narrative* scenario with more

---

[10] See e.g. http://www.merriam-webster.com/dictionary/scenario

qualitative than quantitative features. It is also *normative*, as it highlights the plan’s underlying values, predictions and strategic guidelines[11].

As a response to the narrative of the City Plan, the emission scenarios of this study are characteristically quantitative and based on a mathematical model, the Climate Swing scenario tool. According to Kemp-Benedict (2004) there is a growing concern that mathematical models are limiting in future studies. However, robust scenarios can be constructed if a formal quantitative model is combined with a profound narrative. Such an integrated approach is fundamental also for this thesis.

It is advised not to develop too many different storylines within a certain scenario process. Practical experience has shown that a maximum of 4 or 5 scenarios can be processed cognitively and thus interpreted (Kosow & Gaßner 2008, 28). This study includes one reference scenario called “More people” (MP) and two policy scenarios called “Less emissions” (LE) and “City plan” (C). The policy scenarios are further modified with a plus-option so that the total number of scenarios in this study is 5.

3.2.1 Climate Swing scenario tool

The Climate Swing is Helsinki Region Environmental Services’ (HSY) online application that allows user to explore strategies for mitigating climate change. The tool can be used to calculate and compare the impacts of various mitigation measures, or alternatively the user can construct a comprehensive greenhouse gas emission scenario for the city including all the emissions from electricity, heating of buildings and transport. The service also provides information on how emissions are split between residential, services and industry sectors. (HSY 2015b)

The Climate Swing has around 70 different variables (see appendix 2) starting from the scenario’s target year and the population growth, and through numerous

---

[11] See e.g. Kosow, H. & Gaßner, R. 2008, 31

energy-related parameters reaching residents’ travelling habits and the amount of biofuels. The user can consider, for example, how the district heating is produced, what size of homes do we have in the future, and what is the role of electric cars in the scenario. The adjustments of the variables can be directly seen in the emission results.

Methodologically, the Climate Swing can be used to create both explorative and normative scenarios. Explorative scenarios are valuable in identifying possible developments, obstacles, opportunities, and relationships between factors whereas a normative scenario is a goal-oriented, desired image of the future (Slocum-Bradley & van Langenhove 2011, 311). Overall the tool provides a new way of communication, i. e. a systemic, yet sectoral approach to climate change mitigation at regional or at city level. Moreover, it serves the decision-making function of scenarios as well (see chapter 3.2; Kosow & Gaßner 2008).

The mathematical model of the Climate Swing is based on the annual greenhouse gas emission assessment carried out by HSY. The calculations focus on direct greenhouse gas emissions from heating of buildings and transport within a city as well as emissions from electricity consumption. Heating has been further divided into district heating, electric heating, and other separate heating methods. Transport comprises of cars, ships and boats, local trains, metro and trams. Emissions from waste and wastewater treatment, agriculture, and industry and machinery’s fuel consumption are excluded from the online service. However, they are included in the scenarios of this report by means of simple trend extrapolation (see chapter 3.3.1.6).

HSY’s greenhouse gas emissions calculation method is based on the Association of Finnish Local and Regional Authorities’ and Finnish Environment Institute’s greenhouse gas and energy balance model Kasvener (Petäjä 2007), the results of which have been further adjusted with regard to emissions from electricity consumption and heating of buildings. The greenhouse gas emissions from combined heat and power production are calculated with benefit distribution method which favours cogeneration’s both energy products. The emissions are allocated to heat and electricity in proportion to fuel consumption of their alternative, separate production methods (see e.g. Siitonen & Holmberg 2010).

The emissions from electricity consumption, excluding electric heating, are calculated on the basis of a national emission factor. The factor is derived by dividing the total emissions generated by electricity production in Finland with total consumption (excluding emissions and consumption of electric heating). In order to balance out the annual fluctuations in emissions from electricity production, a five-year average of the emission factor is used in the calculations. Emissions from electric heating are calculated with a higher emission factor.

The impact of annual temperature fluctuations due to weather is reduced by using a heating demand correcting factor when calculating emissions from electric heating, separate heating, and district heating. The Finnish Meteorological Institute calculates annual heating degree day values for a number of locations (FMI 2015). The average value for Helsinki in 1971-2000, 3986, is used as a benchmark. In 2012 the figure was 3796, meaning that the heating demand for that year was lower than average. For district heating, a correcting factor is calculated in accordance with the Motiva guidelines (Motiva 2015), while standardised consumption levels for electric and oil-powered heating as well as ground.source heat pumps are generated based on default values.

The emission scenarios focus on energy-based greenhouse gas emissions within a city. The emissions from private and public spending, generated outside the city boundaries, are excluded from the calculations. Bio fuels, including the bio part of waste, are calculated as a zero carbon fuels.

In the Climate Swing, the greenhouse gas emissions for the target year are derived from the baseline emissions using the variables chosen by the user. Table 2 describes the course of the calculations, using district heating as an example.

Table 2. The Climate Swing calculation methodology. The course of the calculations, using district heating as an example.

The course of calculations; district heating	Initial data, variables, results	Data sources, calculations
Baseline	Initial data: - Consumption of district heat - Fuel-mix of the production - GHG emissions of district heating, calculated with benefit sharing method	Data source: HSY’s annual GHG monitoring
Target year	Variables: - Population - Number of jobs - Space efficiency of homes and premises - Change in energy efficiency - Share of district heating of the heating methods	Data source: user defines

	Results: the new consumption of district heating	Calculations: the change in consumption based on the user’s choices
		↓
	Variables: - New fuel-mix - Carbon capture and storage	Data source: user defines
		↓
	Results: the new GHG emissions of district heating	Calculations: the change in emissions based on the user’s choices, and the new consumption

The online service of Climate Swing proved to have some limitations for the purposes of this thesis. Therefore, a spreadsheet version of the tool was used for devising the emissions scenarios and analysing the impacts of different factors. The tool’s suitability for assessing the climate impacts of a master plan is evaluated in chapter 5.1. The default values that the scenario tool uses, and the user-definable variables are listed in appendices 1 and 2.

3.3 Research data

An essential part of the scenario development is the identification of key factors, i.e. those central factors that form a description of the scenario field and at the same time have an impact on the field itself (Kosow & Gaßner 2008, 26-27). Regarding the emission scenarios of this thesis, there are a number of underlying general trends and assumptions based on the goals and the related material of the master plan itself, as well as expert reviews and literary sources described in the previous chapter. A lot of those variables, parameters, developments and events have been recognized and analysed in previous scenario exercises in Helsinki.

To start with, major qualitative scenario work has been done in connection with the new City Plan development process. Besides the narrative framework, some crucial numerical data has been received from that exercise. These target values for population, jobs and floor area express the strong growth trend of Helsinki.

Important source of data was also the Helsinki 30 % emission reduction study conducted by Gaia Consulting and Finnish Environment Institute (Helsinki 2014b). This analysis was first of its kind to utilize the Climate Swing scenario tool. The target year for the emission reductions was 2020, but most of the assumptions were relevant and could be exploited in this report's scenarios up to 2035 and 2050. In many occasions the parameters were maintained at the same level as in the scenario baseline year of 2012, if uniform estimates of the future changes affecting the greenhouse gas emissions could not be identified.

Besides the two vital data sources, energy-related values and trends were gathered from the Ministry of Employment and the Economy's Energy and climate strategy 2013 update (MEE 2013), International Energy Agency's Nordic Energy Technology Perspectives -scenario report (IEA 2013), and Helen's environmental impact assessment report on increasing the use of bio fuels in the energy production of Helsinki (Helen 2014).

The cornerstone of the emission scenarios is nonetheless the annual greenhouse gas inventories of the cities of the Helsinki Metropolitan Area, and the related initial data, compiled and calculated by Helsinki Region Environmental Services (HSY 2015a).

The basic assumptions collected from the above-mentioned data sources, common to all emission scenarios of this report, are presented in the next chapter. Besides these general trends, the scenario-specific parameters are introduced with each scenario in chapter 4.

3.3.1 Growth trends and general assumptions

In all emissions scenarios featured in this study the following assumptions are valid:

- ► Population growth +260 000
- ► Jobs +190 000
- ► New floor area (not more than) +23 million square meters
- ► District heating remains as the primary heating method with a share of 86 % of building floor area
- ► Electricity consumption will grow in proportion to the population and jobs
- ► Global warming decreases the heating energy demand by 9 %
- ► Commercial van traffic grows with the population until 2035 but not thereafter
- ► Heavy-duty truck traffic and shipping stay at current levels
- ► The emissions from industry fuel use and machinery, waste treatment and agriculture will decline according to the current development

Chapter 4 presents emissions scenarios up to the year 2050, which all contain these general assumptions. The variables in the development paths are mobility changes and traffic volumes, vehicle technology development and biofuels, energy efficiency of buildings, district heating fuel mix, heating methods outside the district heating network, Finnish electricity supply, and on-site electricity production. In the following sections the common assumptions are addressed in detail.

3.3.1.1 Population growth

The number of inhabitants in Helsinki has grown fairly steadily. After the more stable period in the early 2000s the annual growth has been well over one percent.

There are mixed reviews about the future development. The objectives of the new City Plan are based on rapid growth forecast, in which the population will increase with almost 160 000 by the year 2035. In 2050, the city is home to nearly 260 000 people more than now (Figure 7).

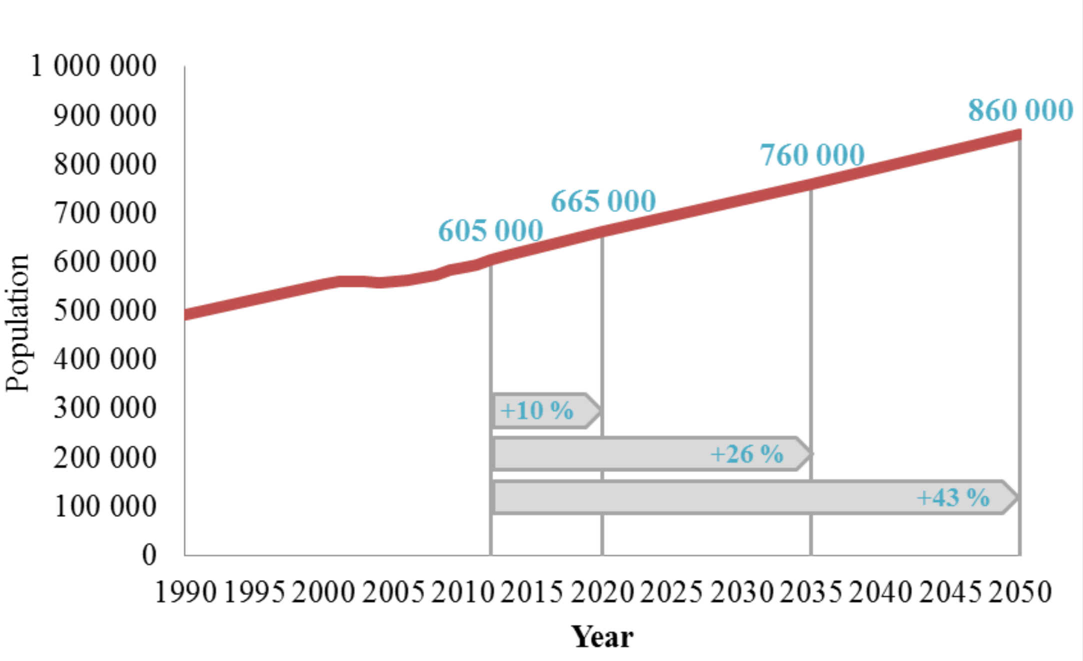

Figure 7. The number of inhabitants in Helsinki in 1990 and 2000–2013 (VRK 2014), population forecast 2020 (Helsinki 2013b) and the 2035 and 2050 objectives of the City Plan. The percentages indicate the change compared to 2012.

In principle, the population growth increases the greenhouse gas emissions. New inhabitants need housing that consumes heat and electricity, and the use of public and private transport is increased.

3.3.1.2 Jobs

The number of jobs, together with the population, indicates the city growth. In the emission studies the workplaces have an effect on the electricity consumption of services, public sector, and industry as well as the floor area of other than residential buildings. The City Plan contains a substantial amount of new office construction. The number of jobs in Helsinki is estimated to increase with over 100 000 by 2035, and with almost 200 000 by 2050 (Figure 8).

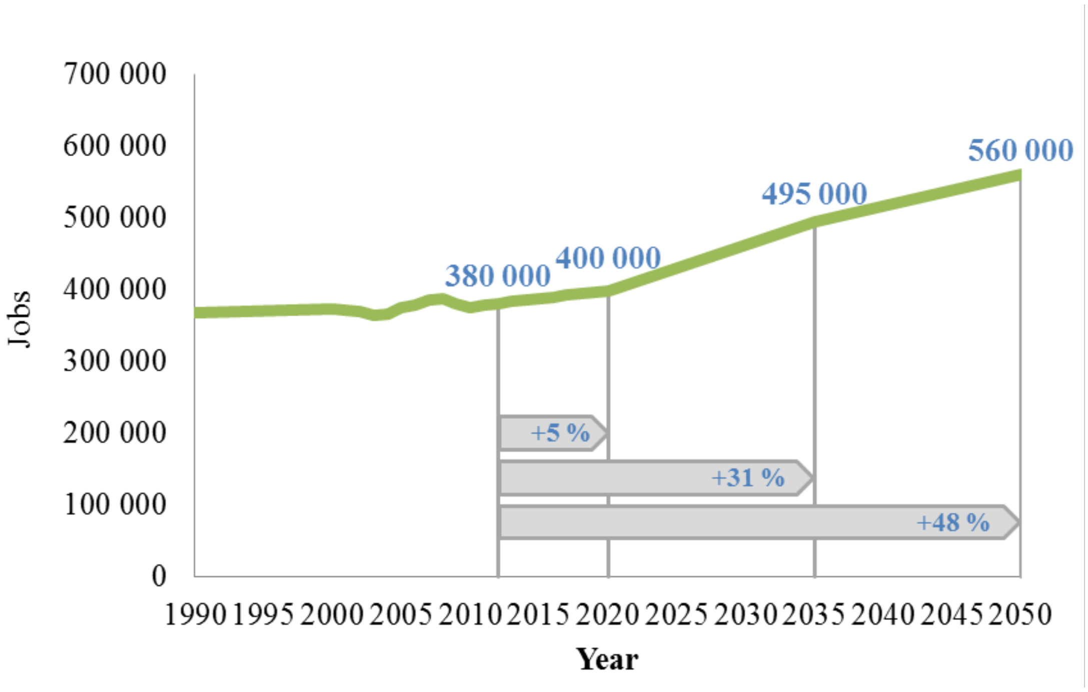

Figure 8. The number of jobs in Helsinki in 1990 and 2000–2009 (Aluesarjat 2014), the rapid growth forecast to 2020 (Kaupunkitutkimus 2014) and the City Plan objectives 2035 and 2050. The percentages indicate the change compared to 2012.

Besides the total amount of jobs, the emissions are affected by the sectoral split between services and industry. Workplaces in the industry sector demand substantially more floor area. Industry’s share of all jobs in Helsinki was 5.5 percent in 2012. It is expected to be less than 5 percent by 2020, and according to the current trend to drop further to only 2.2 percent by 2050 (Figure 9).

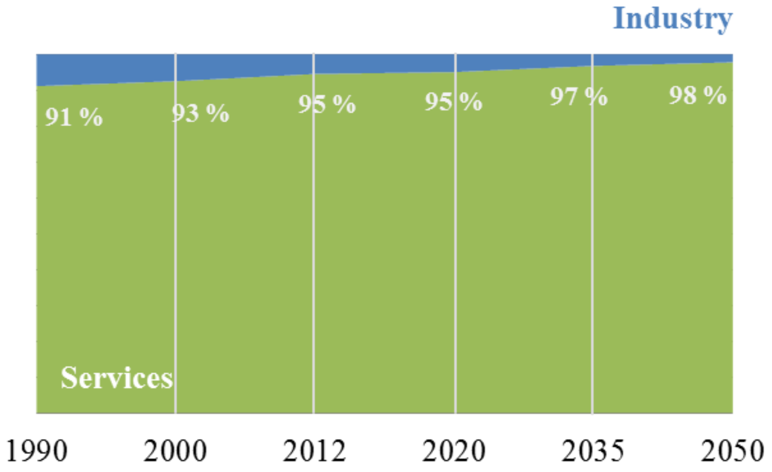

Figure 9. Services and public sector share of jobs in Helsinki. The figures from 1990 and 2000 are statistical information (Aluesarjat 2014). 2012 and 2020 are based on the employment projections in Uusimaa and Helsinki region (Kaupunkitutkimus 2014). The shares in 2035 and 2050 are derived from actual development and from the forecast up to the year 2020.

3.3.1.3 The increase of the floor area

The starting point of the new Helsinki master plan is a rapidly growing city. Extensive zoning of new housing and services allows for new residents moving to Helsinki and contribute to job creation. The growth of floor area directly increases the energy consumption of the city and thereby also the greenhouse gas emissions, if changes in the energy efficiency of buildings are not taking place. On the other hand, building a dense city with a high-quality energy economy prevents urban sprawl and can indirectly reduce emissions elsewhere in the country. In this study, however, the emissions calculations are limited to the direct emissions within the city borders.

The master plan enables several million square meters of new construction. At maximum, the plan prepares for a growth of over 17 million square meters of new residential floor area. Also new office premises significantly complement the city, by 2050 with up to 5 million square meters (Figure 10). Some of the provisions in the city plan are left out in the detailed planning phase, so the plan is intentionally somewhat oversized set against the population growth forecasts.

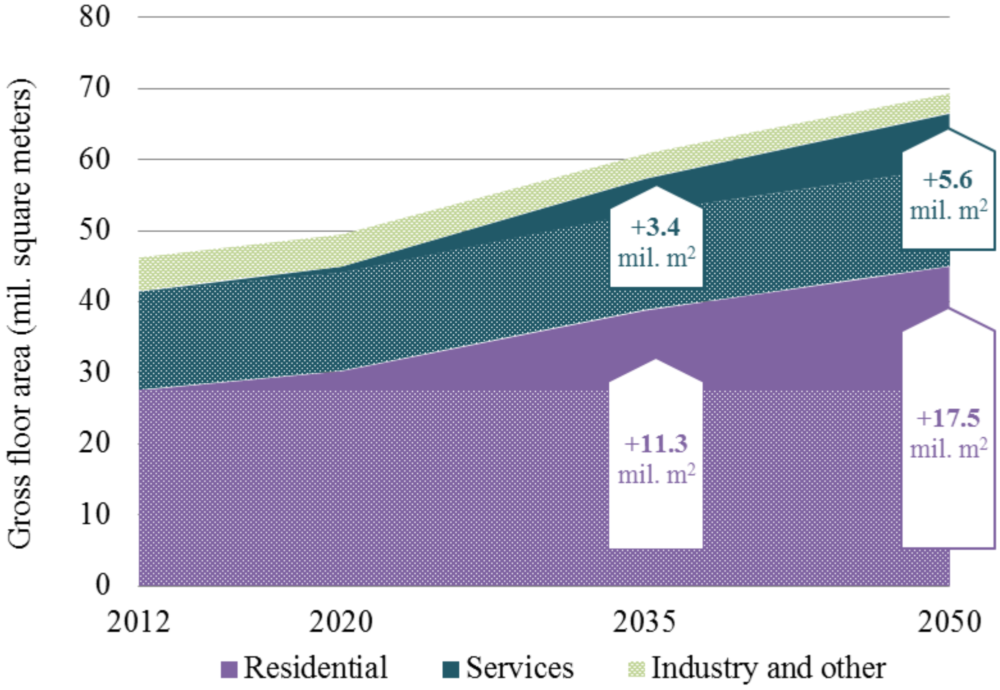

Figure 10. The increase of the housing and office floor area from 2012 onwards conforming to the city plan objectives. The lighter colours illustrate the existing building stock. The figures refer to the maximum amounts of new floor area enabled by the plan. Industrial premises are projected to slightly decrease.

Besides the growth trends of population and jobs, average living space per person and space efficiency are essential factors contributing to the amount of floor area. Counted as total square meters including stairways, walls etc., the mean living space of a Helsinki resident was 41.7 m^2 in 1990 and 45,5 m^2 in 2012 (Tilastokeskus 2014a). A variety of different views on the future development has been presented. Calculated from the City Plan’s maximum floor areas for 2035 and 2050, and the population growth projections, the average living space per person seems to increase and the space efficiency of office premises remain unchanged (Table 3). However, these are neither forecasts nor targets of the city plan, but theoretical values used in the emissions scenarios in this report.

Table 3. The theoretical living space per person and space efficiency of premises used in the emissions calculations (total m^2/capita/job). N.B. the figures are based on the maximum growth of floor area and they are not target values of the city plan.

m^2	2012	2035	2050
Residential	45.5	51.0	52.1
Services	38.9	38.7	39.2
Industry	223.2	223.2	223.2

3.3.1.4 Heating methods and energy consumption

The predominant way of heating buildings in Helsinki is district heating. In 2012 its share of heating methods was 86 percent in the residential building stock and even more in the services sector. The general assumption in the emission analyses of the City Plan is that the relative share of district heating remains unchanged in all scenarios.

For electricity consumption a conservative estimate has been used, according to which the specific electricity consumption per person in residential buildings and per job in services, public sector, and industrial buildings remains the same, i.e. at the 2012 level. The number of electrical appliances is likely to increase, but on the other hand their energy efficiency will improve. Altogether, the total electricity consumption in Helsinki will increase in proportion to population and the number of jobs.

Global warming has a considerable effect on the heating energy demand of buildings. The average global temperature has already risen by 0.85 degrees in just over one hundred years, and the warming is expected to continue (IPCC 2014). If climate change mitigation advances significantly, and the fossil fuels are phased out completely, the global warming may be limited to +2 degrees Celsius.

The forecast for heating demand used in this report is roughly equivalent to the kind of positive development mentioned above, where climate change does not further accelerate from the recent trend of global warming. The change of heating demand has been calculated by the Finnish Meteorological Institute based on the heating degree days from the year 1971 (Figure 11). The reduction of heating energy consumption caused by climate change is significant, by 2050 nearly 9 percent, even with the current development.

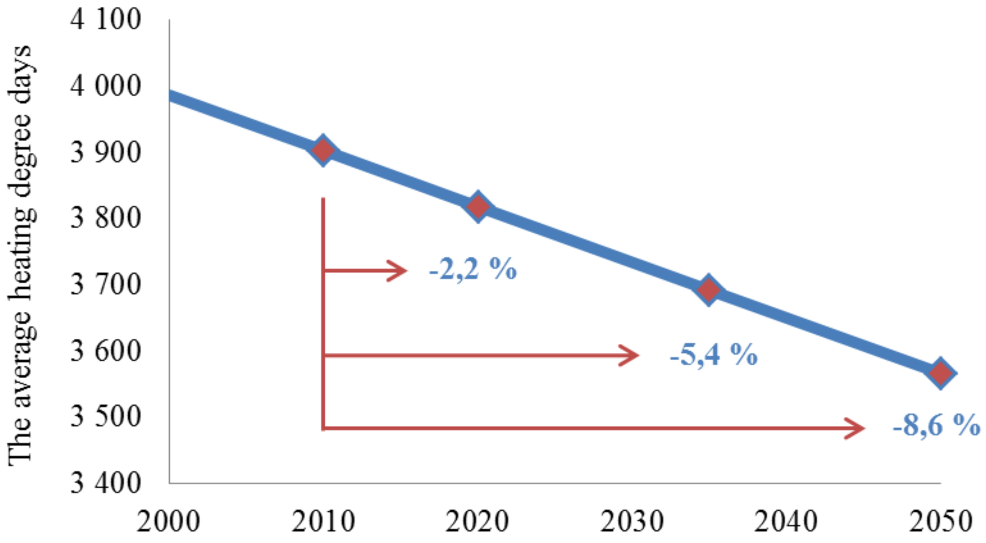

Figure 11. Climate-change-induced change in heating demand in Helsinki. The average heating degree days were 3986 during the normal period 1971–2000 and 3902 in 1981–2010 respectively (Ilmatieteen laitos 2014). The heating degree days and the change in heating demand for the years 2020, 2035 and 2050 are based on the linear trend calculated from these figures.

3.3.1.5 Traffic

The basic assumption for traffic in all the scenarios described here is that the commercial van traffic will increase in line with the population until 2035 but not thereafter. The truck traffic volume is expected to stay at the present-day level due to the development of logistics and the increase in average size of the vehicles. Furthermore, shipping is estimated to remain unchanged.

3.3.1.6 Industry and machinery, waste treatment and agriculture

The most of Helsinki’s greenhouse gas emissions arise from heating of buildings, electricity consumption and traffic (see figure 1). The fuel use of industry and machinery, and the emissions from waste treatment and agriculture accounted altogether for just over 3 percent of the total emissions in 2012 (HSY 2015a). The emissions from these sectors have been reduced significantly, and the trend is expected to continue up to the target year and the vision year of the City Plan.

The Climate Swing scenario tool only illustrates the effects of the main emission sources, and does not include a separate option to change factors affecting the emissions in other sectors. This report presents, however, the emissions and their changes in all sectors, corresponding to the greenhouse gas emission accounting of the cities of the Helsinki Metropolitan Area.

The emission trends of the fuel use of industry and machinery, waste treatment, and agriculture have been calculated with a simple mathematical model based on the actual emissions in 1990 and 2012 (Figure 12).

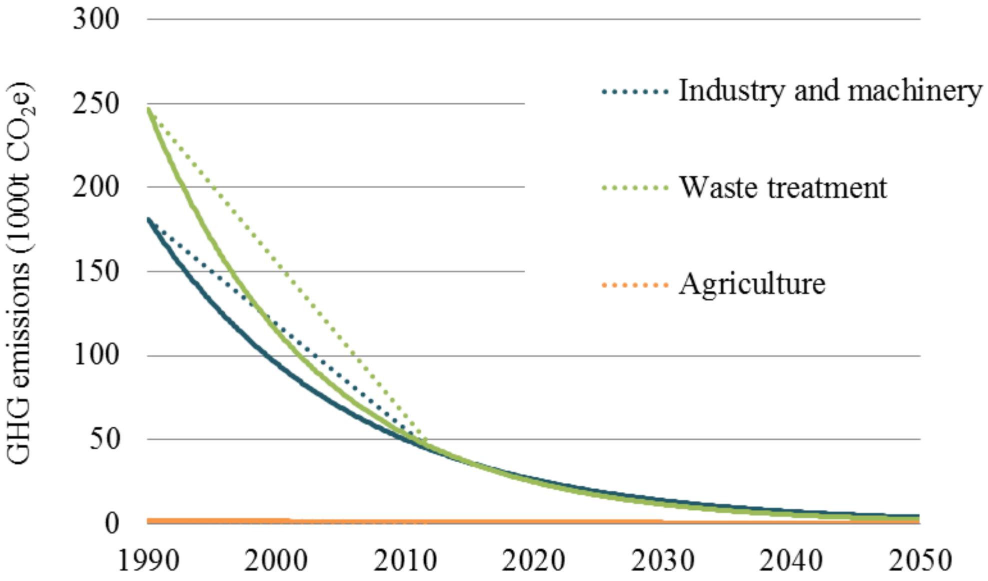

Figure 12. The greenhouse gas emission trends of the fuel use of industry and machinery, waste treatment and agriculture. The dotted lines illustrate the actual emissions of 1990 and 2012. The emissions in 2020, 2035 and 2050 have been estimated by an exponential trend shown in continuous lines.

4 RESULTS: THE EMISSION SCENARIOS FOR 2035 AND 2050

The scenarios in this study demonstrate the greenhouse gas emission trends based on various different assumptions. ”More people” -scenario shows the effect of mere growth of population and building stock to the emissions. In the ”Less emissions” -scenario, besides the targets of the City Plan, the climate change mitigation measures are carried on according to the aims and ambitions of the city of Helsinki, Finland, and European Union. The scenarios are also studied measure by measure. For instance the emission reduction potentials of energy renovations or changes in transportation habits are calculated independently.

The comprehensive development paths describing the city growth and the mitigation measures, the emission reductions enabled by the new City Plan are studied separately. ”City Plan” and “City Plan+” -scenarios focus on the greenhouse gas emissions from energy consumption in buildings and traffic.

4.1 “More People” (MP-scenario)

”More people” -scenario (MP) serves as reference for other development paths presented in later chapters. It demonstrates the greenhouse gas emissions of Helsinki in conditions where the population is growing, but otherwise the city is similar to now. Ongoing emission reduction measures and plans are frozen at the 2012 situation. General growth trends are realized (see chapter 3.3.1).

”More people” assumptions:

- ► People move as now and vehicles and fuels are similar to the present
- ► The energy efficiency of buildings, also new construction, is the same as the current average
- ► The share of oil and electric heating remains unchanged
- ► The production and the fuel mix of district heating stay the same
- ► No changes in the Finnish electricity supply

The MP development path can be regarded as a kind of worst case scenario, where climate change mitigation is not part of urban planning and strategic management priorities. For example, transport systems or district heating production have been expanded to meet the needs of new residents, but not so much developed from the perspective of greenhouse gas emission reductions.

4.1.1 Emission trends in the MP scenario

The population growth, new buildings and traffic unambiguously increase the greenhouse gas emissions, if the status quo setting is maintained in other aspects. In 2012, the Helsinki's emissions were little less than 3 million tonnes of carbon dioxide. In the "More people" -scenario the annual emissions are expected to grow by more than one million tonnes by 2050 (Figure 13).

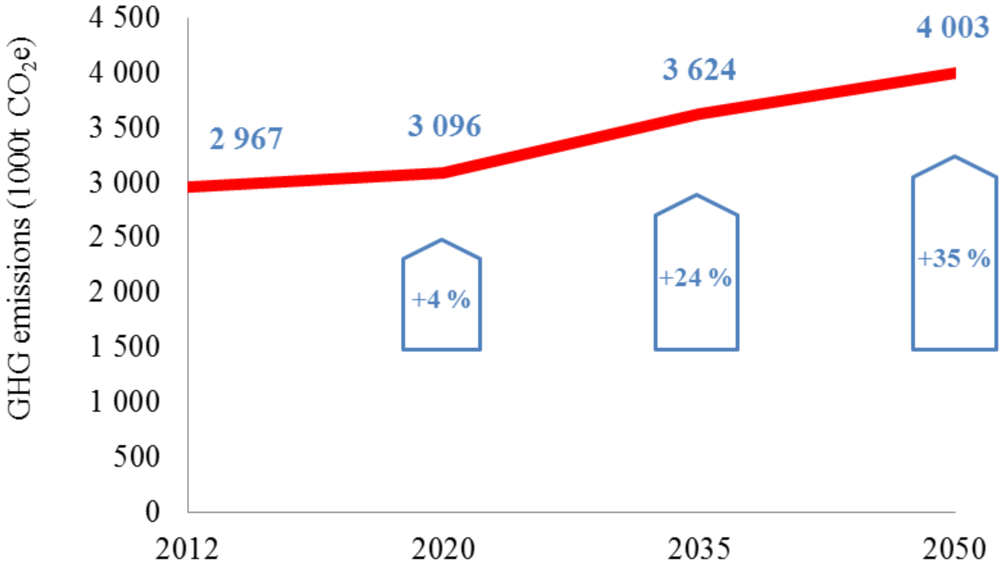

Figure 13. The greenhouse gas emissions of Helsinki in the MP-scenario.

Compared to the current situation in Helsinki, the mere-growth-model produces nearly a quarter more greenhouse gas emissions for the year 2035. In 2050, the change is +35 %. Calculated per inhabitant, a slight decrease can be noticed

(Table 4). Furthermore, in the MP-scenario, the magnitudes of the emission sources in relation to each other stay roughly the same in the future.

Table 4. ”More people” -scenario’s emissions by sector (1000t CO_2e) in 2012, 2020, 2035 and 2050 along with the percentage changes compared to 2012.

MP	**2012**	**2020**	**2035**	**2050**	**% change 2012-2035**	**% change 2012-2050**
District heating	1 356	1 440	1 748	1 942	29	43
Separate heating	234	246	294	323	26	38
Electricity	619	646	779	880	26	42
Transport	667	711	784	850	18	28
Industry and	44	26	10	4	-77	-91
Waste treatment	46	25	8	3	-83	-95
Agriculture	1	1	1	0	-43	-60
TOTAL	2 967	3 096	3 624	4 003	22	35
Per capita (t)	4.9	4.7	4.8	4.6	-3	-5

4.2 ”Less emissions” (LE-scenario)

The “Less emissions” scenario can be seen as basic development of Helsinki’s greenhouse gas emissions, or as a business as usual -scenario (BAU) up to the year 2050. BAU generally refers to a future in which current trends continue. Helsinki’s development has been favourable regarding climate change mitigation, and, when sustained, this trend entails significantly lower emissions.

In the LE-scenario, the City Plan is implemented as planned and emission reduction measures are carried out decisively. The EU norms and targets for construction are effectively achieved and public transport is further developed. The city-owned energy company Helen, for its part, responds to the climate goals of the city.

4.2.1 LE-scenario assumptions

In the ”Less emissions” -scenario, the city grows according to the objectives of the master plan with 260 000 inhabitants and 190 000 new jobs. More than 23 million square meters of new floor area is constructed by the year 2050. In addition to these, as well as other growth trends and general assumptions common to all scenarios (see chapter 2), several other choices have been made in the LE-scenario, all of which have an effect on the greenhouse gas emissions while supporting the climate-friendly business as usual development path:

► The energy efficiency of buildings is improved

2 percent of the existing building stock is renovated each year bringing 0.75 % energy savings annually (ERA17 2010). The specific heating energy consumption of new buildings is projected to gradually decrease up to the year 2020, after which all the new construction is at zero energy level. Including the impact of climate change, the energy efficiency of buildings is greatly improved (Table 5).

Table 5. The change in the specific heating energy consumption of the building stock of Helsinki in 2020, 2035 and 2050, compared to 2012.

LE	2020	2035	2050
Residential	-12 %	-42 %	-60 %
Services	-11 %	-40 %	-58 %
Industry	-8 %	-21 %	-33 %

The Climate Swing tool does not distinguish between new and old building stock. Therefore, the impacts of the retrofitting of existing buildings, and the zero energy norms of new construction have been combined in proportion to the corresponding floor areas. In addition, the decrease in heating demand caused by global warming is counted in in the figures in Table 5.

► Biofuels are used in the district heat production

Helen energy company’s development program is implemented as follows: In 2020 wood pellets replace 7 % of coal in the fuel mix. In 2035 a new multi-fuel power plant Vuosaari C is built, where the share of bio fuels is 80 %. The Salmisaari coal power plant’s production continues with a bio-share of 5 % (Helen 2014). In 2050 Vuosaari C uses 100 % bio fuels and Helen’s district heat production is carbon neutral, corresponding to the development program. The Katri Vala heat pump plant production remains unchanged.

► Separate heating shifts to geothermal

At the current rate of change in heating systems of detached houses in Finland, oil heating may be phased out already in 15 years (Vihola & Heljo 2012). The main new heating method is ground source heat pumps. In the LE-scenario, oil heating is projected to fall by one third by 2020, and to be completely cut out by the year 2035. Also the share of electric heating is diminished. By 2050, ground source heat pumps cover as much as 70 % of the separately heated buildings.

► The emissions of Finnish electricity supply are reduced

In the greenhouse gas emissions accounting of the cities of the Helsinki metropolitan area, the emissions from electricity consumption are calculated using a national emission factor for electricity. Besides, for the electricity used for heating, a higher standard emission factor of 400 gCO_2-e/kWh is used (Ympäristöministeriö 2001). In recent years the five-year-average emission factor for consumption electricity has been in the range of 150–200 g/kWh. The factor is expected to decline significantly in the future, primarily due to the increase of nuclear and wind power (Figure 14).

It is difficult to reliably predict the electricity production structure far into the future. Up to the year 2030 the assumptions in the LE-scenario are based on the Ministry of Employment and the Economy’s Energy and Climate Strategy 2013 update (MEE 2013) and expert estimates by Gaia Consulting Oy. The biggest changes occur before the year 2030. Thereafter, the CHP production is reduced and the electricity demand increases (Gaia 2014).

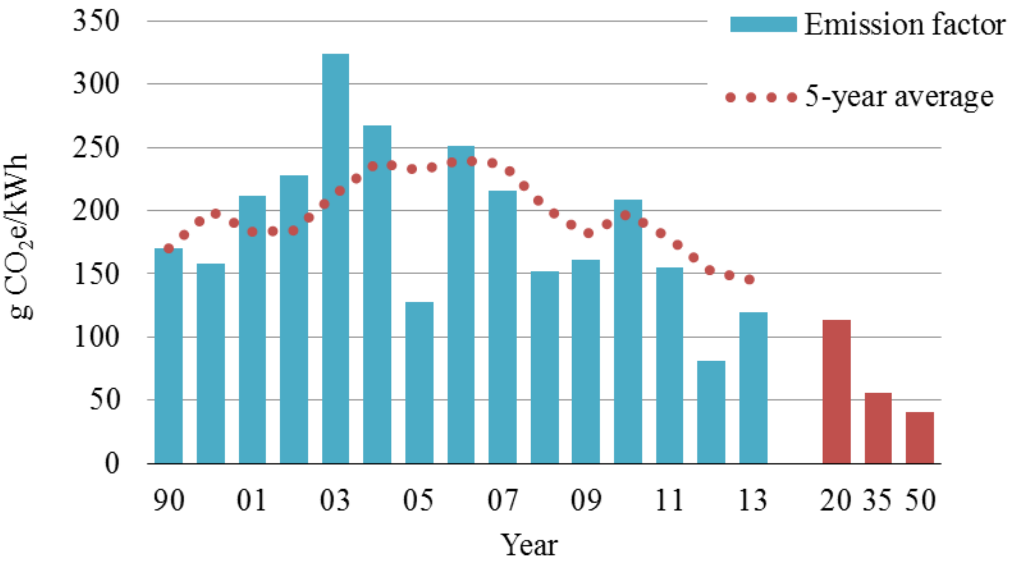

Figure 14. The national emission factor for consumption electricity in 1990 and 2000–2013 along with estimated emission factors for 2020, 2035 and 2050 (Tilastokeskus 2014b; Energiateollisuus 2014; Ympäristöministeriö 2001).

By 2050, the share of nuclear power of the Finnish electricity supply grows to little more than 50 percent from the current 25 percent. Share of wind power increases considerably from the current 1 percent to 7 percent. Also, the amount of waste used for electricity production increases. In contrast, the natural gas, coal and peat are reduced. The electricity supply fuel mixes used in the calculations are shown in Table 6.

Table 6. The Finnish electricity supply fuel mixes up to 2030, according to the Ministry of Employment and the Economy’s Energy and Climate Strategy 2013 update. Thereafter status quo with the exception of decreasing combined heat and power (CHP) production and the growing demand (TEM 2013; Gaia 2014; Energiateollisuus 2013).

%	2012	2020	2030	2035	2050
Hydro	20	15	14	14	14
Wind	0.6	6	7	7	7
Nuclear	26	36	55	54	52
Coal	8	11	5	4	3
Oil	0.3	0.7	0.3	0.3	0.2
Gas	8	10	5	5	3
Peat	4	5	3	3	2
Bio	12	10	10	9	9
Waste	1	3	3	3	3
Net import/ other renewables	21	1	-3	0	7

The shares of electricity production by fuel type assessed by MEE and Gaia (Table 6) cannot directly be entered in the Climate Swing because the scenario tool compares the situation to the five-year-average emission factor used in the 2012 GHG calculations. This is much higher than the actual emissions in that year, and thus the emissions in 2035 and 2050 will also be too high.

More detailed results are achieved when the new fuel mix is compared to the fuels used, the actual emissions, and furthermore to the not averaged, real emission factor of 2012 (Table 7).

Table 7. The emission factors for consumption electricity (gCO2e/kWh). The factors in the ”5-year average” -line are from the Climate Swing with the fuel mixes presented in Table 4. The ”Not averaged” -factors are calculated respectively in relation to the real emission factor of 2012. The bolded figures are used in the scenario studies.

gCO_2e/kWh	2012	2020	2030	2035
5-year average	**151.6**	211.8	103.7	76.2
Not averaged	81.4	**113.8**	**55.7**	**40.9**

► Solar panels become more common

In the LE-scenario the share of electricity produced with solar panels increases steadily up to 10 percent of all electricity consumed in Helsinki by the year 2050. The change refers to the exponential growth in the number of solar panels. In this estimate about 580 gigawatt hours of solar electric power would be produced. With current technology (Motiva 2014) this would require nearly 400 hectares of panel surface area equalling to 4.5 square meters per resident. On the other hand, solar energy breakthrough may happen also in Finland. Technological development is progressing by leaps and bounds, and more efficient solar energy solutions that are integrated into the structures will be more common.

► Urban mobility

Condensing urban structure brings changes to people's everyday mobility. The new City Plan envisions Helsinki as a network city, where daily services are located in a close proximity to the residents. The several sub-centers of the city are interconnected by metro, tram, and transverse light rail lines (Helsinki 2013c). The estimated changes in the travelling habits in the LE-scenario are, however, rather moderate. The assumption suggests that the everyday mobility of all new inhabitants is similar to those currently living within the inner city limits. The habits of the remaining population[12] stay the same as before. Table 8 shows the average distances travelled during the day with different transport modes in the Helsinki inner city compared to the average for the whole Helsinki. The estimations for the years 2035 and 2050 are calculated based on the population growth and the above-mentioned assumption.

Table 8. The everyday travelling habits of a Helsinki resident (km/day/pers) in 2012 in the inner city and the average for the entire Helsinki area (HSL 2013) in 2012 as well as in the City Plan target years 2035 and 2050.

LE	**Inner city**	**The entire Helsinki area**		
(km/day/pers)	2012	**2012**	**2035**	**2050**
Private car	4.9	**10.5**	**9.4**	**8.8**
Bus	3.0	**4.1**	**3.8**	**3.7**
Rail	3.2	**4.3**	**4.1**	**4.0**
Walking and	2.7	**2.1**	**2.2**	**2.3**
Total	13.7	21.0	19.5	18.8

► Vehicle technology

The evolution of vehicle technology and new transport fuels has a great significance in the context of urban greenhouse gas emissions. The car tax reform in 2008 has already been effective in reducing specific emissions from passenger cars: the average carbon dioxide emissions of newly registered passenger cars were 177 g/km in 2007, 128 g/km in 2014 and 122 g / km in August 2015 (TraFi 2015).

---

[12] The split between old and new inhabitants is a simplification made for the scenario examinations. In practice this means shares of population equaling to the current number of inhabitants and the growth in population respectively.

In the LE-scenario up to the year 2020, a VTT's estimate that the average fuel consumption is reduced by 1.3 percent a year (Nylund 2013) is used. In 2020 the renewable bio component, calculated with zero-emissions, accounts for 15 percent of total traffic fuel energy content. With this share of biofuels, Finland will meet the 2020 target of 20 percent, as 5 percentage points of biofuels are so called second-generation biofuels, which can be double-counted (Finlex 2010).

In 2050, the assumption is the climate favourable 2DS Scenario in the Nordic Energy Technology Perspectives study conducted by the International Energy Agency (IEA 2013). In line with the NETP assessment, in 2050 about 45 percent of the cars are electric, and the share of biogas and bio ethanol is altogether 15 percent. Fuel consumption is reduced by 55 percent, and the share of bio-component in the fuels will increase to 35 percent. The conditions in 2035 are calculated along a linear trend line leading to these figures from the 2020 approximation.

4.2.2 Emission trends in the LE-scenario

In the "Less Emissions" -scenario Helsinki grows in accordance with the goals of the new City Plan, and climate change mitigation is the key factor governing the activities of the city organization and other urban actors. Limiting global warming to two degrees Celsius requires emission reductions of around 80-95 percent by 2050 (IPCC 2013). With the background assumptions of the LE-scenario, the greenhouse gas emissions of Helsinki will be halved by 2035 and 80 percent less by the middle of the century compared to the year 2012 (Figure 15). This development suggests that Helsinki is quite capable to meet the national and international climate goals. The percentage changes are even greater compared to the reduction target base year 1990 (Table 9).

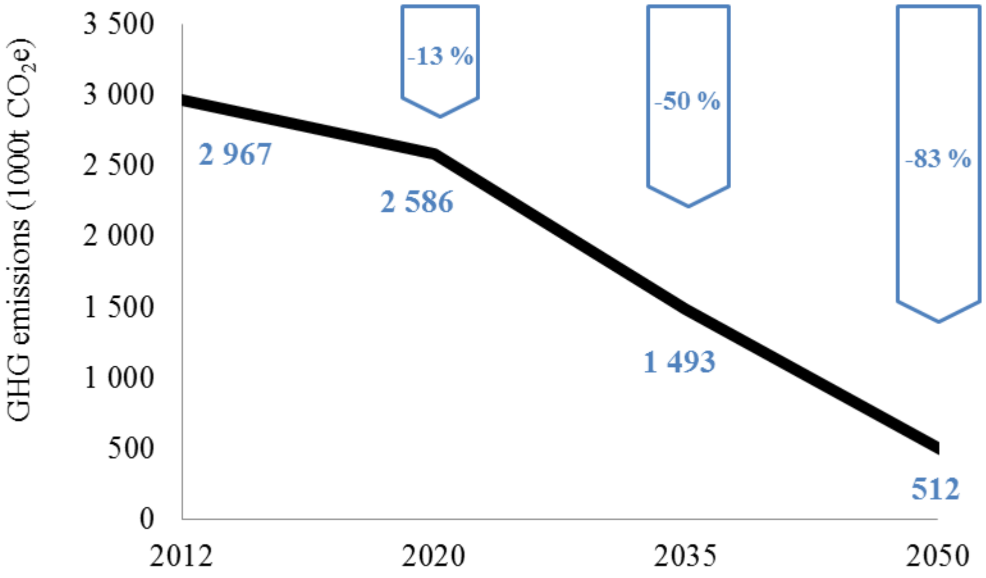

Figure 15. The greenhouse gas emissions of Helsinki in the LE-scenario.

Table 9. Percentage change in emissions in the ”Less emissions” -scenario compared to the actual emissions in 1990 and 2012. In the year 1990 the greenhouse gas emissions of Helsinki were 3 615 tonnes of carbon dioxide (HSY 2015a).

Compared to	2020	2035	2050
2012	-13 %	-50 %	-83 %
1990	-28 %	-59 %	-86 %

The greenhouse gas emissions of Helsinki by sector, calculated according to the background assumptions of the LE-scenario, are presented in the Table 10. Overall, the emissions are reduced rather gradually between the years in focus, but the split between different emission sources shows notable differences from 2035 to 2050. Then the district heating system in Helsinki shifts completely to carbon neutral production which diminishes the emissions steeply. Thus, transport and electricity consumption gain more importance (Figure 16). The emissions in Helsinki in 2050 are 0.6 tonnes calculated per capita which is sustainable in the global framework of preventing dangerous climate change.

Table 10. ”Less emissions” -scenario’s emissions by sector (1000t CO_2e) in 2012, 2020, 2035 and 2050 along with the percentage changes compared to the year 2012 and to the ”More People” -scenario (MP).

LE	**2012**	**2020**	**2035**	**2050**	**%-change 2012-2035**	**%-change 2012-2050**
District heating	1 356	1257	746	16	-45	-99
Separate heating	234	201	97	58	-58	-75
Electricity	619	484	272	214	-56	-65
Transport	667	591	359	218	-46	-67
Industry and	44	26	10	4	-77	-91
Waste treatment	46	25	8	3	-83	-95
Agriculture	1	1	1	0	-43	-60
TOTAL	2 967	2 586	1 493	512	-50	-83
Change cf. MP	0	510	2 131	3 491		
%-change cf. MP	0	-16	-59	-87		
Per capita (t)	4.9	3.9	2.0	0.6	-60	-88

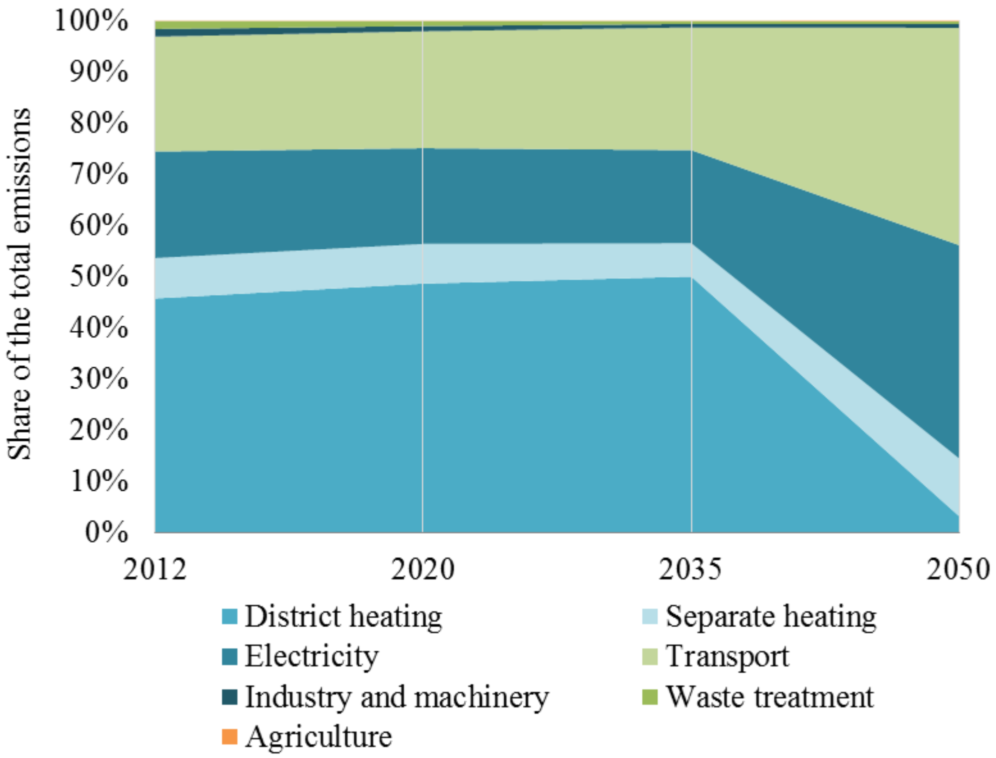

Figure 16. The split between greenhouse gas emissions sources in Helsinki in 2012 and in the LE-scenario in the years 2020, 2035 and 2050.

4.2.3 The emission reduction potential of mitigation measures

It is relevant to compare the greenhouse gas emission trend of the “Less emissions” -scenario to that of the “More people” -scenario, in addition to the baseline year of 2012. Hereby the effects of various mitigation measures, as well as their relationship to each other, can be illustrated. The influence of the City Plan in reducing emissions is considered separately in the next chapter.

The greatest potential for emission reductions is discovered in the energy efficient new construction, changes in the fuel mix of district heat production, the low-emission grid electricity, and in the development of vehicle technology (Figure 17). Altogether, it is possible to cut emissions by over 2 million tonnes by the year 2035, compared to the current practices and the growth-based development of the city. By 2050, respectively calculated reduction potential for Helsinki is close to 3.5 million tonnes.

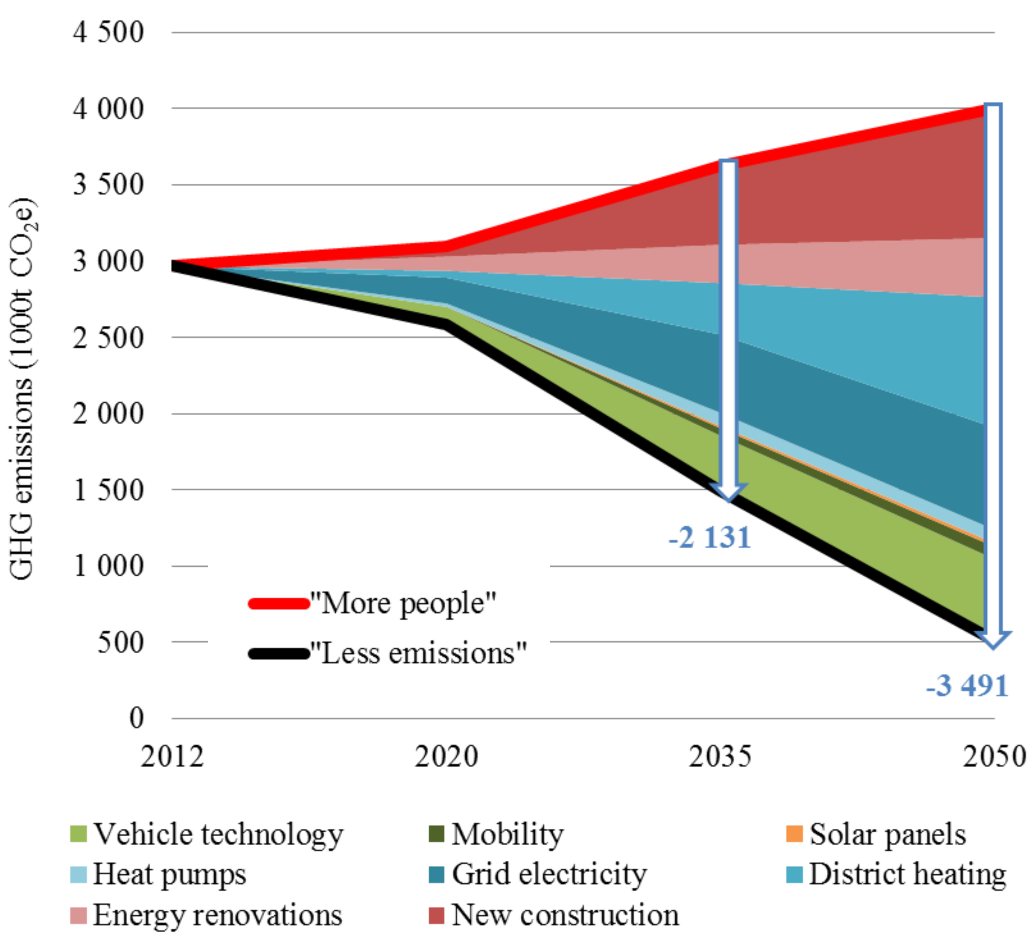

Figure 17. The impact of various LE-scenario's mitigation measures to the greenhouse gas emissions trends of Helsinki, contrasted with the MP-scenario.

The impacts of mitigation measures have been examined with the Climate Swing so that the assumptions of the LE-scenario were successively entered into the scenario tool in an order shown in Figure 13, i.e. from new construction to vehicle technology. The principle is that the energy consumption is altered first and secondly the type of energy being consumed. Thus, for example, the changes in travelling habits are emphasized more than the development of vehicle technology or the increment of bio fuels. The greenhouse gas emissions of a city are, however, always a complex issue, affected by numerous factors. The conclusion of emissions from transport is the same, regardless of which component is adjusted first.

It is assumed in the LE-scenario that after 2020 all new buildings are constructed according to zero-energy standards. By 2035, this would contribute to emission savings of more than 0.5 million tonnes compared to a situation where the building stock would be qualitatively analogous to that of the present day. Completely zero level heating energy consumption cannot be reached in practice, but up to the year 2035 new construction is the single most important factor affecting the greenhouse gas emissions in Helsinki. By 2050, the most significant emissions reductions can be achieved in the production of district heating (Figure 18).

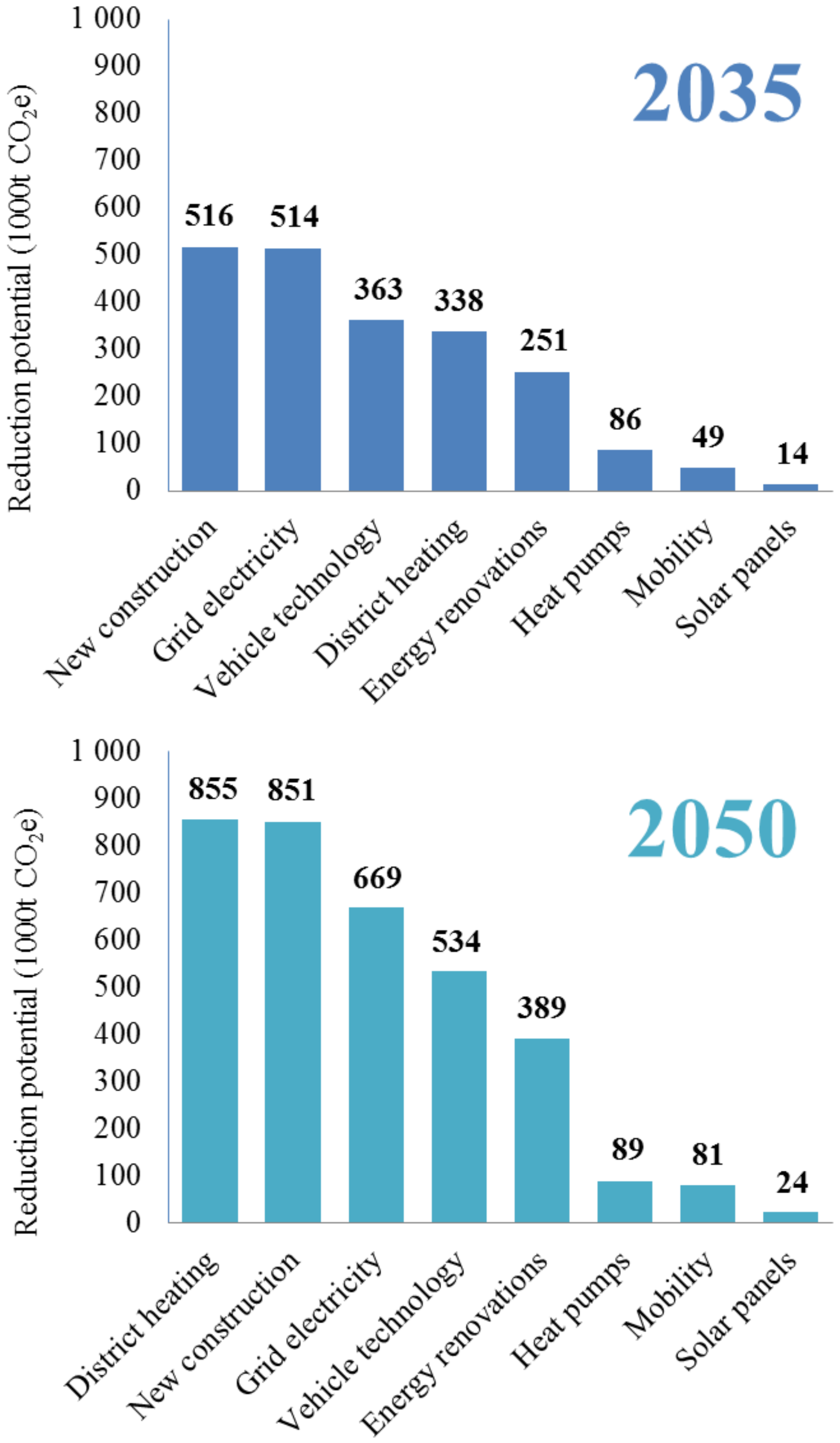

Figure 18. The emission reduction potentials of various mitigation measures in Helsinki in 2035 and 2050. The figures illustrate the amount of greenhouse gas emissions that can be lowered with each measure, compared to the ”More people” -scenario, which is based on current practices and the city growth.

4.3 The impact of the City Plan on emissions

The emission impacts of numerous urban planning actions and measures (see chapter 2.2) cannot be assessed as such with the tools currently available. Instead, larger entities, such as energy consumption and production, mobility, and vehicle technology, need to be considered. In this report the climate impacts of the new Helsinki City Plan are assessed based on Climate Swing scenarios. The scenarios are built on certain underlying basic assumptions, and the end result demonstrates the urban greenhouse gas emissions in the target years of 2035 and 2050. The calculations are based on the city's current annual emissions monitoring including the heating of buildings, electricity consumption, transport, industry and machinery, waste treatment, and agriculture. The emissions from construction are excluded from the assessment.

The "Less emissions" -scenario describes the impacts of 1. energy efficient new construction, 2. the Finnish grid electricity, 3. vehicle technology, 4. the fuel mix of the district heating production, 5. energy renovations in buildings[13], 6. ground-source heat pumps, 7. mobility changes, and 8. solar panels (Figure 18). The combined emission reduction potential of the measures is 2.1 million tonnes in 2035 and 3.5 million tonnes in 2050, compared to the MP-scenario of mere growth.

Out of the 8 measures, the City Plan can be argued to have an effect on the construction, retrofitting and mobility, which enable a total emission reduction of 0.8 and 1.3 million tonnes for the years 2035 and 2050 (Figure 19). The fuels used for producing district heating have great significance regarding the target years' emissions but the City Plan has no influence over the fuel mix. At the same time the plan allows for an urban structure dense enough for district heating to maintain its position as the primary heating method in Helsinki also in the future.

---

[13] also: retrofitting; energy renessaince

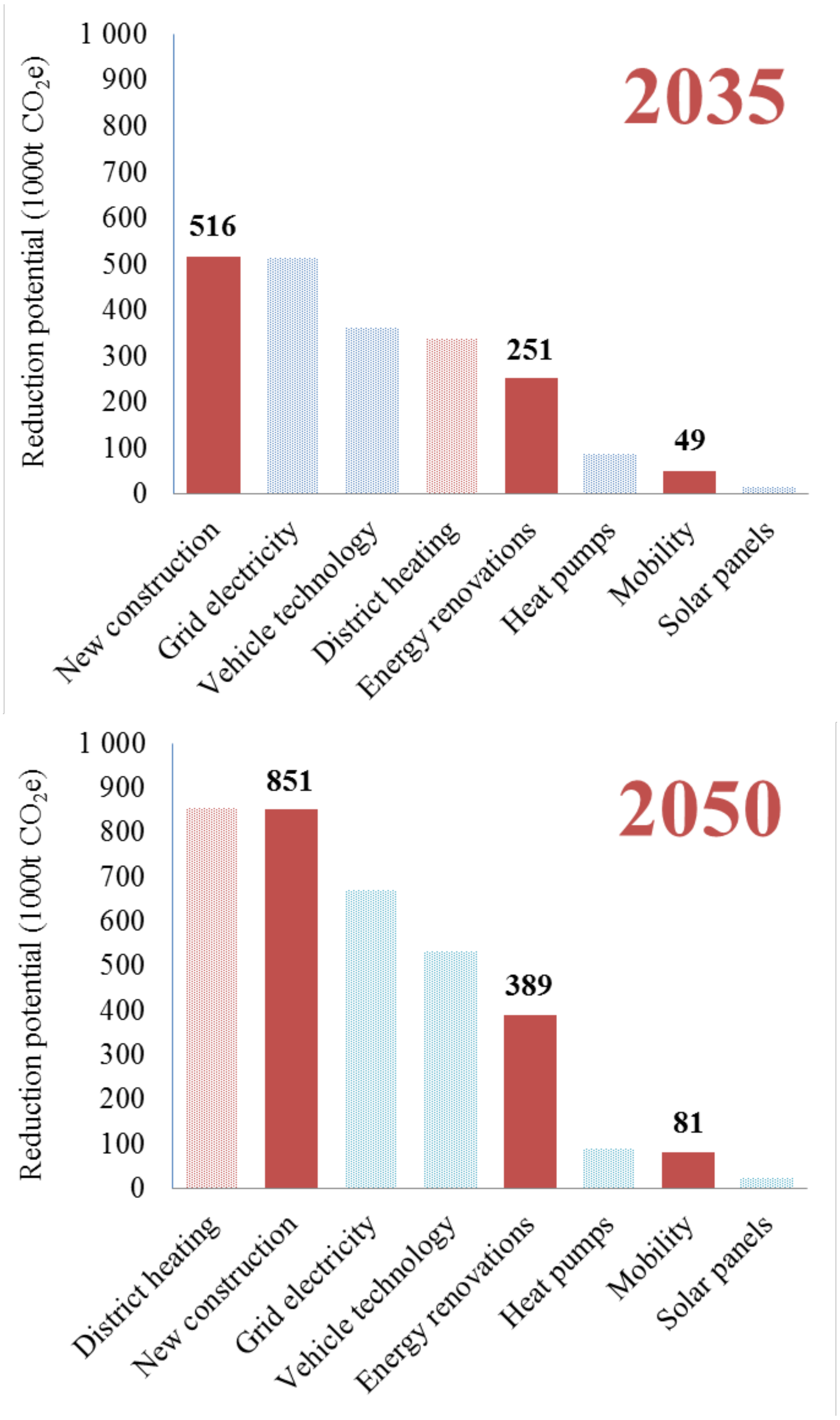

Figure 19. The emission reduction potentials of various mitigation measures in Helsinki in 2035 and 2050. The red colour illustrates the reductions enabled by the City Plan, without district heating a total of 816 and 1 320 thousand tonnes of carbon dioxide in the years 2035 and 2050.

In reality the measures of the City Plan cannot be reasonably separated from other urban development, but as a theoretical framework also a “City Plan” -scenario (C) may be studied. Table 11 shows the emission impacts of new construction, retrofitting and mobility changes by sector.

Table 11. ”City Plan” -scenario’s emissions by sector (1000t CO_2e) in 2012, 2020, 2035 and 2050 along with the percentage changes compared to the year 2012 and to the ”More People” -scenario (MP).

C	**2012**	**2020**	**2035**	**2050**	**%-change 2012-2035**	**%-change 2012-2050**
District heating	1 356	1 306	1 091	879	-20	-35
Separate heating	234	223	185	147	-21	-37
Electricity	619	646	779	880	26	42
Transport	667	711	734	768	10	15
Industry and	44	26	10	4	-77	-91
Waste treatment	46	25	8	3	-83	-95
Agriculture	1	1	1	0	-43	-60
TOTAL	2 967	2 938	2 807	2 681	-5	-10
Change cf. MP	0	158	817	1 322		
%-change cf. MP	0	-5	-23	-33		
Per capita (t)	4.9	4.4	3.7	3.1	-25	-37

4.3.1 Energy efficient new construction

The Energy Performance of Buildings Directive requires that from 2019 all new public buildings and from 2021 all buildings are nearly zero-energy buildings (EU 2010). Such a building needs to have, according to the directive, almost non-existent energy consumption that can be covered by energy from renewable sources produced on-site or nearby. The directive leaves a lot of room for interpretation, and the national specifications are currently being drafted (FInZEB 2014).

The zero-energy construction has a strict interpretation in the ”Less emissions” -scenario. From 2020 onwards the heating energy consumption of new buildings is expected to be zero. In other words, theoretically the very low energy demand of the new buildings is covered with solar thermal collectors or heat pumps. In reality, carbon neutral district heating is an apparent option in Helsinki.

The new Helsinki City Plan, if fully implemented, delivers an addition of as much as 50 percent to the current building stock of the city. A maximum of 23 million square meters of new floor area with heating would generate a massive upsurge in the greenhouse gas emissions with the current level of energy efficiency. However, as the nearly zero-energy construction progresses, the emissions in 2035 may be over 500 thousand tonnes, and in 2050 about 850 thousand tonnes lower than with the present solutions.

The role of the master plan is still not straightforward in terms of cutting emissions from new construction. It does not in itself govern the energy efficiency of new buildings, but the obligations come from the directives and the building regulations. The role of the master plan is de facto enabling. As a result, massive zero-energy construction undertakings can be executed in Helsinki, and hence the in-use emissions of buildings remain very low. In the case of new construction, the emissions not covered by the emission scenarios of this report, i.e. the emissions generated during the construction phase itself, must be acknowledged.

4.3.2 Energy renovations

In the City Plan vision year of 2050 in Helsinki there will still be clearly more buildings constructed before the year 2020 than after that in Helsinki. In order to reach the climate goals it is of utmost importance that the energy efficiency of the existing building stock is improved significantly. Especially the heating energy demand of the building stock erected in the 1960s and 1970s is in general quite high. In Helsinki a lot of such buildings are located in the suburban areas in particular.

In the ”Less emissions” -scenario the general assumption is, based on the ERA17 report, that 2 percent of the building stock is renovated annually, which decreases energy consumption by 0,75 percent on average. Up to the year 2035 the energy efficiency of existing buildings improves 16 percent and by 2050 about 25 percent. The changes in the energy consumption of the whole building stock are presented in Table 5. In the LE-scenario retrofitting renovations decrease the emissions of Helsinki by 250 thousand tonnes in 2035, and 390 thousand tonnes in 2050.

The majority of the blocks of flats built between 1950 and 1980 is facing a major renovation in the near future. Hence the importance of retrofitting measures is reduced when approaching the year 2050. In connection with the basic renovations emerges anyhow an excellent opportunity to cost-efficiently improve the energy efficiency of the existing building stock.

By the means of spatial planning it is possible to support the investments needed for energy renovations. According to the City Plan, several areas will be notably condensed. Concurrently the renewal of the building stock is enhanced if additional building permits are allocated to owner-occupied plots. Also rented plots may receive compensations for complimentary construction.

4.3.3 Urban mobility

Out of the various factors causing greenhouse gas emissions, a master plan can most directly influence the urban transport and residents’ commuting habits. In Helsinki the emissions from transport have turned to a slight decline after 2007 (HSY 2015a), which is mainly due to a more low-emission car fleet. The traffic volumes in aggregate in the road and street network of the city have still increased with the exception of the year 2013 (VTT 2014). Last year also cycling increased considerably (Helsinki 2014c).

In Helsinki no significant changes have occurred in the transport sector related to greenhouse gas emissions. Even so, the vision of the new City Plan for the year 2050 is quite different from the present conditions. The mobility is supposed to be mainly based on rail traffic and other sustainable modes of transport. Car traffic remains an option but the attractiveness of walking, cycling, and public transport is clearly improved (Helsinki 2013c).

According to the underlying assumption in the LE-scenario, the growing population of Helsinki uses private car for their everyday movement less than before. In the emission assessment it is calculated that the so called new inhabitants, i.e. the number of people equalling to the population growth, move as those currently living within the inner city limits, and others as before on average. The emissions in the city of Helsinki in 2035 and 2050 would then be about 50 and 80 thousand tonnes of carbon dioxide smaller, compared to a situation where the travelling habits of the citizens remain unchanged.

The condensing urban structure improves the conditions for urban public transport as well as bicycle and pedestrian traffic. However, actualizing the traffic vision of the City Plan requires large-scale allocation of financial resources in public transport and cycling. Especially investments in rail traffic may generate a lot larger emission reductions than is presented in the LE-scenario, if the traffic then shifted more and more from road to rail (cf. Table 8).

4.3.4 ”City Plan+” (C+)

The City Plan’s possibilities to affect the greenhouse gas emissions of Helsinki through energy efficient new construction, energy renovations in the existing building stock and changes in mobility have been assessed in the ”Less emissions” -scenario. Altogether with these changes the emissions could be 0.8 and 1.3 million tonnes smaller in 2035 and 2050, compared to the “More people” -scenario of mere growth (Figure 19).

The general assumptions in the LE-scenario are rather conservative, particularly in respect to urban mobility. Alongside this climate-friendly business as usual -development path a situation may be studied, where the City Plan has had a stronger impact on the energy efficiency improvements of the old building stock and on the changes in everyday travelling habits. Moreover, the construction of industrial-scale wind power off the coast of Helsinki has been made possible. The background assumptions of the “City Plan+” -scenario differ from the LE-scenario as follows:

► The number of energy renovations is doubled, and the existing building stock is renovated so that the annual energy savings are 1.5 percent. Starting from 2012, the heating energy demand of the old buildings decreases 11, 29 and 44 percent by the years 2020, 2035 and 2050 respectively. Changes in the whole building stock’s heating energy demand in the C+-scenario are shown in Table 12.

Table 12. The percentage change of the specific heating energy demand of buildings in the C+-scenario from 2012 to 2020, 2035 and 2050.

C+	**2020**	**2035**	**2050**
Residential	-17 %	-52 %	-71 %
Services	-16 %	-50 %	-70 %
Industry	-14 %	-35 %	-52 %

► The everyday commuting habits change towards what is typical for downtown more strongly than in the basic development path. Besides all the new inhabitants, by 2035 one half of the old, and by 2050 everyone, moves as the present-day residents of the inner city. Table 13 shows the average distances travelled during the day with different transport modes in the Helsinki inner city compared to the average for the whole Helsinki. The estimations for the years 2035 and 2050 are calculated based on the population growth and the above-mentioned assumption.

Table 13. The everyday travelling habits of a Helsinki resident (km/day/pers) in 2012 in the inner city as well as the average for the entire Helsinki area (HSL 2013) in 2012 and according to the C+-scenario in 2035 and 2050.

C+	**Inner city**	**The entire Helsinki area**		
(km/day/pers)	2012	**2012**	**2035**	**2050**
Private car	4.9	**10.5**	**7.1**	**4.9**
Bus	3.0	**4.1**	**3.4**	**3.0**
Rail	3.2	**4.3**	**3.6**	**3.2**
Walking and	2.7	**2.1**	**2.4**	**2.7**
Total	13.7	21.0	16.6	13.7

► Part of the electricity consumed in city is covered by a large-scale off-shore wind farm erected outside the coast of Helsinki. In the C+-scenario it is estimated what is the impact of electricity produced by 100 wind power plants with 3 MW turbines on the greenhouse gas emissions of the city. The zero-emission wind power generated in Helsinki replaces in its entirety the average grid electricity by default. The total energy production of the wind farm is 900 gigawatt hours per year.

With the assumptions listed above a total of 2.4 and 3.6 million tonnes smaller greenhouse gas emissions may be reached in Helsinki in 2035 and 2050 compared to the “More people” -scenario (cf. Figure 17). Out of this the City Plan+ enables emission reductions of 1.2 and 1.8 million tonnes (Figure 20). The potential is substantially higher than in the climate friendly baseline of LE-scenario. Especially the changes in mobility contribute to even bigger reductions. It should be noted, however, that with the low-emission modes of transport becoming more popular, and the buildings consuming less energy, the importance of heating methods and the district heating production options, as well as the development of vehicle technology in lowering the emissions is reduced respectively. In other words, when less energy is consumed, it is not so significant what type of energy that is.

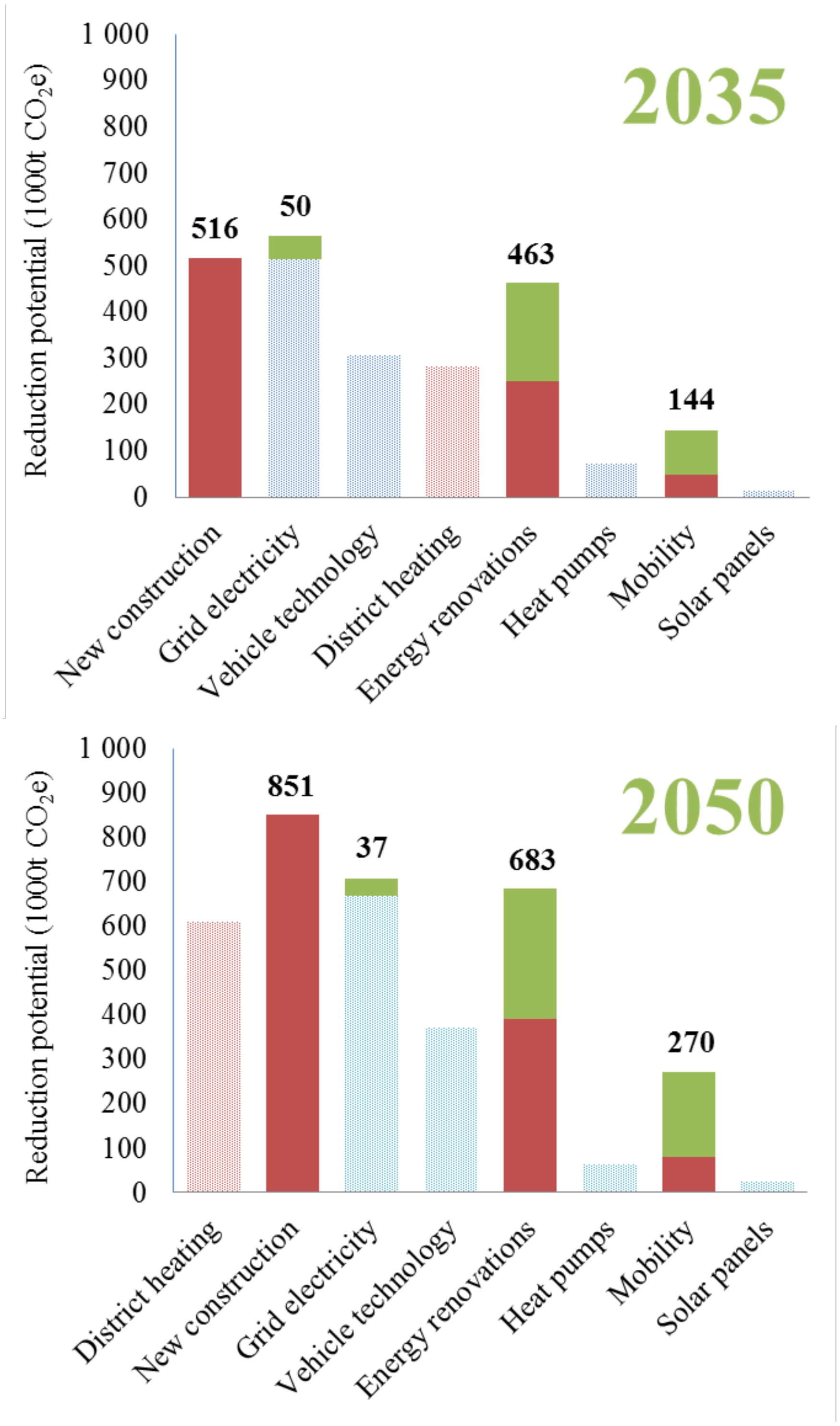

Figure 20. The emission reduction potentials of various mitigation measures in the "City Plan+" -scenario. The figures show the amount of greenhouse gas emissions that can be lowered with each measure, compared to the "More people" -scenario. The green part is the additive reduction potential yielded by City Plan+ -assumptions.

Tables 14 and 15 show the greenhouse gas emissions by sector in the “City Plan+” -scenario and in the “Less emissions” -scenario recalculated with the new assumptions (LE+).

Table 14. ”City Plan+” -scenario’s emissions by sector (1000t CO_2e) in 2012, 2020, 2035 and 2050 along with the percentage changes compared to the year 2012 and to the ”More People” -scenario (MP).

C+	**2012**	**2020**	**2035**	**2050**	**%-change 2012-2035**	**%-change 2012-2050**
District heating	1 356	1 306	909	627	-33	-54
Separate heating	234	223	154	105	-34	-55
Electricity	619	646	729	843	18	36
Transport	667	711	638	576	-4	-14
Industry and	44	26	10	4	-77	-91
Waste treatment	46	25	8	3	-83	-95
Agriculture	1	1	1	0	-43	-60
TOTAL	2 967	2 938	2 449	2 158	-17	-27
Change cf. MP	0	158	1 175	1 845		
%-change cf. MP	0	-5	-32	-46		
Per capita (t)	4.9	4.4	3.2	2.5	-34	-49

Table 15. ”Less emissions+” -scenario’s emissions by sector (1000t CO_2e) in 2012, 2020, 2035 and 2050 along with the percentage changes compared to the year 2012 and to the ”More People” -scenario (MP).

LE+	**2012**	**2020**	**2035**	**2050**	**%-change 2012-2035**	**%-change 2012-2050**
District heating	1 356	1 257	622	11	-54	-99
Separate heating	234	201	81	41	-65	-82
Electricity	619	484	222	177	-64	-71
Transport	667	591	321	190	-52	-72
Industry and	44	26	10	4	-77	-91
Waste treatment	46	25	8	3	-83	-95
Agriculture	1	1	1	0	-43	-60
TOTAL	2 967	2 586	1 265	426	-57	-86
Change cf. MP	0	510	2 359	3 577		
%-change cf. MP	0	-16	-65	-89		
Per capita (t)	4.9	3.9	1.7	0.5	-66	-89

5 CONCLUSIONS

The climate impacts of a master plan can be explored in several ways. This report assessed the effects of the implementation of the new Helsinki City Plan on the greenhouse gas emissions of the city. The starting point was the city’s current annual emissions monitoring produced by Helsinki Region Environmental Services Authority (HSY 2015a), the methodology used in the calculations and the Climate Swing scenario tool (see chapter 3.2.1; HSY 2015b). Other aspects of land-use-planning-related climate change impact assessment could be, for example, the greenhouse gas emissions from the construction of new infrastructure or adaptation and preparedness to the effects of global warming.

The new master plan of Helsinki, the City Plan, defines the long-term target state of urban planning. The target year for the map presentation of the plan, steering the detailed planning, is 2035, accompanied by a strategic future vision of Helsinki for 2050. Estimating the city’s greenhouse gas emissions that far into the future is challenging, because the emissions are affected by numerous different factors. The future is not predetermined, so it is rational to study several potential story lines.

The main research question of this thesis was *how big are Helsinki’s greenhouse gas emissions in 2035 and 2050 when the new city plan is fully implemented?* The study also answers to *how do the future emissions of Helsinki comply with the emission reduction targets of city* and *what are the roles of city planning, energy production and other measures in terms of emissions?* Furthermore, *the strengths and weaknesses of Climate Swing as a tool for master plan emission assessments* were evaluated.

The City Plan is based on intensive growth. By 2050, there will be up to 260 000 more inhabitants and almost 200 000 more jobs in Helsinki compared to the present day. The plan allows for as much as 23 million square meters of new floor area. In order to demonstrate the emission trends, two scenarios were constructed, both of which include the planned implementation of the City Plan. The ”More people” -scenario (MP) illustrates the growth of the city with the current boundary conditions affecting the emissions and the “Less emissions” -scenario (LE) exemplifies a situation where climate leadership is constant, and emission reduction measures are taken up to the target year of 2050. The possibilities of the City Plan in decreasing the emissions are assessed separately.

In the MP-scenario the greenhouse gas emissions of Helsinki increase to over 4 million tonnes of carbon dioxide by the year 2050 (Figure 21). That is around 35 percent higher than now (see also Table 4). The situation is comparable to the swelling of the current Helsinki according to the City Plan’s goals of population growth, jobs and floor area. It serves as a baseline for other scenarios.

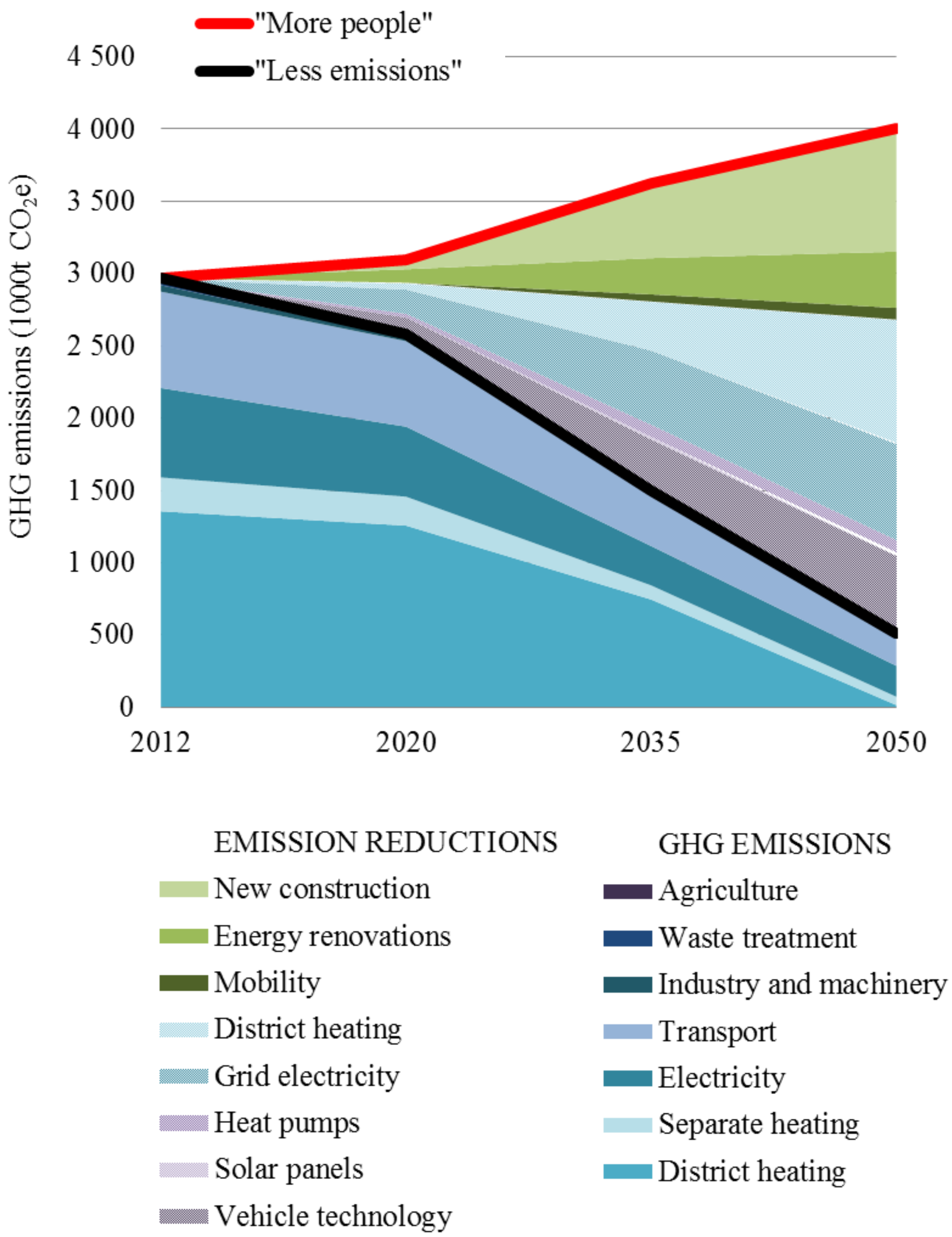

Figure 21. The greenhouse gas emissions of Helsinki in the MP-scenario, emission reductions from various measures and emissions by sector in the LE-scenario. The share of city plan in the emission reduction potential is shown in green colour.

The City Plan’s influence on the greenhouse gas emissions cannot be explicitly distinguished from the general progress and the various operations of the city.

Nevertheless, it can be argued that the plan enables the zero-energy new construction, the execution of energy renovations in the existing building stock and the changes in transportation habits and urban mobility. As a result of these actions, the emissions of Helsinki in 2050 are about one third less than in the MP-scenario (Figure 22; see Table 11).

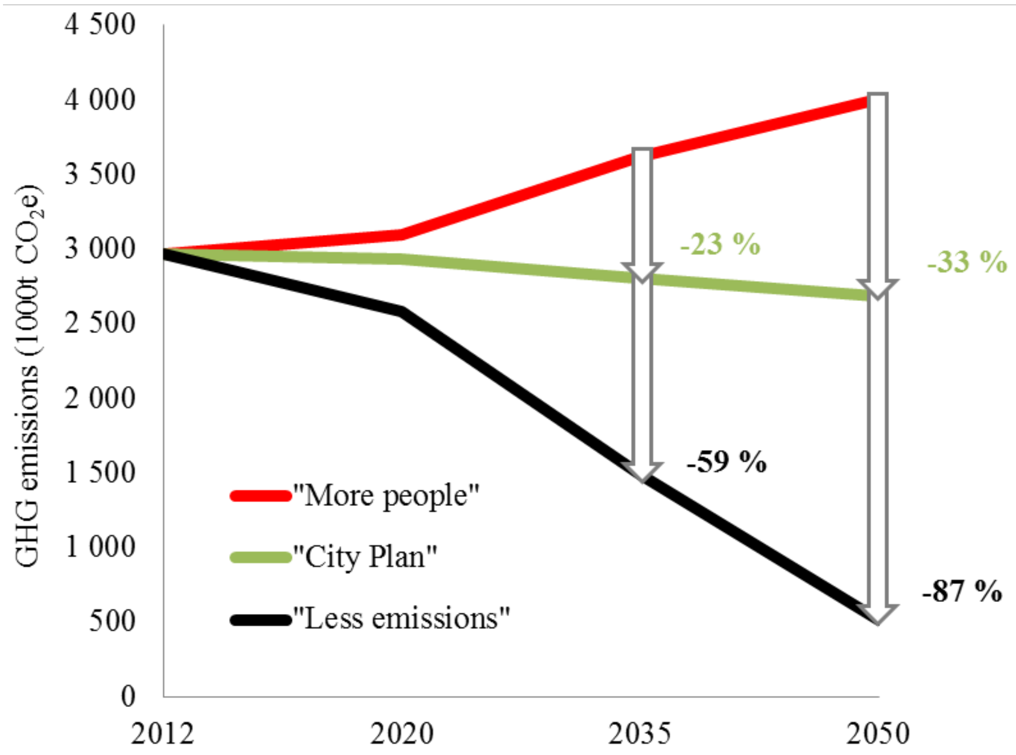

Figure 22. The greenhouse gas emissions of Helsinki in various scenarios. The arrows illustrate the changes in 2035 and 2050 in the C- and the LE-scenarios, compared to the MP-scenario.

The “Less emissions” -scenario can be seen as a climate friendly business as usual -development path. The greenhouse gas emissions of Helsinki have decreased over 20 percent from the year 1990 (HSY 2015a), and the favourable development presumably continues. After 2020, the emissions will be reduced even more sharply due to the measures enabled by the City Plan as well as other activities. In addition to the actions of the City Plan, the emission reduction potential in the LE-scenario builds up from the fuel-mix of district heating production, low-emission green electricity, the development of vehicle technology and the increase of ground source heat pumps as well as solar panels.

With the selected assumptions of the LE-scenario, the annual greenhouse gas emissions of the city decrease to almost 500 thousand tonnes by the year 2050 (Figure 21). That is 87 percent lower than in the scenario of mere growth (Figure 22) and equals to 0.6 tonnes per capita, which is a sustainable level of emissions in terms of effective mitigation of climate change. The change compared to the year 2012 would be -83 (see Table 10). Thus, the new master plan *does not* lock Helsinki into a development path unsustainable in terms of climate change but indirectly enables achieving the carbon neutrality objective of the city's environmental policy.

The ”City Plan+” -scenario is a sensitivity analysis of the master plan's possibilities to influence the greenhouse gas emissions of the future Helsinki. In the Plus-option the number of energy renovations is doubled and people's everyday mobility resembles more that of the inner city residents than in the baseline scenario. Furthermore, the wind farm of 100 turbines off the coast of Helsinki decreases emissions from electricity consumption. In the C+-scenario the significance of the plan in reducing emissions increases, but other measures have somewhat lesser importance respectively. All in all, Helsinki would then achieve even greater emission reductions (Figure 23).

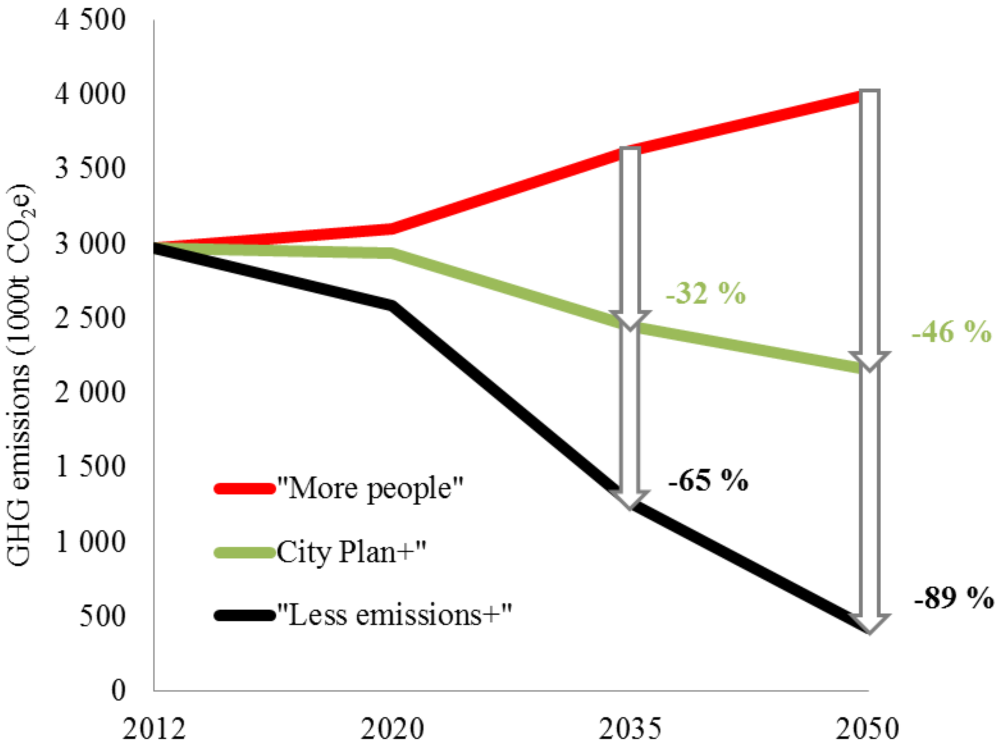

Figure 23. The greenhouse gas emissions of Helsinki in various scenarios. The arrows illustrate the changes in 2035 and 2050 in the C+- and the LE+-scenarios, compared to the MP-scenario.

The first research question of Helsinki's greenhouse gas emissions in 2035 and 2050 has therefore, in the light of the different scenarios, more than one correct answer. Based on results of this study (see chapters 4 and 5) it can be confirmed, however, that the emissions will be substantially smaller in the future than they are now. The growth of the city fundamentally increases the emissions, but the enabling role of the City Plan and the other expected measures bring the emissions down to a level where the city's emission reduction targets are almost met. The second research question may be answered positively; Helsinki is on the right path to sufficiently contribute to the climate change mitigation. The LE-scenario suggests a decrease of greenhouse gas emissions by 28 percent in 2020, and 86 percent in 2050 from the 1990 level (see Table 9), whereas Helsinki's official climate objectives are -30 percent by 2020, and carbon neutrality by 2050.

The third research question concerns the roles of city planning, energy production and other measures in reducing emissions. The effects of different actions are often intertwined but, as previously discussed, urban planning certainly has influence in the mitigation of climate change. The impact of eight selected measures of the scenarios of this study are analysed in detail in chapter 4.2.3. The Climate Swing calculations revealed that the biggest potentials for reducing emissions lie in the *new construction* and changes in the production of *grid electricity*. By the year 2050, *district heating* replaces grid electricity as major potential provider of CO_2 savings (see Figure 14).

The greenhouse gas emissions of Helsinki come primarily from energy consumption in buildings and in traffic. This is likely to continue, even though major changes are expected in the energy sector and the heating of buildings will certainly have less importance as a source of emissions (Figure 21). The energy efficiency standards for buildings are tightened so that while the city grows extensively, conforming to the goals of the City Plan, the consumption of district heating decreases with the assumptions of the LE-scenario. Presumably district heating also retains its predominant share of the heating methods. The consumption of electricity will still increase (Table 16), and while the emissions decrease (see Chapter 4.2.1 and Table 8, electricity's significance as a source of emissions grows in the future (see also Figure 12).

Table 16. The consumption of heat and electricity (GWh) in Helsinki in the LE-scenario.

LE	2012	2020	2035	2050
District heating	6 763	6 455	5 395	4 345
Ground-source heat	4	34	97	93
Oil heating	307	194	0	0
Electric heating	333	319	208	120
Other electricity	4 007	4 260	5 139	5 808

In the transport sector the traffic mileage calculated per person and the average distance travelled by a private car are estimated to decrease slightly (see Table 8). The total traffic volume in turn increases due to the strong demographic growth (Table 17). The changes in the volumes lower the emissions in comparison with the MP-scenario, but only the increase of biofuels and the development of *vehicle technology* turn the greenhouse gas emissions from transport into a pathway that will meet the climate change mitigation objectives.

Table 17. The total change in the traffic volumes in Helsinki from 2012 according to the background assumptions of the LE-scenario.

LE	**2020**	**2035**	**2050**
Passenger cars	10 %	12 %	20 %
Vans	10 %	26 %	26 %
Trucks	0 %	0 %	0 %
Buses	10 %	19 %	31 %
Ships and boats	0 %	0 %	0 %
Rail traffic	10 %	19 %	32 %

The background assumptions used in the scenarios exercises of this thesis may naturally be challenged. For example, the assumed Finnish electricity supply fuel mix includes a substantial increase of nuclear energy, and on the other hand fossil fuels are still in use in 2050 (see Table 6). Currently it looks like wind, and especially solar power, will reach the position of the most important energy source in the coming decades, possibly also in Finland. Furthermore, after the Climate Swing calculations, the situation regarding energy policy and district heating in Helsinki has changed, and the Vuosaari C multi-fuel power plant will probably not be built. The emissions from district heating may yet be quite similar to what is presented in this study; the decision on future production is more of an economic one.

Besides the electricity supply, the assumptions on the urban mobility also seem rather conservative. It could be argued that the narrative of the City Plan vision

2050 implies stronger shifts towards sustainable modes of transportation. On the other hand, all the new construction is estimated to cause zero emissions from the heating of buildings, which is clearly not a completely realistic state of affairs.

The key findings of this thesis are the following:

- The City Plan does not lock Helsinki into a climatically unsustainable path and the target of carbon neutrality may be reached.
- Population growth and the new construction mass fundamentally increase the greenhouse gas emissions of the city, but
- By 2050, the City Plan enables 33 percent and indirectly 87 percent lower emissions compared to the scenario of mere growth.
- With the implementation of the City Plan together with various climate measures the greenhouse gas emissions of Helsinki are 2,0 tonnes of carbon dioxide per capita in 2035 and 0,6 tonnes in 2050.
- The greatest reduction potentials can be identified in the zero-energy new construction, the fuel-mix of the district heat production, green electricity, vehicle technology, and energy renovations.
- By 2050, electricity consumption and traffic emerge as largest sources of emissions while the heating of buildings will have smaller significance.
- Besides decreasing the emissions within the city, the implementation of the City Plan may prevent urban sprawl and growth in emissions elsewhere in the Helsinki Region.

5.1 Evaluation of Climate Swing as a planning tool

The tools used and the experience gained from European climate change mitigation projects, such as the EUCO$_2$ 80/50 (EUCO2 2013; HSY 2011), encouraged HSY to develop an emissions scenario tool tailored for the conditions of the Helsinki Metropolitan Area. The shortcomings discovered in the international examples concern mainly the district heating production as the primary heating method. The distinguished large scale combined heat and power production in the Helsinki Metropolitan Area, and the related options for future changes in the system, was not incorporated in the tools previously used. Also, the calculation methodology for monitoring the annual greenhouse gas emissions of Helsinki and the neighbouring cities is well established (see chapter 3.2.1), so it is worthwhile to be able to draw up scenarios whose results are comparable to current emissions assessments.

The Climate Swing scenario tool (HSY 2015b) was developed to support decision makers and city officials, or in general people and institutions interested in environmental affairs and urban development, in various situations where reliable information about city-level greenhouse gas emissions is needed. It can be used to facilitate for instance strategic energy policy workshops with varied stakeholders represented, or to estimate the emission impacts of selected measures in a narrower sector, e.g. in the field of a certain interest group in transport. The Climate Swing could also have potential for educational use. Generally speaking, it is an urban planning tool, but principally it was not designed for more detailed land use planning and zoning.

The fourth research question of this thesis was about *the strengths and weaknesses of the scenario tool.* Overall the Climate Swing is a useful tool for assessing changes in greenhouse gas emissions of a region, a metropolitan area or a whole city. Therefore, it serves the purpose of assessing the climate change impacts of a master plan, or other more general level land use plan. However, as discussed in chapter 2.2, the means of spatial planning to directly reduce greenhouse gas emissions in the given sectors may be rather limited, due to the complex factors affecting the emissions, the general nature of the plan or the restrictions in the emissions accounting. Yet the precise, plan-based mathematical figures may be combined with the more ambiguous variables, derived from the narrative scenario, to obtain a demonstrative, overall view of the city’s future greenhouse gas emissions.

Using the Climate Swing scenario tool for assessing a master plan’s impacts on the city-level greenhouse gas emissions is basically fairly straightforward. The selected variables are entered in the web application and the results can be viewed instantly. This can be done for example with the population and the job projections, resulting typically in increased emissions. Many other variables need more work as the background assumptions acquired from e.g. previous studies and literature have to be adjusted to match the parameters featured in the Climate Swing scenario. A thorough master plan impact assessment with the scenario tool is quite demanding and time-consuming.

Firstly, to determine the relevant values of the dozens of parameters of the Climate Swing calls for stakeholder workshops, expert discussions, a literature review as well as an agreement on the framework narrative. For the Helsinki City Plan 2016 emission scenario assessment presented in this thesis, much of that preparatory work was done in previous studies (see chapter 3.3). Secondly, the approach of the Climate Swing, in the case of many of its variables, is individual-orientated whereas a master plan predominantly steers the urban structure. Thirdly, the scenario tool does not separate between the existing buildings stock and the urban structure from the new construction, but the parameters are average values for the whole city in a certain year. Thus, several additional calculations had to be completed, and instead of the web application, a spreadsheet version of the scenario tool was used before appropriate and credible results could be achieved.

The first drag in the City Plan emission assessment process with the Climate Swing was estimating the total floor area. Climate Swing uses average living space per person and average office of industrial space per job as parameters, whereas the City Plan plays with the overall residential floor area, total floor area for office and business premises and outgoing industrial floor area. Climate Swing shows the percentage change of total floor area, not the absolute volumes. Therefore, extra effort was needed to work out the figures to be entered in the scenario tool (see chapter 3.3.1.3).

In a situation where massive new construction is planned, the changes in the energy efficiency of the building stock and the related greenhouse gas emissions from the heating of buildings would not be accurately enough estimated without extra calculations. The Climate Swing offers a ‘change in specific heating demand’ variable for all residential, service and industrial buildings within the district heating network and on the other hand for separately heated buildings. The total change of heating demand is difficult to determine, as it is recognised that the energy demand of the new buildings is different from the old ones, and on the other hand the existing building stock is being renovated also in terms of energy efficiency. Furthermore, the effect of global warming should be ruled in (see chapters 3.3.1.4 & 4.2.1).

Besides the consumption of energy, the urban greenhouse gas emissions can be effectively reduced by changing the type of energy production and the fuels used. Hence the energy-related initial data and the assumptions were carefully entered in the Climate Swing. As reported in chapter 4.2.1, the assumed grid electricity supply portfolios could not be directly entered in the scenario tool, but the figures had to be adjusted in order to get fair results. Also the district heating fuel-mix in the future Helsinki, conforming to Helen’s development program (see chapter 4.2.1), and large-scale off-shore wind power’s impact on the emissions (see chapter 4.3.4) were calculated separately.

Furthermore, additional work was needed to adjust the average passenger-kilometres travelled in Helsinki in the target years of 2035 and 2050, given the assumption that the transportation system linked with the new residential areas enables the kind of everyday mobility typical of the current inner city residents.

Based on the experience gained from the City Plan emission assessment process, some upgrades may be suggested to the Climate Swing online scenario tool. The following bullet points are reflected upon the smoothest possible user experience, taking account of the different starting points and the available initial data of each scenario exercise.

- Heating
    - The changes in the total floor area should be shown in percentages *and* in absolute values.
    - The energy efficiency variable need not to be split in district heating and separate heating, but in new and existing housing stock.

    - An option to include the impact of global warming in the heating demand, e.g. according to a 0-, a 2- and a 4-degree scenario would be a valuable addition.
- Traffic
    - The emissions from passenger transport could be based on the percentage changes in the modal split, and the average daily kilometres travelled by car, instead of the average passenger kilometres with each mode of transport.
    - The new and the existing infrastructure should be considered separately.
- Electricity
    - The changes in the electricity consumption should be shown in percentages *and* in absolute values.
    - The amount of local renewable on-site electricity could be determined by the area of rooftops covered with solar panels and by the number of small-scale and large-scale wind mills installed, instead of the share of the total electricity consumed.
- Residents
    - The changes in the number of inhabitants and jobs should be shown in percentages *and* in absolute values.
    - The slider for distribution of jobs should recognize decimals.
- Report section
    - Besides the percentages, the absolute values of the changes should be added to the scenario results.

The weaknesses notwithstanding, the Climate Swing functioned reasonably well in assessing the new City Plan’s impacts on the greenhouse gas emissions of Helsinki. In conclusion, the *best* qualities of the scenario tool are

- the methodological consistency with the annual greenhouse gas emission monitoring of the Helsinki Metropolitan Area,
- a sufficient amount of variables enabling comprehensive scenarios,
- clearly presented ‘real-time’ results and a compilation report and
- the well designed user interface of the online tool.

6 DISCUSSION

The climate impacts of a master plan twine around the question of urban density and its influence on the city's greenhouse gas emissions. This is most evident regarding residents' travelling habits. Walking and cycling is supported in the City Plan, and the conditions required for organizing an efficient public transport system are enhanced by complimentary construction of the suburban centres. Freeing up space for construction purposes along major express roads also addresses the pursuit for a dense urban structure. The location of workplaces, the right-sizing of commercial services and the parking norms greatly affect the emissions from transport. Furthermore, in the implementation program of the master plan it can be ensured that public transport is organized in the target areas before other operations.

Chapter 2.2.1 explained that urban density alone does not necessarily lead to sustainability. According to Bertaud et al. (2009), four types of urban structure can be recognized. In the *mono-centric* model, most of the amenities are concentrated in the central business district. In *polycentric* cities most trips are made from suburbs to suburbs. The *composite*, or *multiple-nuclei*, model is the most common type of urban form typically having a dominant centre in connection with a lot of jobs in the suburbs. The fourth, idealistic type can be called an *urban village model*. Sustainability may be achieved with each of the four models, although their densities are different. Michael Neuman (2005, 23) claims, that

> *…the compact city is neither a necessary or sufficient condition for a city to be sustainable and that the attempt to make cities more sustainable only by using urban form strategies is counterproductive.*

However, a multinuclei city that grows not only denser but also *smarter* through public transport networks and modern and efficient energy, water and waste systems, seems to be the most sustainable model of urban development empowering the drastic changes required for the low-carbon future. With this kind of master planning, at least Helsinki is rising to the challenge.

After all there are many benefits resulting from a dense urban form (see Chapter 2.2.1). The proximity breeds culture, innovation, economic prosperity and a sense of urban community. The central paradox of new urbanism in the modern metropolis is that the closeness has become ever more valuable as the cost of connecting across long distances has fallen (Glaeser 2011, 5). It is predicted that by 2030, more than two-thirds of the North Americans prefer smart growth to decentralization, in the form of walkable and diverse neighbourhoods (Tachieva 2010, 4). The modern ethos is that the quality of life is better in the densely built and mixed use urban agglomerations. The zeitgeist no longer catalyses the residential shift to the suburbs.

The present and the future community structure of Helsinki has an effect on, in addition to transport, also on other energy consumption, and in a wider perspective on the environment within the city and also elsewhere in the Helsinki region. In densely built urban areas, the use of infrastructure is efficient and, for example, the degree of utilization of public facilities is high. Also, sufficiently high area density allows for installing an effective and well-functioning district heating network. It may be discussed that also the emission reduction potential of district heating could be counted in in the direct climate impacts of the master plan and as a part of the “City Plan” and “City Plan+” –scenarios (see Chapter 4.3).

The greenhouse gas emission calculations of Helsinki do not include the indirect, consumption-based emissions from construction materials, foodstuff and other commodities produced outside the city. In the annual emission monitoring, construction is incorporated in the estimated fuel use of machinery and other energy consumption. The greenhouse gas emissions arising from large-scale construction projects are therefore excluded from the emission scenarios of this report.

The emissions from construction are an important part of land use plans’ climate impacts and they should be examined separately, although it can be argued whether the emissions from construction within the city borders should be attributed to the master plan, if the same amount of new floor space and infrastructure would anyhow be built elsewhere. In principle, however, complimentary construction supported by the existing infrastructure generates fewer emissions than the development of completely novel areas and the choices of construction materials play a major role regarding the emissions of the constantly growing Helsinki.

Together with the emission trends within the city of Helsinki, it is important to review the City Plan’s climate impacts regardless of the geographical boundaries. Besides the emissions from construction, the future development of Helsinki has a wider, strategic meaning in terms of housing and transport elsewhere in Finland and the Helsinki region. Sufficient densification of Helsinki and the metropolitan area can prevent the urban sprawl development that typically adds to the greenhouse gas emissions. Thereupon the carbon sinks of rural areas, forests and other vegetation can be secured.

Forests, parks and gardens are in many aspects important also within the city borders. The urban forests absorbing carbon from the atmosphere are particularly noteworthy regarding climate impacts. In the ILKKA-project the carbon storage of Helsinki was estimated to contain as much as 1 250 thousand tonnes of carbon with an addition of 35 thousand tonnes per year (ILKKA 2014). This annual carbon sink corresponds to 130 thousand tonnes of carbon dioxide emissions. The city’s carbon stocks should be preserved when allocating new land use rights for construction. If the green areas should be built, it needs to be done as densely and efficiently as possible to minimize the effects elsewhere in the city.

When building a high-standard city with respect to area density, and when assessing its climate impacts, also the effects of climate change and adaptation to them must be considered. A climate neutral city has not only exceptionally low emissions, but is also prepared to the extreme weather events that become more common with the global warming (IPCC 2014a). Significant challenges of urban planning are stormwater management, the rising sea level and the micro-climate of the city.

There are unavoidably plenty of impervious surfaces in a densely built city, which exposes to stormwater flooding as the precipitation increases. The rising sea level, and particularly in the case of the Baltic Sea, the increasing fluctuation of the extreme values must be taken into account as part of the new Helsinki is erected on a made-up ground by the sea. Climate change also increases the number of heat wave incidents and windiness. The cities are already warmer than the surrounding environment as such, and this so called urban heat island effect intensifies in the future.

To conclude, the intersection of population growth, urbanization and climate change poses great challenges to urban planning. There definitely is a role to play for planning in promoting sustainable development, but it is still debated whether it is the lead or a supporting role. The means of planning to reduce the city level greenhouse gas emissions are anyhow more or less questionable, partly because their impacts may be dependent on the scope of the emission assessment (see chapter 2.2). Nevertheless, when it comes down to the livable future of the planet, it is crucial how the cities are build and rebuild globally. With the new City Plan proposal, the city of Helsinki and its planning department, the city planning committee and the city council have all what it takes to lead the way.

The objective of urban planning should not be a dense community structure, low emissions according to a given calculation methodology or for instance a certain number of new houses alone. Instead, a systemic, cross-administrative approach to urban development is required, to again be able to operate within the planetary boundaries and secure the future of the coming generations.

The city planners can help to shape the policy environment within which acting responsibly is conceivable for a range of stakeholders. While facilitating the prevalent use of public transportation and at least indirectly enabling the large-scale construction of zero-energy housing and the energy renovations of the existing building stock, a climate-friendly and an ecologically sound city of the future also promotes sustainable businesses and lifestyles in a broader sense. The individual consumption patterns of the citizens, the urban metabolism, the material flows and the related greenhouse gas emissions as well as the means of urban planning to promote circular economy are subjects for further research.

The new Helsinki, defined by the City Plan, has all things considered a great opportunity to distinguish itself as an ecocity of the future. The development according to the “Less emissions” -scenario does not imply very high, additional investments aimed at emission reductions with the exception of district heat production. The scenario is a kind of a baseline of modern urban development. It is justified to reduce car traffic and its disadvantages in a condensing urban structure. Together with the inevitable major renovations of the old building stock, it is only rational to improve the insulation level as well. It pays off constructing the new buildings, with a lifespan of over one hundred years, with as high quality as possible. In energy production the fossil fuels are phased out also for the sake of the financial risks they contain (Carbon Tracker 2013). Such measures are sensible with or without the framework of sustainable development. On the other hand, from the perspective of climate change they appear even more important.

SOURCES AND LITERATURE

Alcamo, J. & Henrichs, T. 2009. Towards guidelines for environmental scenario analysis. Published in Alcamo, J. (ed.). Environmental futures. The practice of environmental scenario analysis. Developments in integrated environmental assessment 2. Amsterdam: Elsevier.

Angel, S., Sheppard. S. C. & Civco, D. L. 2005. The Dynamics of Global Urban Expansion. Transport and Urban Development Department. The World Bank.
Available at:
http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/dynamics_urban_expansion.pdf

Aluesarjat 2014. Tilastokanta. Helsingin seutu. Työmarkkinat ja työssäkäynti. Työpaikat (alueella työssäkäyvät) toimialan (TOL 1988) mukaan 31.12.1987–1992.
Available in Finnish at: www.aluesarjat.fi

Bai, X. 2007. Industrial Ecology and the Global Impacts of Cities. Published in Journal of Industrial Ecology, vol. 11, no. 2, pp. 1-6.
Available at: http://xuemeibai.org/Industrial-ecology-and-the-global-impacts-of-cities-Editoria.pdf

Bertaud, A., Lefevre B & Yuen, B. 2009. GHG emissions, urban mobility and efficiency of urban morphology. A hypothesis. Urban Research Symposium 2009, Cities and Climate Change: Responding to an Urgent Agenda, 28–30 June, Marseille.
Available at:
http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1256566800920/6505269-1268260567624/Bertaud.pdf

Bugliarello, G. 2010. The Future of Urban Sustainability. Some Urgent Sociotechnological Challenges. Published in Sustainability: The Journal of Record, vol. 3, issue 6, pp. 351-358.
Available at: http://online.liebertpub.com/doi/pdf/10.1089/SUS.2010.9730

Carbon Tracker 2011. Unburnable Carbon. Are the world’s financial markets carrying a carbon bubble?
Available at: http://www.carbontracker.org/wp-content/uploads/2014/09/Unburnable-Carbon-Full-rev2-1.pdf

Carbon Tracker 2013. Unburnable Carbon. Wasted capital and stranded assets. Carbon Tracker & The Grantham Research Institute, LSE.
Available at: http://carbontracker.live.kiln.it/Unburnable-Carbon-2-Web-Version.pdf

Christidis, N., Jones, G.S. & Stott, P.A. 2015. Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. Published in Nature Climate Change 5, pp. 46–50.

Climate Interactive 2015. Climate Scoreboard.
Available at: https://www.climateinteractive.org/tools/scoreboard/

Coutard O., Finnveden G., Kabisch S., Kitchin R., Matos R., Nijkamp P., Pronello C. & Robinson, D. 2014. Urban megatrends. Towards a European research agenda. A report by the Scientific Advisory Board of the Joint Programming Initiative Urban Europe.
Available at: http://jpi-urbaneurope.eu/downloads/jpi-urban-europe-megatrends-report/

De Cauter, L. 2000. The Mad Max Phase. Published in Plunz, R. & Sutto, M. P. (eds.) Urban Climate Change Crossroads, pp. 111-116. New York: Ashgate Publishing.

Dhakal, S. 2008. Climate change and cities. The making of a climate friendly future. Published in Droege, P. (ed) Urban Energy Transition. From Fossil Fuels to Renewable Power, pp. 173–192. Oxford: Elsevier.

Economist 2014. Rapid urbanisation, climate change and resource scarcity. A disaster in the making? The Economist Intelligence Unit.
Available at: http://www.economistinsights.com/sustainability-

resources/opinion/rapid-urbanisation-climate-change-and-resource-scarcity-disaster

EEA 2015. Assessment of global megatrends. An update.
Available at: http://www.eea.europa.eu/themes/scenarios/global-megatends/global-megatends

Engels, F. 1845. The Condition of the Working-class in England. Panther Edition, 1969. Transcribed by Tim Delaney in 1998.
Available at: https://www.marxists.org/archive/marx/works/1845/condition-working-class/

Energiateollisuus 2013. Sähkötilastot. Sähkön hankinta energialähteittäin. Vuosi 2012.
Available in Finnish at: http://energia.fi/tilastot-ja-julkaisut/sahkotilastot/sahkontuotanto/sahkon-hankinta-energialahteittain

Energiateollisuus 2014. Energiavuosi 2013. Sähkö.
Available in Finnish at: http://energia.fi/ajankohtaista/lehdist-tiedotteet/l-mmin-s-piti-s-hk-nkulutuksen-l-hes-ennallaan

ERA17 2010. Vehviläinen, I., Pesola, A., Heljo, J., Vihola, J., Jääskeläinen, S., Kalenoja, H., Lahti, P., Mäkelä, K. & Ristimäki, M. Rakennetun ympäristön energiankäyttö ja kasvihuonekaasupäästöt. Sitran selvityksiä 39. Sitra: Helsinki.
Available in Finnish at: http://era17.fi/wp-content/uploads/2010/10/sitran_selvityksia_39.pdf

EU 2010. Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings.
Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&qid=1445427334273&from=EN

EUCO2 2013. The European Future Project against Climate Change. Strategies for Metropolitan Regions to reduce 80 % of CO2 until 2050. Web page.
Available at: http://www.euco2.eu/index.html

European Commission 1990. Green paper on the urban environment. Communication from the commission to the Council and the Parliament. Commission of the European Communities. COM(90) 218 final.
Available at: http://ec.europa.eu/environment/urban/pdf/com90218final_en.pdf

EY 2015. Megatrends 2015. Making sense of a world in motion. Ernst & Young.
Available at: http://www.ey.com/Publication/vwLUAssets/ey-megatrends-report-2015/$FILE/ey-megatrends-report-2015.pdf

Finlex 1999a. 132/1999 English. Land Use and Building Act (amendment 222/2003 included). Ministry of the Environment.
Available at: https://www.finlex.fi/en/laki/kaannokset/1999/en19990132.pdf

Finlex 1999b. 895/1999 English. Land Use and Building Decree. Ministry of the Environment.
Available at: https://www.finlex.fi/en/laki/kaannokset/1999/en19990895.pdf

Finlex 2010. 1420/2010. Laki biopolttoaineiden käytön edistämisestä liikenteessä annetun lain muuttamisesta. 30.12.2010.
Available in Finnish at: http://www.finlex.fi/fi/laki/alkup/2010/20101420

FInZEB 2014. FInZEB-hanke. Lähes nollaenergiarakennus (nZEB). Käsitteet, tavoitteet ja suuntaviivat kansallisella tasolla. Hankekuvaus lyhyesti.
Available in Finnish at: http://finzeb.fi/wp-content/uploads/2014/03/FInZEB_esittelykalvot_20140623.pdf

FMI 2015. Finnish Meteorological Institute. Heating degree days.
Available at: http://en.ilmatieteenlaitos.fi/heating-degree-days

Gaia 2014. Vehviläinen, I. Kirjallinen tiedonanto 3.6.2014.

GHG Protocol 2014. Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. An Accounting and Reporting Standard for Cities. World Resources Institute, C40 Cities Climate Leadership Group & ICLEI – Local Governments for Sustainability.
Available at: http://ghgprotocol.org/files/ghgp/GHGP_GPC.pdf

Glaeser, E. 2011. Triumph of the City. How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier. New York: The Penguin Press.

Glenn, J.C. & Florescu, E. 2015. 2015-16 State of the Future. Washington: The Millennium Project.

Global Carbon Budget 2014. C. Le Quéré, R. Moriarty, R. M. Andrew, G. P. Peters, P. Ciais, P. Friedlingstein, S. D. Jones, S. Sitch, P. Tans, A. Arneth, T. A. Boden, L. Bopp, Y. Bozec, J. G. Canadell, F. Chevallier, C. E. Cosca, I. Harris, M. Hoppema, R. A. Houghton, J. I. House, T. Johannessen, E. Kato, A. K. Jain, R. F. Keeling, V. Kitidis, K. Klein Goldewijk, C. Koven, C. Landa, P. Landschützer, A. Lenton, I. Lima, G. Marland, J. T. Mathis, N. Metzl, Y. Nojiri, A. Olsen, W. Peters, T. Ono, B. Pfeil, B. Poulter, M. R. Raupach, P. Regnier, C. Rödenbeck, S. Saito, J. E. Salisbury, U. Schuster, J. Schwinger, R. Séférian, J. Segschneider, T. Steinhoff, B. D. Stocker, A. J. Sutton, T. Takahashi, B. Tilbrook, N. Viovy, Y.-P. Wang, R. Wanninkhof, G. Van der Werf, A. Wiltshire, and N. Zeng (2015). Earth System Science Data, DOI:10.5194/essd-7-47-2015
Available at: http://www.earth-syst-sci-data.net/7/47/2015/essd-7-47-2015.html

Gordon, T.J. 2003. Trend Impact Analysis. Published in Glenn, J.C. & Gordon, T. J. (eds.). Futures Research Methodology v2.0. Washington, DC: American Council for the United Nations University, The Millenium Project.

Greenpeace 2015. China’s Energy Challenge. China coal demand falls for twelve straight months. Greenpeace Energy Desk.
Available at: http://energydesk.greenpeace.org/2015/09/09/china-coal-demand-falls-for-eleven-straight-months/

Greeuw, S., van Asselt, M., Grosskurth, J., Storms, C., Rijkens-Klomp, N., Rothman, D. & Rotmans, J. 2000. Cloudy crystal balls. An assessment of recent European and global scenario studies and models. Experts' corner report. Prospects and scenarios No 4. European Environment Agency. Environmental issues series No 17. Copenhagen: EEA.
Available at: http://bookshop.europa.eu/en/cloudy-crystal-balls-pbKH3300170/

Hajkowicz, S. 2015. Global Megatrends. Seven Patterns of Change Shaping Our Future. Melbourne: CSIRO Publishing.

Hass-Klau, C. 1993. Impact of pedestrianization and traffic calming on retailing. A review of the evidence from Germany and the UK. Published in Transport Policy, vol. 1, issue 1, pp. 21-31.

Helen 2014. Biopolttoaineiden käytön lisääminen Helsingin energiantuotannossa. Ympäristövaikutusten arviointiselostus.
Available in Finnish at:
http://www.ymparisto.fi/download/noname/%7B1C088FB0-E530-453F-B580-56B97190C088%7D/97188

Heljo, J., Nippala, E. & Nuuttila, H. 2005. Rakennusten energiankulutus ja CO_2-ekv päästöt Suomessa. Ympäristöklusterin tutkimusohjelma. Rakennuskannan ekotehokkaampi energiankäyttö (EKOREM) -projekti. Loppuraportti. Tampere University of Technology. Institute of Construction Economics. Report 2005:4.
Available in Finnish at:
http://webhotel2.tut.fi/ee/Materiaali/Ekorem/EKOREM_Loppuraportti_051214.pdf

Helsinki 2002. Helsingin Yleiskaava 2002, ehdotus. Vaikutusten arviointi. Luonnoksen ilmastovaikutukset. Helsingin kaupunkisuunnitteluviraston yleissuunnitteluosaston selvityksiä 2002:13. Helsinki City Planning Department.
Available in Finnish at:
http://www.hel.fi/static/ksv/www/yk2002/Luonnoksen%20ilmastovaikutukset%20Arvio12.pdf

Helsinki 2012. Helsingin kaupungin ympäristöpolitiikka.
Available in Finnish at:
http://www.hel.fi/hki/ymk/fi/Ymp_rist_ohjelmat/Helsingin+kaupungin+ymp_rist_politiikka

Helsinki 2013a. Strategiaohjelma 2013–2016.
Available in Finnish at:

http://www.hel.fi/static/taske/julkaisut/2013/Strategiaohjelma_2013-2016_Kh_250313.pdf

Helsinki 2013b. Tilastoja 2013:29. Helsingin ja Helsingin seudun väestöennuste 2014–2050. Ennuste alueittain 2014–2023. City of Helsinki Urban Facts.
Available in Finnish at:
http://www.hel.fi/hel2/tietokeskus/julkaisut/pdf/13_09_18_Tilastoja_29_Vuori.pdf

Helsinki 2013c. Urban plan - the new Helsinki city plan. Vision 2050. Reports by the Helsinki City Planning Department general planning unit 2013:23
Available at: http://www.hel.fi/hel2/ksv/julkaisut/yos_2013-23_en.pdf

Helsinki 2013d. Helsingin ilmastopäästöjen vähentämisen mahdollisuudet yleiskaavassa. Helsingin kaupunkisuunnitteluviraston yleissuunnitteluosaston selvityksiä 2013:11. Tani, A. Helsinki City Planning Department .
Available in Finnish at: http://www.hel.fi/hel2/ksv/julkaisut/yos_2013-11.pdf

Helsinki 2013e. Esikaupunkien asemanseutujen kehittämisen edellytykset. Helsingin kaupunkisuunnitteluviraston yleissuunnitteluosaston selvityksiä 2013:3. Ahokas, S. Helsinki City Planning Department .
Available in Finnish at: http://www.hel.fi/hel2/ksv/julkaisut/yos_2013-3.pdf

Helsinki 2014a. Yleiskaavan ilmastovaikutusten arviointi. Helsingin kaupunkisuunnitteluviraston yleissuunnitteluosaston selvityksiä 2014:42. Helsinki City Planning Department.
Available in Finnish at: http://www.hel.fi/hel2/ksv/julkaisut/yos_2014-42.pdf

Helsinki 2014b. Helsingin 30 % päästövähennysselvitys. Kasvihuonekaasupäästöjen kehitys ja vähentämisen kustannustehokkaat toimenpiteet. Helsingin kaupungin ympäristökeskuksen julkaisuja 7/2014. Helsinki City Environment Centre.
Available in Finnish at: http://www.hel.fi/static/ymk/julkaisut/julkaisu-07-14.pdf

Helsinki 2014c. Liikenteen kehitys Helsingissä vuonna 2013. Helsingin kaupunkisuunnitteluviraston yleissuunnitteluosaston selvityksiä 2014:1. Helsinki

City Planning Department.
Available in Finnish at: http://www.hel.fi/hel2/ksv/julkaisut/los_2014-1.pdf

Helsinki 2015a. Yleiskaava. Helsinki City Planning Department.
Available in Finnish at: http://www.yleiskaava.fi/yleiskaava/

Helsinki 2015b. Aineistot. Yleiskaava. Helsinki City Planning Department.
Available in Finnish at: http://www.yleiskaava.fi/yleiskaava/aineistot/

Helsinki 2015c. Kaupunkikaava. Helsingin uusi yleiskaava. Ehdotus 6.10.2015. Helsingin kaupunkisuunnitteluviraston yleissuunnitteluosaston selvityksiä 2015:7. Helsinki City Planning Department.
Available in Finnish at: http://www.hel.fi/hel2/ksv/julkaisut/yos_2015-7.pdf

Helsinki 2015d. Kaupunkikaava. Helsingin uusi yleiskaava. Kaavakartta. Helsinki City Planning Department.
Available in Finnish at:
http://www.hel.fi/hel2/ksv/Liitteet/2015_kaava/yleiskaavaehdotus_kartta_061015.pdf

Howard, E. 1902. Garden Cities of Tomorrow. MIT Press edition 1967.
Available at: http://www.sacred-texts.com/utopia/gcot/index.htm

HSL 2013. Helsingin seudun liikenne. HLJ 2015. Liikkumistottumukset Helsingin seudulla 2012. Tausta-aineisto. Edita Prima Oy: Helsinki.
Available in Finnish at:
https://www.hsl.fi/sites/default/files/uploads/liikkumistottumukset_helsingin_seudulla2012.pdf

HSY 2011. EUCO2 80/50. Euroopan kaupunkiseutujen vähähiilinen tulevaisuus. Pääkaupunkiseudun skenaariotyöpajat 5.-8.10.2010. HSY:n julkaisuja 1/2011. Helsinki:Edita Prima Oy.
Available in Finnish at:
https://www.hsy.fi/sites/Esitteet/EsitteetKatalogi/Julkaisusarja/1_2011_euco2.pdf

HSY 2015a. Pääkaupunkiseudun kasvihuonekaasupäästöt. Päästötaulukot. KHK-päästöt 1990 ja 2000–2014. Helsinki Region Environmental Services Authority. Available in Finnish at: https://www.hsy.fi/fi/asiantuntijalle/ilmastonmuutos/hillinta/seuranta/Sivut/Paastot.aspx

HSY 2015b. The Climate Swing Sceanrio Tool. Helsinki Region Environmental Services Authority.
Available at: www.ilmastoveivi.fi

HSY 2015c. ELIAS - Elinvoimaiset asemanseudut Helsingin seudulla ja Uudellamaalla. Tynys, P. PP-presentation 17.9.2015. Helsinki Region Environmental Services Authority.
Available in Finnish at: http://www.mal-verkosto.fi/filebank/1122-Tynys-HSY_ELIAS-asemanseudut_20150917_SYKE.pdf

IEA 2008. World Energy Outlook 2008. International Energy Agency.
Available at: http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf

IEA 2013. Nordic Energy Technology Perspectives. Pathways to a Carbon Neutral Energy Future. Pathways to a Carbon Neutral Energy Future. International Energy Agency.
Available at: http://www.nordicenergy.org/wp-content/uploads/2012/03/Nordic-Energy-Technology-Perspectives.pdf

IEA 2015. Global energy-related emissions of carbon dioxide stalled in 2014. International Energy Agency.
Available at: http://www.iea.org/newsroomandevents/news/2015/march/global-energy-related-emissions-of-carbon-dioxide-stalled-in-2014.html

ILKKA 2014. Ilmastonkestävä kaupunki – työkaluja suunnitteluun. Kuntien hiilitasekartoitus. Osa 1. Helsingin, Lahden, Turun, Vantaan ja Espoon hiilinielut ja hiilivarastot. Helsingin kaupungin ympäristökeskus. Simosol & Ramboll.
Available in Finnish at: http://www.ymk-

projektit.fi/suunnitteluopas/files/2014/07/ILKKA_Kuntien-hiilitasekartoitus_osa_1_final.pdf

IPCC 2013. Stocker, T.F., Qin, D., Plattner, G-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P.M. (eds.). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, USA: Cambridge University Press. Available at: http://www.ipcc.ch/report/ar5/wg1/

IPCC 2014a. Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., & White, L.L. (eds.). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. : Cambridge, United Kingdom and New York, USA: Cambridge University Press. Available at: http://www.ipcc.ch/report/ar5/wg2/

IPCC 2014b. Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel T. & Minx, J. C. (eds.). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, USA: Cambridge University Press.
Available at: http://www.ipcc.ch/report/ar5/wg3/

Jacobs, J. 1961. The Death and Life of Great American Cities. New York: Random House.

Jenks, M., Burton, E. & Williams, K. 1995. The Compact City: A Sustainable Urban Form? Oxford: Oxford Brookes University.

Jenks, M. & Dempsey, N. 2005. The Language and Meaning of Density. Published in Jenks, M. & Dempsey, N. (eds.) 2005. Future Forms and Design For Sustainable Cities. Oxford: Architectural Press.

Kaupunkitutkimus 2014. Laakso, S. & Lahdelma, T. Uudenmaan ja Helsingin seudun työpaikkaprojektiot 04/2012. Kaupunkitutkimus TA Oy.
Available in Finnish at: http://www.kaupunkitutkimusta.fi/wp-content/uploads/2013/12/RAPORTTI_Työpaikkaprojektiot_Um_V2_2012_04.pdf

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havránek, M., Pataki, D., Phdungsilp, A., Ramaswami, A. & Villalba Mendez, G. 2009. Greenhouse Gas Emissions from Global Cities. Published in Environmental Science & Technology, 43 (19), pp. 7297–7302.
Available at: http://pubs.acs.org/doi/pdf/10.1021/es900213p

Kemp-Benedict, E. 2004. From Narrative to Number: A Role for Quantitative Models in Scenario Analysis. iEMSs 2004 International Congress: "Complexity and Integrated Resources Management". International Environmental Modelling and Software Societey, Osnabrueck, Germany, June 2004.
Available at: http://www.iemss.org/iemss2004/pdf/scenario/kempfrom.pdf

Kosow, H. & Gaßner, R. 2008. Methods of future and scenario analysis. Overview, assessment, and selection criteria. Studies 39. Deutsches Institut für Entwicklungspolitik.
Available at http://www.die-gdi.de/uploads/media/Studies_39.2008.pdf

Kourtit, K. & Nijkamp, P. 2013. The new urban world. The challenge of cities in decline. Published in Romanian Journal of Regional Science, vol. 7, no. 2, pp. 9-28.

KPMG 2014. Future State 2030. The global megatrends shaping governments. Available at: https://assets.kpmg.com/content/dam/kpmg/pdf/2014/02/future-state-2030-v3.pdf

Lahti, P, Haapio, A., Nystedt, Å., Puurunen, E., Tuominen, P. & Wahlgren I. 2012. Ekologisen ja ekotehokkaan kaupungin kehitysnäkymät. 40

englanninkielistä kirjaa kaupunkikehityksen ekologiasta, ekotehokkuudesta ja niiden arvioinnista. VTT Tutkimusraportti VTT-R-03879-12.
Available in Finnish at: http://www.vtt.fi/inf/julkaisut/muut/2012/VTT-R-03879-12.pdf

Lampinen, S. 2015. Here is the road, where is the city. Transport planning and urban sprawl. Acta Universitatis Tamperensis 2090. Tampere: Tampere University Press Tampere.
Available at in Finnish at: http://tampub.uta.fi/bitstream/handle/10024/97965/978-951-44-9894-7.pdf

Lee, M. 2012. Knowing our future: The startling case for futurology. Oxford: Infinite Ideas Limited.

Lenzen, M., Wood, R. & Foran, B. 2008. Direct versus Embodied Energy. The Need for Urban Lifestyle Transitions. Published in Droege, P. (ed.) Urban Energy Transition. From Fossil Fuels to Renewable Power, pp. 91–120. Oxford: Elsevier.

Marcott, S.A., Shakun, J.D., Clark, P.U. & Mix, A.C. 2013. A Reconstruction of Regional and Global Temperature for the Past 11,300 Years. Published in Science, vol. 339, no. 6124, pp. 1198-1201.

McCormick, K., Anderberg, S., Coenen, L. & Neij, L. 2013. Advancing Sustainable Urban Transformation. Published in Journal of Cleaner Production, vol. 50, pp. 1-11.
Available at: http://lup.lub.lu.se/record/3799933/file/3799934.pdf

Meadows, D.H, Meadows, D.L., Randers, J. & Behrens III, W. 1972. The Limits to Growth. A Report For the Club of Rome’s Project on the Predicament of Mankind. A Potomac Associates Book. New York: Universe Books.

ME 2005. Land use planning system. Ministry of the Environment.
Available at: http://www.ymparisto.fi/en-us/Living_environment_and_planning/Land_use_planning_system

ME 2008. Valtioneuvoston päätös valtakunnallisista alueidenkäyttötavoitteista 30.11.2000 ja alueidenkäyttötavoitteiden tarkistamisesta 13.11.2008. Ministry of Environment. Council of State.
Available in Finnish at:
http://www.ymparisto.fi/download/noname/%7BA2516D1A-DF52-4E0B-A00C-E2DDC51EF440%7D/59386

MEE 2013. Kansallinen energia- ja ilmastostrategia. Taustaraportti. Ministry of Employment and the Economy.
Available in Finnish at: https://www.tem.fi/files/36279/Kansallinen_energia-_ja_ilmastostrategia_taustaraportti.pdf

Mikkonen, S., Laine, M., Mäkelä, H.M., Gregow, H., Tuomenvirta, H., Lahtinen, M. & Laaksonen, A. 2014. Trends in the average temperature in Finland, 1847–2013. Published in Stochastic Environmental Research and Risk Assessment. Volume 29, Issue 6, pp. 1521-1529.
Available at: http://link.springer.com/content/pdf/10.1007%2Fs00477-014-0992-2.pdf

Mindali, O., Raveh, A. & Salomon, I. 2004. Urban density and energy consumption. A new look at old statistics. Published in Transportation Research Part A: Policy and Practice. Vol. 38, issue 2, pp. 143-162.

Motiva 2014. Aurinkosähkö. Aurinkopaneelien asentaminen.
Available in Finnish at:
http://www.motiva.fi/toimialueet/uusiutuva_energia/aurinkoenergia/aurinkosahko/hankinta_ja_asennus/aurinkopaneelien_asentaminen

Motiva 2015. Kiinteistöjen energianhallinta. Kulutuksen normitus. Laskukaavat: lämmitysenergiankulutus.
Available in Finnish at:
http://www.motiva.fi/julkinen_sektori/energiankayton_tehostaminen/kiinteistojen_energianhallinta/kulutuksen_normitus/laskukaavat_lammitysenergiankulutus

Naisbitt, J. 1982. Megatrends. Ten New Directions Transforming Our Lives. New York: Warner Books.

Nasa/GISS 2015. GISS Surface Temperature Analysis (GISTEMP). Goddard Institute for Space Studies. National Aeronautics and Space Administration. Available at: http://data.giss.nasa.gov/gistemp/

Neuman, M. 2005. The Compact City Fallacy. Published in Journal of Planning Education and Research, issue 25, pp. 11-26.
Available at: http://understandtheplan.info/wp-content/uploads/2014/08/The-Compact-City-Fallacy.pdf

NSIDC 2012. Arctic sea ice extent settles at record seasonal minimum. Arctic Sea Ice News & Analysis. The National Snow and Ice Data Center.
Available at: http://nsidc.org/arcticseaicenews/2012/09/arctic-sea-ice-extent-settles-at-record-seasonal-minimum/

Nylund, N-O. 2013. Teknologian tutkimuskeskus VTT. Asiantuntijahaastattelu. ILARI-perusskenaario ja Liisa-malli. 5.12.2013.

OECD 2010. Cities and Climate Change. OECD Publishing.
Available at: http://dx.doi.org/10.1787/9789264091375-en

Ottelin, J., Heinonen, J. & Junnila, S. 2015. New Energy Efficient Housing Has Reduced Carbon Footprints in Outer but Not in Inner Urban Areas. Published in Environmental Science & Technology, vol. 49, issue 16, pp. 9574-9583.

Petäjä, J. 2007. Kasvener. Kuntatason kasvihuonekaasu- ja energiatasemalli. [Excel-tiedosto].

PwC 2015. Megatrends. PricewaterhouseCoopers.
Available at: http://www.pwc.co.uk/issues/megatrends.html

Rajala, P., Hirvonen, H., Perttula, S., Lähde, E., Pulkka, P., Jarmala, L., Laukkanen, J., Patronen, J., Jokinen, M., Rintala, T., Rajakallio, K. & Kauppinen, T. 2010. Energiatehokkuus kaavoituksessa. Skaftkärr, Porvoo. Kaavarunkovaiheen loppuraportti. Porvoon kaupunki, Sitra, Posintra Oy, Porvoon Energia Oy, Ympäristöministeriö. Sitran selvityksiä 41.

Available in Finnish at: https://www.sitra.fi/julkaisut/Selvityksi%C3%A4-sarja/Selvityksi%C3%A4%2041.pdf

Robine, J-M., Cheung, S.L., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J-P. & Herrmann, F.R.. 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. Published in Comptes Rendus Biologies, volume 331, issue 2, pp. 171-178.

Rubin, A. 2000. Megatrendit. Tulevaisuudentutkimus. Futurix.
Available in Finnish at:
http://www.futunet.org/fi/materiaalit/tutkimus/03_lahestymistapoina/07_megatrendit/

Ruosteenoja, K. 2013. Maailmanlaajuisiin ilmastomalleihin perustuvia lämpötila- ja sademääräskenaarioita. Sektoritutkimusohjelman ilmastoskenaariot (SETUKLIM) 1. osahanke. Finnish Meteorological Institute.
Available in Finnish at:
http://ilmatieteenlaitos.fi/c/document_library/get_file?uuid=c4c5bf12-655e-467a-9ee0-f06d8145aaa6&groupId=30106

Satterthwaite, D. 1999. The key issues and the works included. Published in Satterthwaite, D. (ed). The Earthscan Reader in Sustainable Cities, pp. 2-21. London: Earthscan.

Shakun, J.D., Clark, P.U., He, F., Marcott, S.A., Mix, A.C., Liu, X.L., Otto-Bliesner, B., Schmittner, A. & Bard, E. 2012. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. Published in Nature, vol. 484, pp. 49–54.

Siitonen, S. & Holmberg, H. 2010. Estimating the value of energy saving in industry by different cost allocation methods. International Journal of Energy Research. Volume 36, Issue 3, pp. 324–334, 10 March 2012.

Sirr, L., Stewart, D. & Kelly, R. 2006. Smart Growth. A Buffer Zone Between Decentrist And Centrist Theory? Published in International Journal of Sustainable Development, Vol. 1, Iss. 1, pp. 1-13.

Available at:
http://arrow.dit.ie/cgi/viewcontent.cgi?article=1003&context=beschrecart

Slocum-Bradley, N. & van Langenhove, L. 2011. Participatory foresight techniques applied to regional integration processes. Published in De Lombaerde, P., Flóres Jr, R., Iapadre, P.L. & Schulz, M. (eds.). The regional integration manual. Quantitative and qualitative methods. Routledge/Warwick studies in globalisation. Abingdon: Routledge.

Solomon, S., Plattner, G-K., Knutti, R. & Friedlingstein, P. 2009. Irreversible climate change due to carbon dioxide emissions. Published in Proceedings of the National Academy of Sciences, vol. 106, no. 6, pp. 1704-1709,
Available at: http://www.pnas.org/content/106/6/1704

Swart, R.J., Raskin, P. & Robinson, C. 2004. The problem of the future, Sustainability science and scenario analysis. Published in Global Environmental Change 14 (2004), pp. 137-146.

SYKE 2014. Parjanne, A. & Huokuna, M. (eds.) Tulviin varautuminen rakentamisessa. Opas alimpien rakentamiskorkeuksien määrittämiseksi ranta-alueilla. Ympäristöopas 2014. Finnish Environment Institute, Finnish Meteorological Institute, Ministry of Environment & Ministry of Agriculture and Forestry. Helsinki: Edita Prima Oy.
Available in Finnish at: http://hdl.handle.net/10138/135189

SYKE 2015a. Kaupunkien ja kuntien alueellinen ekolaskuri - KEKO B.
Available in Finnish at: http://www.syke.fi/fi-FI/Tutkimus__kehittaminen/Tutkimus_ja_kehittamishankkeet/Hankkeet/Kaupunkien_ja_kuntien_alueellinen_ekolaskuri__KEKO_B

SYKE 2015b. Yhdyskuntarakenteen vyöhykeanalyysi. Liikkumistottumukset auto-, joukkoliikenne- ja jalankulkuvyöhykkeillä & yhdyskuntarakenteen vyöhykkeet suunnittelussa (Urban Zone 1-3).
Available in Finnish at: http://www.syke.fi/fi-FI/Tutkimus__kehittaminen/Tutkimus_ja_kehittamishankkeet/Hankkeet/Yhdyskuntarakenteen_vyohykeanalyysi_liikkumistottumukset_auto_joukkoliikenne_ja_jal

ankulkuvyohykkeilla_Urban_Zone_1/Yhdyskuntarakenteen_vyohykeanalyysi_liik(4774)

Säynäjoki, A., Heinonen, J. & Junnila, S. 2012. A scenario analysis of the life cycle greenhouse gas emissions of a new residential area. Published in Environmental Research Letters, vol. 7, no. 3, pp. 1-10.
Available at: http://iopscience.iop.org/article/10.1088/1748-9326/7/3/034037/pdf

Tachieva, G. 2010. Sprawl Repair Manual. Washington: Island Press.

Tilastokeskus 2014a. Asuminen. Rakennukset ja kesämökit. Rakennukset (lkm, m2) käyttötarkoituksen ja lämmitysaineen mukaan.
Available in Finnish at:
http://pxweb2.stat.fi/Database/StatFin/Asu/rakke/rakke_fi.asp

Tilastokeskus 2014b. Energiatilasto 2013.
Available in Finnish at:
http://pxweb2.stat.fi/sahkoiset_julkaisut/energia2013/alku.htm

TraFi 2015. Liikenteen turvallisuusvirasto. Tilastot. Tieliikenne. Ensirekisteröityjen henkilöautojen keskimääräiset CO2-päästöt.
Available in Finnish at:
http://www.trafi.fi/tietopalvelut/tilastot/tieliikenne/ensirekisteroinnit/ensirekisterointien_paastotilastot

UN 2015. World Urbanization Prospects. The 2014 Revision. Department of Economic and Social Affairs. Population Division. United Nations. ST/ESA/SER.A/366. New York: United Nations.
Available at: http://esa.un.org/unpd/wup/FinalReport/WUP2014-Report.pdf

UN-Habitat 2011. Cities and Climate Change. Global Report on Human Settlements 2011. United Nations Human Settlements Programme.
Available at: http://unhabitat.org/wp-content/plugins/wpdm-download-button/images/10.png

Unruh, G.C. 2000. Understanding carbon lock-in. Published in Energy Policy, vol. 28, issue 12, pp. 817-830.

UNTV 2015. SDG Dilma Roussef. United Nations audiovisual library. UNIFEED-UNTV.
Available at: http://www.unmultimedia.org/avlibrary/asset/1446/1446511/

USGCRP 2014. The National Climate Assessment. Climate change impacts in the United States. U.S. Global Change Research Program.
Available at: http://nca2014.globalchange.gov/

Vihola, J & Heljo, J. 2012. Lämmitystapojen kehitys 2000–2012. Aineistoselvitys. Tampereen teknillinen yliopisto. Rakennustekniikan laitos. Rakennustuotanto ja -talous. Raportti 10.
Available in Finnish at:
https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/21114/vihola_heljo_lammitystapojen_kehitys_2000_2012.pdf?sequence=1

VRK 2014. Väestörekisterikeskus. Suomen asukasluku kunnittain suuruusjärjestyksessä.
Available in Finnish at: http://www.vrk.fi/default.aspx?id=278&docid=3973

VTT 2014. Lipasto. Pääkaupunkiseudun tieliikenteen päästöt.

Ympäristöministeriö 2001. Suomen ympäristö 473. Kansallinen ilmasto-ohjelma. Ympäristöministeriön sektoriselvitys. Helsinki: Oy Edita Ab.
Available in Finnish at:
http://www.ymparisto.fi/default.asp?contentid=67221&lan=fi

Wamsler, C., Brink, E. & Rivera, C. 2013. Planning for climate change in urban areas. From theory to practice. Published in Journal of Cleaner Production, vol. 50, pp. 68-81.
Available at: http://lup.lub.lu.se/record/3628877/file/3912019.pdf

Welbank, M. 1996. The Search for a Sustainable Urban Form. Published in Jenks, M. Burton, E. & Williams, K. (eds.) The Compact City: A Sustainable Urban Form? Pp. 74-82. London: E & FN Spon.

World Bank 2010. Cities and Climate Change: an Urgent Agenda. Urban development series. Knowledge papers. Urban development & local government. The World Bank.
Available at: http://siteresources.worldbank.org/INTUWM/Resources/340232-1205330656272/CitiesandClimateChange.pdf

Worldwatch 2015. Worldwatch Institute. Vital Signs. Global trends that shape our future.
Available at : http://vitalsigns.worldwatch.org/

Östersundom 2015. Yhteinen Östersundom. Website.
Available in Finnish at: http://yhteinenostersundom.fi/

APPENDICES

Appendix 1. The default values used in the Climate Swing scenario tool

Specific consumption of electric heating	125 kWh/m2
Ground source heat pumps COP[14]	3
Emission factor of electric heating	400 g CO2-e/kWh
Oil consumption of oil heating	170 kWh/m2
Oil-fired boiler efficiency	0,78
Bio-share of heating oil 2012	5 %
Heating demand correction factor 2012	1,03
District heating heat pumps COP	4
Bio-share of mixed waste	50 %
CCS[15] emission reduction efficiency	75 %
Energy consumption of an electric car	17 kWh/100 km
The emissions of a modern car	180 g/km
Energy consumption factor of a hydrogen car cf. electric car	3
Bio-share of gasoline and diesel	6 %

---

[14] COP = coefficient of performance

[15] CCS = carbon capture and storage

Emission factors of fuels

	gCO_2/kWh	$kgCH_4/TJ$	kgN_2O/TJ
Oil heating (light fuel oil)	264	5	2
Coal	341	1	1,5
Natural gas	198	1	0,1
Heavy fuel oil	284	3	0,6
Biomass	(395)	30	4
Mixed waste (bio-share 50 %)	144	30	4
Default oxidation factor = 0,99			
GWP[16] methane = 25			
GWP nitrous oxide = 298			

---

[16] GWP = global warming potential (CO_2 = 1)

Appendix 2. The user-definable variables of the Climate Swing scenario tool

GENERAL			
Population		number of residents	
Jobs		number of jobs	
Share of the jobs	Services	%	
	Industry	%	
ELECTRICITY			
Electricity consumption	Residential	kWh/year/pers.	
	Services	kWh/year/job	
	Industry	kWh/year/job	
Electricity split between local renewables and grid		Renewables	Grid
	Residential	%	%
	Services	%	%
	Industry	%	%
Finnish electricity production	Hydro	% of supply	
	Wind	%	
	Nuclear	%	
	Coal	%	
	Oil	%	
	Gas	%	

	Peat	%		
	Bio	%		
	Waste	%		
	Import/other renewables	%		
HEATING OF BUILDINGS				
Floor area	Residential	kWh/year/pers.		
	Services	kWh/year/job		
	Industry	kWh/year/job		
Energy efficiency		District heating	Separate heating	
	Residential	% change in specific consumption	% change	
	Services	% change	% change	
	Industry	% change	% change	
Heating method		District heating	Separate heating	
	Residential	% of floor area	%	
	Services	%	%	
	Industry	%	%	
Separate heating split		Residential	Services	Industry
	Electric	% of floor area	%	%

	Oil	%	%	%
	Heat pumps[17]	%	%	%
	Solar	%	%	%
	Wood pellets and other bio	%	%	%
Fuel-mix of district heat production	Coal	% of the total energy content of fuels		
	Gas	%		
	Oil	%		
	Bio	%		
	Waste	%		
	Heat pumps	%		
CCS		% share of power plant units		
TRANSPORT				
Passenger traffic	Private cars and motorcycles	km/day/pers.		
	Buses	km/day/pers.		
	Rail	km/day/pers.		

---

[17] = ground-source heat pumps

	Walking and cycling	km/day/pers.	
Freight and marine traffic	Vans	% change of traffic volume	
	Trucks	% change of traffic volume	
	Ports	% change of port visits	
Vehicle power sources		Cars	Ships and boats
	Electric	% share of vehicle fleet	% share of vehicle fleet
	Hydrogen	%	%
	Biogas	%	%
	Bio ethanol	%	%
	Gasoline, diesel, gas	%	%
Fuel consumption and biofuels	Gasoline, diesel & gas fuelled vehicles	Cars	Ships and boats
	Change in consumption	%	%
	Share of biofuels	%	%

	Rail traffic	% change of electricity consumption	