POCACITO

european post-carbon cities of tomorrow

SUSTAINABILITY IMPACTS OF POST CARBON CITIES

QUALITATIVE AND QUANTITATIVE ANALYSIS OF BAU AND PC2050 SCENARIOS

CONTRIBUTING PARTNERS

IVL, Aarhus University, FEEM and CUNI

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AUTHOR(S)

Main author and editor: Steve Harris, IVL

With contributions from:

Albin Pettersson, IVL

Gregor Levin and Marianne Zanderson, Aarhus University

Jan Weinzettel, CUNI

Margaretha Breil and Andrea Bigano - FEEM

Project coordination and editing provided by Ecologic Institute.

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LIST OF ABBREVIATIONS

APA	Portuguese Environment Agency
APMP	Ambient particulate matter pollution
BAU	Business-as-usual
COICOP	Classification of Individual Consumption According to Purpose
CPH	Copenhagen
DGEG	Directorate-General for Energy and Geology
EE-MRIO	Environmentally extended multi-regional input output analysis
INE	Portuguese
MCI	Manufacturing, construction and installation
MRIO	Multi-regional input output analysis
NUTS	Nomenclature of territorial units for statistics
NPV	Net Present Value
nZEB	Nearly Zero Emission Buildings
O&M	Operation and maintenance
PC2050	Post Carbon Scenario for 2050
RET	Renewable energy technologies
RUM	Random Utility Model
WP	Work Package

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I EXECUTIVE SUMMARY

I.I INTRODUCTION

It is well documented that the world's population is becoming increasingly urbanised, and it is expected that by 2050 more than 66% will live in urban areas (UN, 2014). Europe already has 74% of its population living in urban areas which is expected to rise to 80% by 2050 (UN, 2014). Meanwhile due to the socio-economic strength and importance of cities, combined with related consumption, cities are responsible for over 78% of the global energy consumption and over 60% of greenhouse gas emissions (UN Habitat, 2016).

The POCACITO project involves working with ten European cities to develop local strategies to reach post carbon status by 2050. Local stakeholders were engaged in a series of workshops involving a visioning and backcasting exercise to develop strategies for post carbon 2050 scenarios. The ten case study cities are Barcelona, Copenhagen, Istanbul, Lisbon, Litoměřice, Malmö, Milan/Turin, Rostock and Zagreb.

This document presents the modelling and quantification of the post carbon scenarios (PC 2050) and compares the modelled outcome with business as usual (BAU) scenarios. The subsequent aim of POCACITO was to present the gaps in the proposed PC2050 scenarios and develop enhanced local Roadmaps, ultimately leading to a European Roadmap that facilitates the transition of European cities to a post-carbon future. Fundamentally, the project views the move to post carbon as both an opportunity, as well as a necessity, to ensure the three pillars of sustainability (economic, environmental and social) are incorporated into the essence of the city, thereby transitioning cities, to low carbon, liveable and equal places where a high quality of life is central.

This document extends and builds on the POCACITO research presented in "Quantification of the Case Study Cities" (Harris et al. 2016) that modelled and quantified the scenarios in terms of the main physical components that includes population, energy use, transport, GDP and employment.

In order to model, quantify and compare the future scenarios a range of complementary qualitative and quantitative methodologies are utilised. In particular, city scale assessments of the impacts of the scenarios are supported with a footprint analysis (using environmentally extended multi-regional input-output analysis) that enables a comparison of city system level impacts with the total footprint impact occurring through the supply chain on a global level. This is supplemented with a semi-quantitative analysis of sustainability key performance indicators, an analysis of potential land use changes (urban sprawl) and a socio-economic assessment.

I.II METHODOLOGY

The methodology and approach was presented in "Quantification of the Case Study Cities" Harris et al. 2016). It is based on first establishing the current trends for the main components based on historical data. BAU is then projected from the current trends, and where appropriate, considers recent progress made in relevant ongoing and planned projects. PC 2050 is developed from the vision and qualitative scenarios developed in stakeholder workshops presented in "Report on Stakeholder Workshops" (Breil et al. 2015). It is therefore based on an interpretation of the visions, actions and milestones developed in the workshops. This forms the basis for the modelling the impacts of the cities.

The impacts methodology consists of the following four main components:

1. KPI assessment and qualitative analysis
2. Quantitative analysis
    a. Energy and GHG
    b. Environmental footprint (using EE-MRIO)
3. Eco-system services
    a. Spatial modelling of city development for 2050
    b. Recreational benefits from urban green areas (only for Copenhagen and Malmö , and presented in the comparative assessment in Chapter 5)
4. Socio – economic assessment
    a. Investment costs
    b. Cost-benefit analysis

The Key Performance Indicator (KPI) assessment utilises the POCACITO KPI's (see "Report on Key Performance Indicator", (Selada *et al.* 2014)) to provide a semi-quantitative/score assessment of the likely outcome for each indicator under both of the scenarios.

The quantitative analysis consists of two components. The first focuses on the energy use and greenhouse gas (GHG) emissions that are projected to occur under the scenarios. These are based on standard ways of calculating the GHG emissions that result from activities within the city's territorial boundaries (i.e. from electricity, energy use in buildings and industry and transport) using standard emission factors. The second component is the assessment of the footprint of the cities activities including consumption using the MRIO methodology and the EXIOBASE database. This is based on the assumption and definition that the city footprint can be calculated from final demand of household consumption and government expenditure.

The potential impacts caused by urban sprawl and changes in land use are quantified by modelling a continuation of the recent trends. These aim to highlight the potential differences in city development between the BAU and PC2050 scenarios. A further socio-economic assessment provides an indication of the investment costs and compares this with potential benefits.

For the Copenhagen and Malmö case studies an additional assessment was made on the recreational benefits provided by urban green areas. Due to limitations in data availability and the project scope, this was only conducted for these two cities. However, together with the land use assessment it provides an indication of the value of green areas in cities.

I.III RESULTS

The results of the different methods of analysis for the future scenarios of the ten case study cities are presented in the following sections.

I.III.I KEY PERFORMANCE INDICATOR IMPACTS

The KPI modelling and analysis showed that most cities are performing well in most categories for both scenarios. In particular there is good to excellent performance in most of the environmental and energy related indicators. The exception to this is Istanbul, which due to a large increase in population, affluence, associated energy use, and limited progress in renewable energy, faces the risk of vastly increasing GHG emissions.

Despite the recent financial crisis and its impacts still being felt to some degree, many of the cities are continuing to develop well in terms of GDP. It is apparent however, that there is a clear difference between BAU and PC2050, with BAU in most cases only providing “likely positive” progress. This suggests that whilst many cities are heading in a positive direction under BAU, progress is likely to be too slow to achieve excellent results or post-carbon status.

Within the PC2050 scenarios there appears to be a gap for most cities with some environmental factors such as waste recovery. This is partly a reflection of the methodology used in the research, with a limited number of workshops and limited revisions of the actions and milestones associated with the scenarios.

A key area of concern is the poverty level for several of the cities with likely negative progress projected for Litoměřice, Milan, Rostock and Turin under BAU. These cities also have either negative progress or no progress under PC2050. For the majority of other cities the progress under PC2050 is projected to be only minor with only Istanbul having very positive progress. This is a reflection of the increasing disparity between rich and poor in many global cities.

I.III.II QUANTITATIVE ANALYSIS

ENERGY AND GHG EMISSIONS

Energy use per capita for the ten cities is compared in Figure 1. This shows that apart from Istanbul and Lisbon, energy use per capita declines in BAU, and for all cities under PC2050. Energy use per capita under PC2050 declines at various rates due to the associated actions and milestones stipulated under the individual PC2050. However, energy use is around 10 MWh per capita/year for the majority of cities, with Barcelona being the lowest at 6.8 MWh per capita/year. This suggests that there is much room for energy efficiency improvements in the majority of cities.

High energy use does not necessarily translate into high GHG emissions as comparison with Figure 2 illustrates. The three stand out performers under PC2050 are Barcelona, Copenhagen and Litoměřice, with 0.35 tCO_2e per capita/year, 0.18 tCO_2e per capita/year and 0.36 tCO_2e per capita/year, respectively. These cities are also the leading performers under BAU, with Copenhagen the lowest at 0.7 tCO_2e per capita/year.

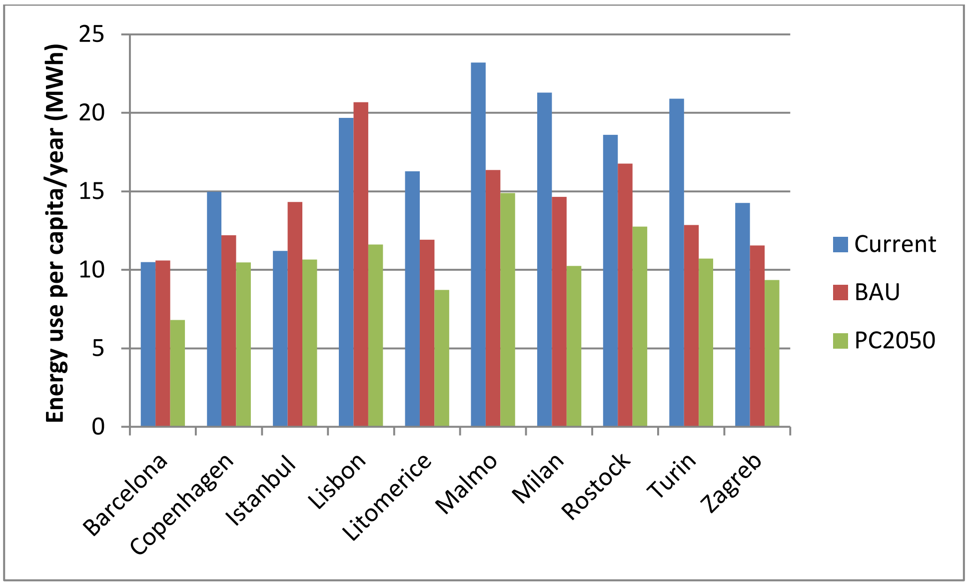

Figure 1: Energy use per capita currently compared to BAU and PC2050

Under PC2050 many cities are around 1 to 2 tCO_2e per capita/year, with Turin and Istanbul being the highest. This is primarily due to weak actions and milestones in the PC2050 workshops, and also partly due to poor data availability. Istanbul with its large increase in population, affluence, associated energy use, and limited progress in renewable energy, faces the risk of vastly increasing GHG emissions. This holds true also on a per capita basis under PC2050.

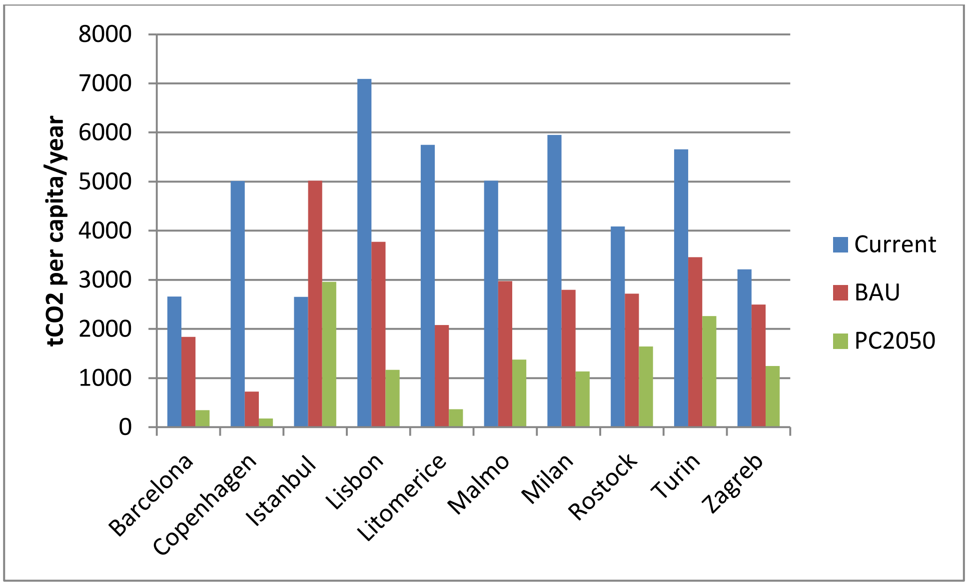

Figure 2: GHG emissions per capita

ECONOMIC OUTPUT PER UNIT OF GHG EMISSIONS

Figure 3 compares GHG emissions per EUR for the current situation and the scenarios and shows that for all cities there is improvement under both BAU and PC2050. Hence, for all cities the productivity per kgCO_2e is expected to improve under BAU and vastly improve under PC2050. In other words there is a decoupling of GHG emissions from economic output. This is further illustrated in Figure 4 that by contrast shows economic output (EUR) per kgCO_2e. Again the outstanding performers under PC2050 appear to be Barcelona and Copenhagen with Copenhagen generating 581 EUR/ kgCO_2e compared to 9.9 EUR/ kgCO_2e for the lowest performer, Istanbul. This is slightly more than the 2013 level for Milan and Malmö.

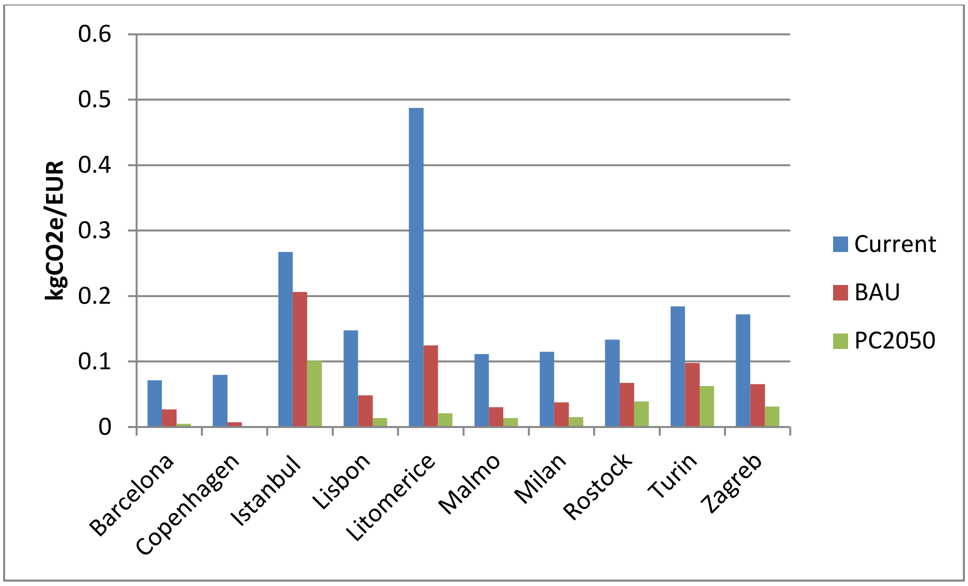

Figure 3: GHG emissions per EUR (GDP)

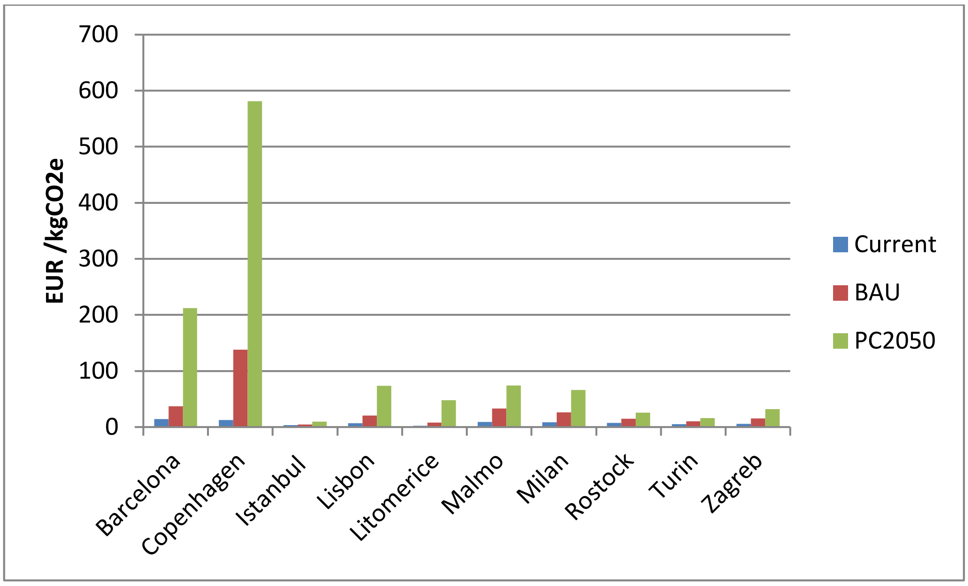

Figure 4: The amount of GDP (EUR) created for each kg of GHG emission

I.III.III FOOTPRINT ANALYSIS (EE-MRIO)

The footprint analysis performed using EE-MRIO delivered very different results for GHG emissions than for the territorial calculations. As discussed above, GHG emissions on a per capita basis decrease for the majority of cities under both BAU and PC2050 (but most dramatically under PC2050).

In comparison, Figure 5 shows that the total GHG emissions per capita increases for eight of the cities under BAU and PC2050. Despite direct emissions falling for the majority of cities under PC2050 the upstream emissions resulting from consumption increases markedly for these cities. The only exceptions are for Milan and Turin which both demonstrate a slight decrease. This is most probably linked to more modest increases in GDP per capita for these cities, but may also be due to limitations of the modelling within the MRIO database. In other words, the adjustments made to the energy profiles of the cities were complex and it was difficult to translate the cities energy profile (which includes all energy use of the city) into related to consumption.

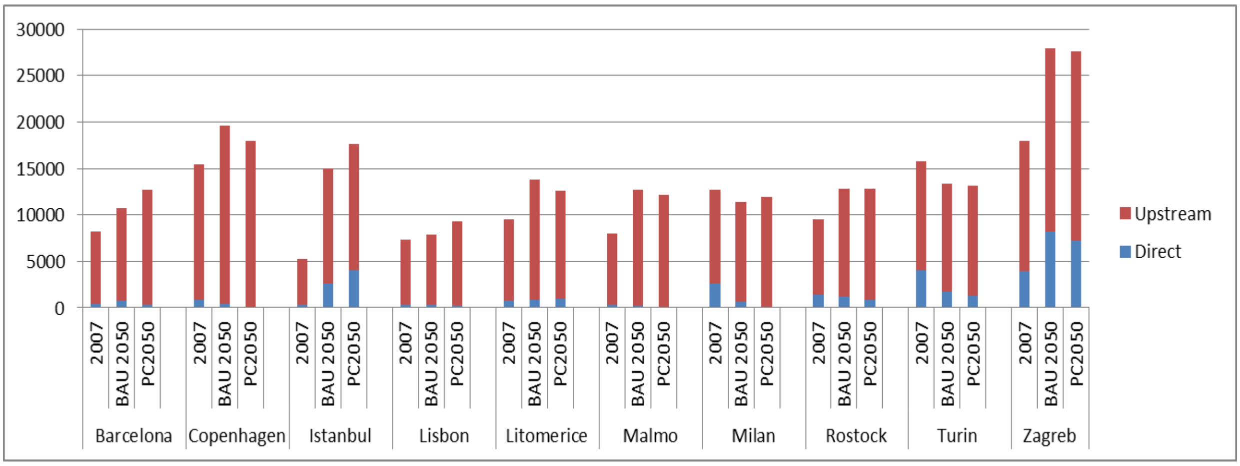

Figure 5: Direct and indirect GHG emissions for all case study cities for 2007, BAU and PC2050

In Figure 6 and Figure 7 the increase in GHG emissions with respect to the base year are compared using the standard territorial method and the MRIO footprint method. This shows that in the former traditional calculation method the GHG emissions per capita decreases for all cities (apart from Istanbul) in both scenarios. The decrease under PC2050 ranges from 60% for Rostock and Turin, up to 96% for Copenhagen.

Conversely, in Figure 7 it can be seen that the total footprint emissions increase for all cities apart from Milan and Turin. Under PC2050 the increase ranges from 234% in Istanbul to 16%, and the majority increase is between 30% and 50%.

This is partly due to the focus of the developed scenarios, in that the city scenarios were generally focussed on energy use and production, and not consumption. However, it also shows that without such a focus European cities risk falling well short of being low/zero carbon and will merely shift the emissions abroad unless consumption is specifically addressed. Recent studies such as Chen *et al.* (2016) which examined five Australian cities also support the notion that a vast share of footprint emissions occur upstream and overseas. They found that over half of the embodied emissions occur from imports.

A further reason for the increasing GHG emissions of the scenarios is also down to the background modelling assumptions. These are derived from standard projections on 2050 efficiencies obtained from reports from international organisations such as the International Energy Agency, World Bank, EU and UN. The background productions system (i.e. the systems supporting the manufacturing of the products) the is assumed to be the same for both BAU and PC2050 as we assume that the actions made by the ten case study cities will not impact on this background system.

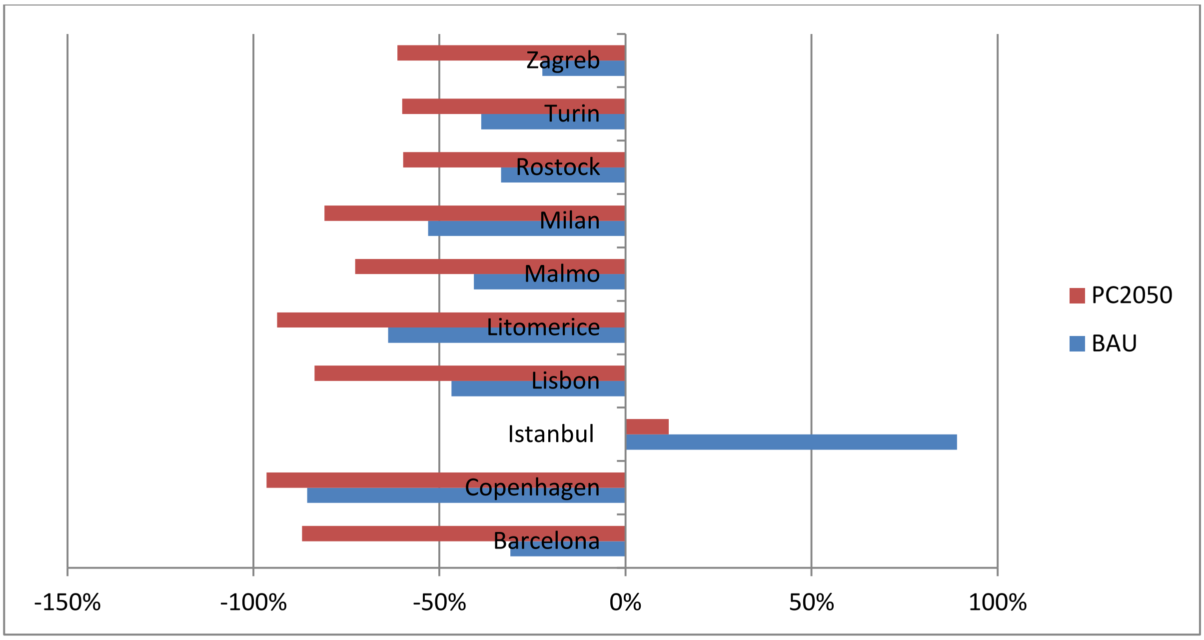

Figure 6: Percentage change in GHG emissions per capita from 2007 to BAU and PC2050 using standard territorial calculation method

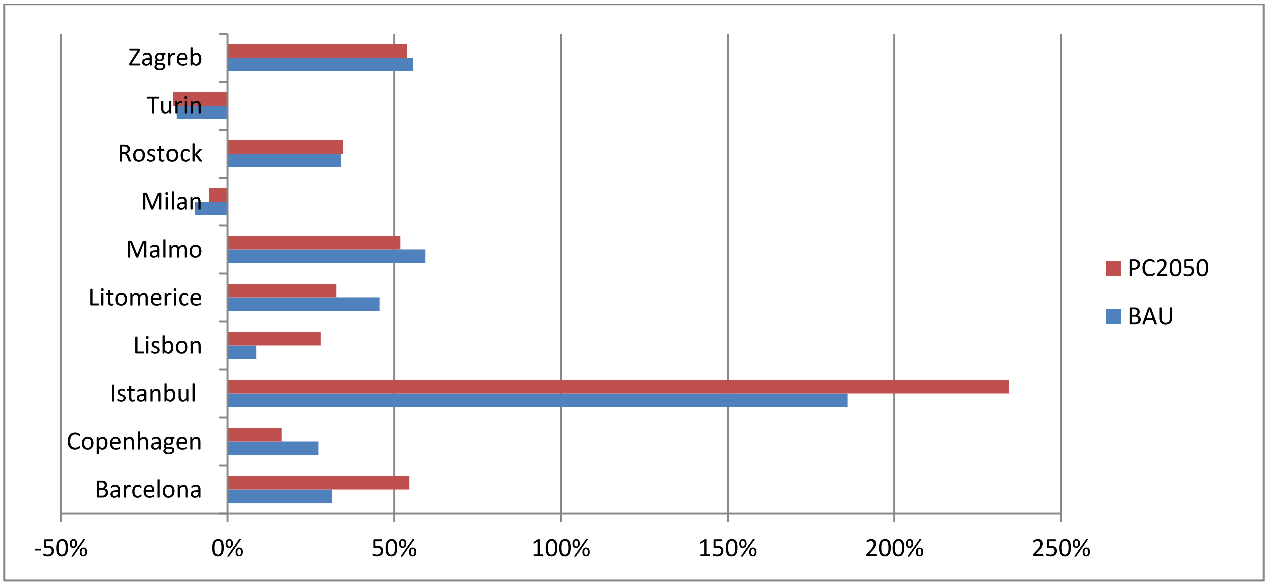

Figure 7: Percentage change in GHG emissions per capita from base year to BAU and PC2050 using footprint analysis

I.III.IV ECO-SYSTEM SERVICES

LAND USE CHANGES

The analysis of land use change showed that all cities would experience various degrees of urban development and loss of non-urban land (continued urban sprawl). It should be noted that the analysis was performed for the wider NUTS III[1] areas and greater metropolitan areas, to encompass the wide scale impacts of the economic activities of the cities. Most of the cities will experience densification in some parts, but also dis-densification where population declines.

Whilst the BAU scenarios were modelled by extending the trends of development from 2000 to 2012, the assumption for the PC2050 scenarios was that policies would ensure no net further development of non-urban land. Therefore densification would be a central policy for PC2050. The result of this is that the BAU results are of most interest as these illustrate the potential impact and encroachment of future development on non-urban land. Table 1 provides a summary of the analysis for the BAU scenarios. It shows that despite some cities experiencing population decline, all cities will experience development of currently non-urban area if trends continue. The cities with the highest potential for further loss of non-urban land, ranging from 43.7% to 19.9%, are Malmö , Istanbul, Copenhagen and Barcelona.

Table 1: The quantity and percentage of projected development for the case study cities under BAU

	Km² change 2012-2050 BAU	% change 2012-2050 BAU
Barcelona	161.0	19.9%
Copenhagen	74.4	23.6%
Istanbul	331.5	30.1%
Lisbon	64.4	10.6%
Litoměřice	0.1	1.9%
Malmö	37.4	43.7%
Milan	40.4	5.6%
Rostock	5.7	10.8%
Turin	32.6	7.1%
Zagreb	11.5	7.1%

This is of concern for two primary reasons. Firstly, the importance of green recreational areas and non-urban land is increasingly recognised by research for health, well-being and quality of life. Secondly, research also shows that sprawling cities require more infrastructure (and are therefore

[1] The NUTS classification (Nomenclature of territorial units for statistics) is the standard EU hierarchical system for territorial regions consisting of three different levels of definition.

more resource intensive), are less energy efficient and have a higher carbon footprint than dense city areas.

Densification and urban sprawl were generally not well covered in the city visions and actions of POCACITO case study cities. Therefore there is a need to ensure policies and strategies are developed to incorporate dense development.

The value of urban green areas is also supported in the analysis of recreational benefits for Malmö and Copenhagen, which showed the high value and use of green areas.

I.III.V SOCIO-ECONOMIC ANALYSIS

A summary of the discounted costs and benefits for all cities is shown in Table 2. It also shows the percentage of cumulative GDP (from 2018 to 2050) for the costs of energy efficiency improvements and additional renewable energy. It shows that for all cities apart from Copenhagen, Istanbul and Malmö , the benefit-cost ratio is positive for BAU. Under PC2050 the benefit-cost is positive for all cities apart from Istanbul (due to poor air quality) with the ratio ranging from 0.6 to 6.4. The highest benefit-cost ratios occur for the cities of Zagreb, Barcelona, Milan and Litoměřice.

The range of costs for PC2050 is related to both the size of the city and the degree of actions stipulated in the city visions (which were used as a basis for the modelling). This limits the comparability of costs between the cities.

Although this needed to be a simplified cost-benefit analysis, it still shows that the return on costs is very positive for most cities, even though the only benefits covered in this analysis are based on changes in air-quality and on changes in premature deaths.

Table 2: Costs and benefits comparison of the scenarios

(MEUR)	DISCOUNTED COSTS (3%)		% OF GDP		DISCOUNTED BENEFITS (1%)		BENEFIT/COST RATIO	
	BAU	PC2050	BAU	PC2050	BAU	PC2050	BAU	PC2050
Barcelona	2792	6597	0.15%	0.31%	19 178	36 063	6.9	5.5
Copenhagen	2 291	4 397	0.18%	0.35%	-2 199	2 499	-1.0	0.6
Istanbul	19 644	32814	0.28%	0.45%	-438 731	-94 711	-22.3	-2.9
Lisbon	1064	2873	0.28%	0.69%	1 008	7 340	0.9	2.6
Litoměřice	66	132	0.77%	1.53%	294	447	4.5	3.4
Malmö	830	2 230	0.13%	0.35%	-154	2 258	-0.2	1.0
Milan	2 903	14 299	0.15%	0.73%	29 552	54 193	10.2	3.8
Rostock	528	1 085	0.34%	0.63%	808	2 179	1.5	2.0
Turin	1 768	4 869	0.26%	0.68%	8 313	13 968	4.7	2.9
Zagreb	1385	3557	0.30%	0.76%	6 363	22 897	4.6	6.4

I.III.VI CONCLUSION

In summary we list some of the most prominent critical factors from the assessment:

1. **Post carbon status will not be reached by 2050 for the majority of case study cities under the current BAU trajectories**

Only Copenhagen is under 1 tonne CO_2e per capita/year with the most extreme case being up to 5 tonnes CO_2e per capita/year for Istanbul. The majority of cities are still in the range of 2-4 tonnes tonne CO_2e per capita/year.

2. **Post carbon status will also be missed under most PC2050 scenario's, due to weak actions and milestones**

   However, there is good potential to counter this in the individual city strategy papers.

3. **When consumption impacts/footprint analysis of the cities are assessed using EE-MRIO the projected impacts are even more pronounced and increase in eight out of ten cases**

   This is primarily linked to rising GDP and a corresponding increase in spending and consumption.

4. **There is a key role for cities to limit the footprint impact by fostering and promoting the circular economy.**

   Cities are the drivers of economic growth but are also the root cause of the majority of consumption. There are many ways in which a city can help foster a circular economy by providing the facilities and infrastructure required to reuse, repurpose, refurbish, and remanufacture, as well as the more traditional (but as yet not perfected or fully implemented) recycling. Cities can work together with businesses to enable this, but cities can also help foster new innovative businesses through appropriate policies.

5. **Energy and resource efficiency measures can significantly reduce the investment required in renewable energy**

   There are still significant opportunities to improve the energy efficiency measures of the PC2050 for most cities. This could be realised by embedding an energy efficiency approach in policy to foster concerted action on transport, buildings, appliances and the planning of infrastructure. Lowering the energy demand would subsequently reduce the requirements for installed capacity of renewable energy and its storage.

6. **The benefits of achieving post carbon status and a performance across sustainable KPI's far out weight the potential costs in most cases**

   Despite our analysis being simplified it shows that the benefit-cost ratio is positive in nine out of ten cities (although an improved PC2050 strategy for the remaining city, Istanbul, would also make this positive), and would be even more so if gaps are addressed. In addition, energy costs are significantly lower (by up to 45% for Lisbon) under PC2050 due to the increased emphasis on energy efficiency measures and the corresponding need for lower capacity. Furthermore, the PC2050 measures would create thousands of jobs related to the energy efficiency and renewable energy provisions.

   Despite factors such as smart grids and transport being omitted from the cost benefit analysis, a growing body of research supports the notion that benefits firmly outweigh costs for improved public transport (e.g. Rode and Floater, 2014; Litman, 2015) and smart grids (e.g. IEA, 2011b; The Climate Group, 2008).

7. **Effective and ambitious long term strategies for energy efficiency and renewable energy are required almost immediately**

The task of developing enough renewable resources to supply most cities, particularly in a time of increasing electrification is enormous and should not be underestimated. However, there is a need for quick implementation of energy efficiency measures and renewable energy technologies to maximise benefits, improve health and well-being, and to avoid a potentially paralysing lock-in of sub-standard physical elements including buildings and transport.

8. **Urban sprawl is a concern for all cities, even for those with a projected population decrease, with up to 43% of non-urban land being converted to urban land.**
9. **Social issues are consistently of concern and need addressing**
   This is true not only for BAU but also for PC2050. One of the most important common KPI's with a poor performance in 2050 is the poverty level and the disparity between rich and poor.

II INTRODUCTION

The POCACITO project aims to facilitate the transition of European cities towards a post-carbon future by defining a Roadmap for the transition. Central to this was the development of post-carbon scenarios and strategies for 2050 for ten case study cities: Barcelona, Copenhagen, Istanbul, Lisbon, Litoměřice, Malmö, Milan/Turin, Rostock and Zagreb. For each of these cities two 2050 scenarios, a business as usual (BAU) and a post-carbon 2050 (PC 2050) scenario, were developed and modelled in order to assess and compare potential pathways and outcomes. Post-carbon refers to a city with net-zero greenhouse gas emissions. The project views the move to post carbon as both an opportunity, as well as a necessity, to ensure the three pillars of sustainability (environmental, economic and social) are incorporated into the essence of the city, thereby transitioning cities, to low carbon, liveable and equal places where a high quality of life is central.

This document presents the quantification of the impacts and comparative analysis of these two possible future scenarios. It extends and builds on the POCACITO presented in Quantification of the Case Study Cities" (Harris et al. 2016) that modelled and quantified the scenarios in terms of the main components that includes population, energy use, transport, GDP and employment. The methodology and approach was presented in D5.2. It is based on first establishing the current trends for the main components based on historical data. BAU is then projected from the current trends, and where appropriate, considers progress made in relevant ongoing and planned projects. PC 2050 is developed from the vision and qualitative scenarios developed in stakeholder workshops (see "Report on Stakeholder Workshops", Breil et al. 2015). It is therefore based on an interpretation of the visions, actions and milestones developed in the workshops. This forms the basis for the modelling the impacts of the cities.

Quantification of the impacts is performed by utilising two complimentary methods. The first focuses on impacts within the city system boundaries and uses the key performance indicators developed in POCACITO (see "Report on Key Performance Indicators", Selada et al. 2014) as a basis to model and quantify the 2050 scenarios for each case study city. The Key Performance Indicators cover the triad of sustainability indicators: environmental, social and economic. The second method aims to account for the total impacts of the city (environmental footprint) including the indirect or upstream impacts caused by consumption. In order to do this it utilises an economic based multi-regional input-output (MRIO) approach based on the EXIOBASE database. Figure 8 provides an overview of the approach and the tasks conducted for the modelling and quantification of impacts. The first stage was reported in "Quantification of the Case Study Cities" (Harris et al. 2016) and forms the basis for the quantification of the scenario impacts.

In addition to the MRIO and KPI analysis, three other types of analysis are conducted in this report to model and assess other impacts of the scenarios. The potential impacts caused by urban sprawl and changes in land use are quantified by modelling a continuation of the recent trends. These aim to highlight the potential differences in city development between the BAU and PC2050 scenarios. A further socio-economic assessment provides an indication of the investment costs and compares this with potential benefits.

For the Copenhagen and Malmö case studies an additional assessment is made on the recreational benefits provided by urban green areas. Due to limitations in data availability and the project scope, this was only conducted for the two cities. However, together with the land use assessment it provides an indication of the value of green areas in cities.

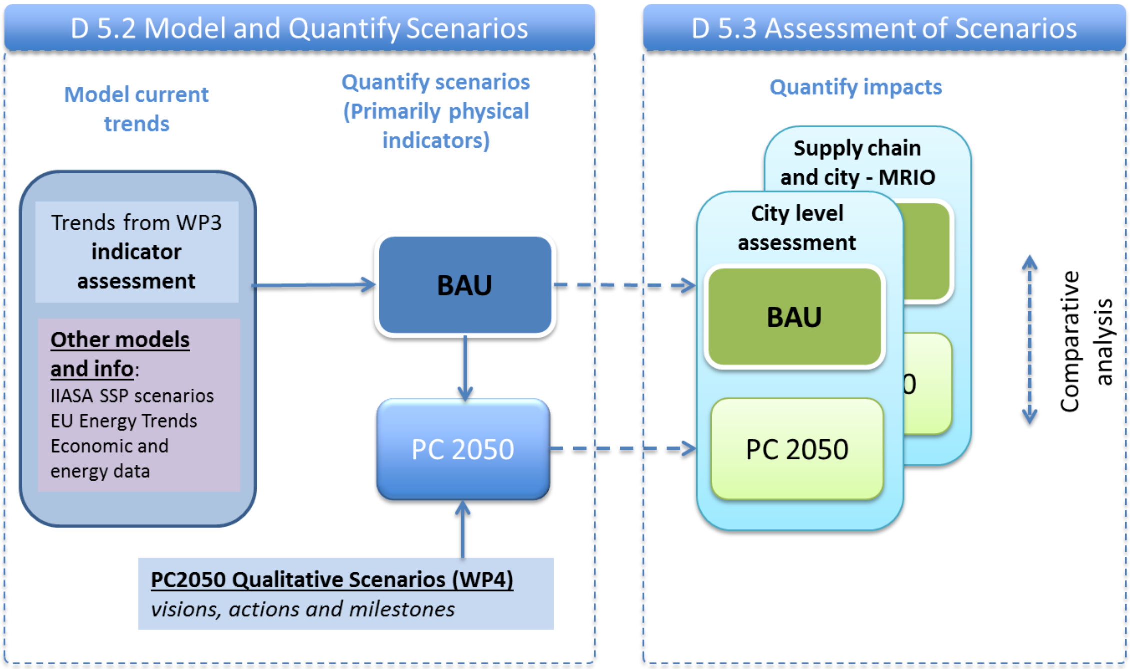

Figure 8: Modelling and quantification processes within WP5

In summary the following analysis is conducted in this report for each case study city for the BAU and PC2050 scenarios:

1. KPI assessment and qualitative analysis
2. Quantitative analysis
    a. Energy and GHG
    b. Environmental footprint (using MRIO)
3. Eco-system services
    a. Spatial modelling of city development for 2050
4. Socio – economic assessment
    a. Investment costs
    b. Cost-benefit analysis

II.I OVERVIEW OF QUANTIFYING THE IMPACTS IN THE POCACITO PROJECT

The objectives of the modelling and quantification stage of the POCACITO project are to:

1. Collect quantitative information on the qualitative strategic transition and BAU scenarios, respectively defined in WP4 as well as quantitative data on measures needed for the transition described in the case studies.
2. Engage selected stakeholders in a structured way by applying the Sensitivity Model to define the most important factors for quantification, and to define and visualise the causal relations

between key factors and semi-quantify the interdependencies. We will select tools and methods for each case study city based on the causal relations.
3. Model and analyse the environmental and socio-economic effects of the post-carbon city scenarios as compared to BAU scenarios.
4. Interpret the results and feed the results of the impact analysis and the conclusions into the Roadmap process and into the global knowledge sharing of the POCACITO project.

To achieve these objectives the main tasks were:

1. Select the key factors to be modelled for each case study city – by using the Sensitivity Model.
2. Model BAU and PC 2050 and to quantify the physical elements of the scenarios
3. Quantify the environmental impacts – this involves identifying which indicators to focus on in each case study city and assessing effects on eco-system services.
4. Quantify the socio-economic effects of the scenarios – this includes
    - an assessment of the financial costs of the required investments and the mitigation costs.
    - Socio-economic costs and benefits
    - Monetise externalities and impacts, and effects on ecosystem services
    - Assess social effects of the scenarios through methods such as the GINI coefficient.
5. Interpret the results and provide an analysis that illustrates the gap between BAU and PC 2050.

This report focuses on the third and fourth objectives and the tasks 3-5 above. Due to project limitations in dealing with ten case study cities and data limitations two deviances from the above were necessary. Externalities of environmental impacts were not monetised, but it is thought that this would not provide valuable lessons in addition to those provided through the comprehensive methodology. Furthermore, the assessment on social effects was limited to the social key performance indicators and the GINI coefficient was not utilised due to data limitations.

II.I.I STRUCTURE OF THIS REPORT

The next chapter describes the methodology and approach used to understand and quantify the impacts of the 2050 scenarios. In Chapter 4 the individual results of the impact quantification assessments are presented for each case study city. Chapter 5 then compares the results of the cities individual assessments, discussing the similarities and differences and why these occur. Finally, Chapter 6 provides a discussion of the research and presents the key lessons and conclusions. Three annexes are provided. Annex I lists the assumptions used in the modelling and quantification. Annex II provides the base results of the land use change analysis, and Annex III gives an overview of the methodology used by Oxford Economics for its forecasting process for consumer spending.

III METHODOLOGY FOR THE QUANTIFICATION OF IMPACTS

The base modelling of the BAU and PC2050 scenarios for each case study city was presented in the "Quantification of the Case Study Cities" (Harris *et al.* 2016). This deliverable built upon the information from previous work packages performed in POCACITO, other literature, data and models, to develop qualitative and quantitative BAU and PC 2050 scenarios for each city. The outcomes are quantitative descriptions of the scenarios that provide the foundations for an assessment of the impacts. The primary elements were: population, energy, transport, buildings and housing, GDP/economic development, industry sectors and employment.

The main stages of the modelling exercise for each city can be summarised as:

1) **Current trends**– developing and understanding the current trends for a set of primarily physical indicators. These are derived from the WP3 assessment and other information sources;
2) **BAU** – the Business as Usual (BAU) scenario is then projected from the current trends, and where appropriate, it considers progress made in relevant ongoing and planned projects.
3) **PC 2050** is developed from the qualitative scenarios developed in in the POCACITO workshops (see "Report on Stakeholder Workshops", Breil et al. 2015). Hence it involves translating and expanding the visions, actions and milestones.

This chapter describes the approach needed for the quantification and comparison of the impacts of the scenarios for each city. As discussed in the introduction, the impacts methodology has four main components each of which are described in the following sections:

1. KPI assessment and qualitative analysis
2. Quantitative analysis
    a. Energy and GHG
    b. Environmental footprint (using MRIO)
3. Eco-system services
    a. Spatial modelling of city development for 2050
    b. Recreational benefits from urban green areas (only for Copenhagen and Malmö, and presented in the comparative assessment in Chapter 5)
4. Socio – economic assessment
    a. Investment costs
    b. Cost-benefit analysis

The KPI assessment utilises the POCACITO KPI's to provide a semi-quantitative/score assessment of the likely outcome for each indicator under both of the scenarios. This is provided in a simple tablature form that illustrates the current trends alongside the projected outcome for each indicator and the scenarios. In addition, a qualitative assessment is provided that discusses the table more in-depth and describes the basis on which the scores were awarded.

The quantitative analysis consists of two components. The first focuses on the energy use and greenhouse gas (GHG) emissions that are projected to occur under the scenarios. These are based on standard ways of calculating the GHG emissions (e.g. the GHG Protocol, 2014) that result from activities within the city's territorial boundaries (i.e. from electricity, energy use in buildings and industry and transport) using standard emission factors. The second component is the assessment of the footprint of the cities activities including consumption using the MRIO methodology and the EXIOBASE database. This is based on the assumption and definition that the city footprint can be calculated from final demand of household consumption and government expenditure (this is discussed further below).

The potential impacts caused by urban sprawl and changes in land use are quantified by modelling a continuation of the recent trends. These aim to highlight the potential differences in city development between the BAU and PC2050 scenarios. A further socio-economic assessment provides an indication of the investment costs and compares this with potential benefits.

For the Copenhagen and Malmö case studies an additional assessment is made on the recreational benefits provided by urban green areas. Due to limitations in data availability and the project scope, this was only conducted for these two cities. However, together with the land use assessment it provides an indication of the value of green areas in cities.

These methodologies are described in more detail in the following sections.

III.I KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

In this assessment the POCACITO sustainability KPI's of POCACITO are modelled and projected for both scenarios. This provides a semi-quantitative and qualitative assessment of how each city performs under both BAU and PC2050. The semi-quantitative assessment is presented in tablature format where each indicator is assessed and scored using both a simple scoring system and colour as shown in Table 3.

The assessment and scoring is based on both the POCACITO modelling and the analysis of current trends, and assesses whether by 2050 the indicator progress is likely to be positive or negative and by how much. For example, green and "++" indicate a very likely positive performance and improvement, whilst red and "--" indicate a very poor or negative performance, as shown in the table below. The qualitative assessment is an extension and discussion of the analysis contained in the table.

Table 3: Scoring system of scenarios

Legend	Explanation for scenario projection compared to current situation
++	Likely very positive
+	Likely positive
0	Likely neutral or similar to current situation
-	Likely negative
--	Likely very negative

III.II QUANTITATIVE ANALYSIS

III.II.I ENERGY AND GHG

The approach to the energy modelling and calculations are described in "Quantification of the Case Study Cities" (Harris et al. 2016). GHG emissions are then calculated using life cycle emission factors[2] to cover the emissions associated with the activities within the city territorial boundaries: transport, electricity use and energy use in buildings. GHG emissions from waste, i.e. from landfill and wastewater treatment are not included primarily because consistent data was not readily available. This is related to the fact that GHG emissions of waste are not typically included in reporting of city GHG emissions.

The data quality and availability on energy and GHG emissions for recent years was available in varying degrees from good (comprehensive and for several years) to poor (only available for one year or only available at the national level). Further details on the data quality are available in the results section. This means that the detail and robustness of the modelling varied across the cities, and in general each city required a slightly different methodology in order to model the scenarios.

III.II.II ENVIRONMENTAL FOOTPRINT IMPACTS (MRIO)

INTRODUCTION

Sustainability impacts of a city are traditionally assessed and reported by examining impacts within the city's territorial boundaries thereby neglecting upstream effects of consumption. This is to primarily focus on activities that cities have operational control over. One exception is the calculation of GHG emissions caused by energy use which typically includes the life cycle emissions such as the upstream effects of electricity production. Nonetheless there is a growing body of research that examines the footprint impacts such as GHG footprint, water footprint and ecological footprint. In addition, British Standards have developed PAS 2070 that provides a specification for assessing direct plus supply chain and consumption based GHG emissions (BSI, 2013).

However, to date, cities that are developing low carbon or carbon neutral strategies do not include upstream emissions caused by the consumption of materials, products and services by the city. The focus is typically limited to energy production and its use. However, there is a growing awareness that the upstream impacts caused by consumption are significant and can represent over 50% of the total footprint emissions of the city (Hillman and Ramaswami, 2010; Harris *et al.* 2016). The calculation of this environmental footprint is still in its infancy and is generally divided into methods based on physical quantities such as urban metabolism and economic based methods such as environmentally extended multi-regional input output analysis (EE-MRIO; see "Quantification of the Case Study Cities", Harris et al. 2016).

In the POCACITO project it was therefore decided to include both calculation of the traditional territorial GHG emissions and the wider environmental footprint. The aim is to further inform the

[2] We utilised the life cycle emission factors of the Covenant of Mayors (2014) as opposed to the standard emission factors to cover the full life cycle impacts of the energy use.

POCACITO 2050 Roadmap and development of appropriate strategies to reduce future emissions. This inclusion is critical because indications from recent research (Chen *et al.* 2016) suggest that whilst cities are reducing the environmental impact caused by direct city activities, the effects of consumption are potentially increasing and becoming the dominant impact. In addition, the goal of POCACITO is to foster future near zero cities and therefore if this is achieved within the city boundaries then the footprint/consumption is likely to represent the bulk of carbon emissions for the city. Hence, consumption could become one of the key issues and challenges for future cities.

At the national level, footprints have been established and calculated for several environmental problems, such as climate change, land use, water use etc. The national environmental footprint has been defined as a footprint of its all citizens (Hertwich *et al.* 2009) but the environmental footprint of a city has thus far not been well defined or accepted. Therefore, for the POCACITO methodology we similarly define the environmental footprint of a city as the environmental footprint of its all citizens.

As mentioned above, there are two main methods applied on the national level to calculate the national environmental footprint: (a) environmentally extended multi-regional input-output analysis, and (b) physical/material/process analysis. Whilst process analysis calculates the national footprint as a result of domestic impact and net impacts of international trade, EE-MRIO connects consumers with producers using the Leontief inverse matrix accounting for the full supply chains of consumed products. The advantage of process analysis is the possibility to work with very specific physical (e.g. mass) data, but at the same time, the number of assessed products and production steps has to be limited to a manageable number. The advantage of EE-MRIO is the completeness, but at the cost of losing sectoral resolution, because products are aggregated into broad product groups which are treated as homogenous. Due to data availability and completeness we apply EE-MRIO method to estimate the environmental footprint of cities.

DEFINITION OF THE ENVIRONMENTAL FOOTPRINT OF CITIES

We define the environmental footprint of a city as the footprint of all citizens and from governmental expenditures. Therefore, due to data limitations at the city level, in contrast to the national environmental footprint approach calculated using EE-MRIO we leave out expenditures of non-profit organizations serving households, changes in inventories and valuables and capital formation.

ENVIRONMENTALLY EXTENDED MULTI-REGIONAL INPUT-OUTPUT ANALYSIS

Environmentally extended multi-regional input-output model consists of three blocks:

a) Intermediate consumption (production recipes), represented in the form of input coefficients per monetary unit of output, i.e. how much of all products are directly needed to produce one unit of a product (a form of a matrix, each column is a recipe for one product)

b) Environmental extension (emission intensities) – emissions and other environmental interventions per unit of output of each sector, e.g. how much CO_2 is emitted per unit of electricity generated

c) Final demand – final consumption of products by households, government and other final demand categories.

THE BASE YEAR CALCULATION – ENVIRONMENTAL FOOTPRINT OF A CITY

Due to data availability, we consider only consumption of households and government in the calculation of the environmental footprint of a city. We utilize the Exiobase MRIO dataset due to the high number of environmental extensions, high product resolution and focus on the European Union. The choice of this dataset determines the reference year 2007. This dataset is focused on national level and contains household and governmental consumption. It was decided to utilise household consumption on a city level from additional sources. For three cities, namely Copenhagen, Milan and Turin city level consumer expenditure surveys were available. For the rest of cities we used data provided by Oxford Economics, which contains projections of the main variables up to 2030 (see "

Annex III: Oxford Economics background projections" for information on projection methodology). The governmental consumption was scaled from the national level based on population due to a number of services provided to households from the national level of government and data availability on a city level.

The household expenditures were adjusted for different pricing, i.e. conversion from purchaser prices into basic prices and from 2010 (reference year for prices of Oxford Economics data) to prices of 2007 (reference year of Exiobase).

The environmental footprint of a city (FP) was calculated using the Leontief approach:

FP = F . L . y

Where F is the environmental extension matrix, L is the Leontief inverse matrix[3] and y is a vector of final demand (household and governmental expenditures). We calculated the footprints on per capita basis in order to compare cities of different sizes because we consider the function of a city to provide a home for citizens and therefore one person can be assumed as a functional unit (in the language of life cycle assessment).

BAU MODELLING – THE POTENTIAL FUTURE IN 2050

For the BAU modelling the Exiobase regions were aggregated into broader groups, as the future international trade and the production technology in individual countries are unpredictable. We assume the country specific technologies will converge to be more similar with increasing level of globalization. A similar approach was applied by Hertwich et al. (2015).

The BAU modelling was restricted to aggregated input coefficients, environmental extensions and final demand. Whilst all those elements are interlinked, for this simplified modelling approach it is necessary to manually adjust all of them independently. For example, if coal consumption is reduced in intermediate consumption, it implies lower CO_2 (and other) emissions from coal combustion. Those emissions, however, must be changed manually in the environmental extension matrix as a separate step.

The basic concept of BAU modelling is to modify those three blocks according to external data/expectations about the future development. It is suggested to modify the technical coefficients of the aggregated system, without changing the origin of the products. For example, if the current structure of the Exiobase database has 20% of plastics in use in Country A as being produced in Country B, this was not changed. However, the plastic production technology in Country B was modified as was the total amount of plastics used in production in Country A based on our assumptions for 2050 of advances and changes in material use and technology. These assumptions are presented in Annex IV.

Final demand consumption of households is adjusted based on the projections provided by Oxford Economics up to 2030 and extrapolated. Equivalent adjustments were applied to governmental expenditures. Further adjustments were made to the energy profile of the cities so that they were in line with those modelled in "Quantification of the Case Study Cities" (Harris et al. 2016) for energy use. This was challenging as the energy profile for a city in total is not the same as the structure for

[3] The Leontief inverse matrix $(I - A)^{-1}$ gives the output rise for each sector due to a unit increase in final demand. A is the input-coefficient matrix from the total input-output table.

final demand of energy. Therefore the total energy spending was first calculated by extending the projections obtained from Oxford Economics. The spending for each energy category (e.g. electricity from solar, petrol and diesel) was then balanced to provide a compromise between the energy spending for the base year and the energy profile of the city in 2007 and 2050.

The volume of consumption respects future expectations of economic growth: the structure respects different needs induced by investment and technological development. E.g. it is expected that houses will need much less energy for heating due to better insulation systems. Therefore, energy use will be reduced.

PC2050 SCENARIO MODELLING

The post-carbon scenario is only modelled at the level of final consumption (i.e. for household consumption and government expenditure), as it is relevant mainly at the city level and it is assumed that the background system remains the same as in BAU. Hence a potential limitation of this research is that the environmental extension and intermediate consumption was not separately modelled for the PC2050 modelling.

This was however not considered a weakness but more in line with the likely potential future situation. This is because the background production recipes and emissions intensities of production would not depend on actions of the city and are more likely to remain as in BAU (and hence the post carbon strategy). One exception could be a city that represent a significant percentage of national production. The only city within the study for which this might be relevant is Istanbul.

The modelling of final consumption is based on adjusting the BAU to reflect differences between BAU and PC2050. Total final demand is first adjusted based on the difference in the ratio of GDP for BAU and PC2050. We therefore essentially assume that the KAYA identify (Total emissions = population × (GDP/population) × (energy/GDP) × (emissions/energy)) holds true in our scenarios. In other words we assume that an increase in GDP results in an increase in final demand. This is perhaps a contentious assumption because it assumes that the elasticity of such an increase is one. In addition, one would hope that by 2050 an increase in GDP would not necessarily lead to a proportional increase in consumption in a post carbon situation.

The energy profile for PC2050 was then adjusted using the same methodology as in BAU. As a basis for modelling the other (non-energy) product groups the analysis of “Quantification of the Case Study Cities” (Harris et al. 2016), its assumptions, and modelling are utilised, in addition to the KPI analysis. From the interpretation of the differences between BAU and PC2050 the final demand is adjusted by assuming that a moderate change from BAU to PC2050 results in a 25% variation and a substantial change means 50% variation.

ENVIRONMENTAL FOOTPRINT RESULTS

For the presentation of results the product groups of final demand were divided into six main groups reflecting the importance of the environmental footprints and the purpose of consumption. These broad product groups comprise of:

- Food - all food purchased, including from restaurants, and related waste treatment services.
- Housing - all materials and products related to construction, construction products and services and real estate services.

- Electricity and heat fuels - all energy products used within homes (excluding transports fuels).
- Transport fuel, equipment and services - all products related to transport, incl. e.g. personal and public transport and services of travel agencies.
- Other goods and materials - all goods not included above, in order to distinguish other goods and services.
- Other services - all services not included above.

It should be noted that the direct emissions calculated with the MRIO method are not the same as those calculated by the traditional territorial method, or in typical emission profiles reported by cities. This is because factors such as electricity are considered under indirect emissions. This stems from the underlying Exiobase model where direct impacts relate only to the direct emissions of the household or government (e.g. from burning gas).

III.III ECO-SYSTEM SERVICES

SPATIAL MODELLING OF CITY DEVELOPMENT FOR 2050

The aim of this analysis is to show possible future trends in development of European cities in terms of urban spread and in terms of population changes within the city boundaries. In addition, the analysis aims to highlight the potential differences in city development between the BAU and PC2050 scenarios. The modelling results are presented as tables and maps showing land use and population changes. Since this analysis is based on specific assumptions and a variety of information sources, it must be stressed that results do not attempt to provide a precise projection of the future, but should rather be interpreted and used as extreme scenarios for future changes.

METHODOLOGY

Demarcation of city boundaries

The model was applied for the 10 case study cities: Copenhagen, Malmö, Rostock, Litoměřice, Zagreb, Milan, Turin, Barcelona, Lisbon and Istanbul. Boundaries of the case study cities were set to reflect the metropolitan area, including surrounding suburbs. For most cities, regions at NUTS III[4] level were applied to set city boundaries, except for Litoměřice and Malmö, where municipal boundaries where applied.

Assessment of historical changes

In order to model the BAU scenario, information on the historical development of the cities was needed. We applied land use and population data for the years 2000 and 2012 to assess urban spread and changes in population numbers. Information on land use was derived from "Corine Land Cover" (EEA 2000, EEA 2012), which is a full registration of land use for all EU countries and Turkey. For this analysis we applied the gridded version with a cell size of 100x100 meters. Population data was

[4] The NUTS classification (Nomenclature of territorial units for statistics) is the standard EU hierarchical system for territorial regions consisting of three different levels of definition.

derived from "Landscan population data" (U.S. Department of Energy), which are gridded data on population numbers produced by the Oak Ridge National Laboratory in the US. Landscan population data are based on a combination of remotely sensed information and census data and are provided in a resolution of approx. 1x1 km. Although both Corine Land Cover and Landscan population data are subject to inaccuracies, these data represent the most suitable data and consistent data sources for this study. Applying these data also ensures replicability to other European cities, in the sense that data are available EU-wide. Corine Land Cover data for 2000 and 2012 were aggregated into 3 superficial land use types (Table 4)

Table 4: Applied land use types

1. Urban, covering	All built up land and transport infrastructure
2. Sea	Water bodies connected to the open sea
3. Other land	All land which is not urban or sea

Landscan population data were disaggregated into 100x100 meter cells corresponding to the Corine Land Cover data. Subsequently the land use and population maps were spatially overlaid and population numbers were calculated for cells with urban land. Finally, spatially overlaying the maps for 2000 and 2012, cells were assigned to change types summarized in Table 5.

Table 5: Types of urban change

Change type	Description
1. Urban spread	Change from non-urban in 2000 to urban in 2012
2. Urban no change	Urban in 2000 and 2012 and no change in population*
3. Population densification	Urban in 2000 and 2012 and population increase
4. Population dis-densification	Urban in 2000 and 2012 and population decrease
5. Non-urban	Non-urban in 2000 and 2012

* A limit of a change of +/-10 persons was assigned to no change in population

Modelling 2050 scenarios

In order to compile the BAU and PC scenarios for 2050, population projections were compiled by utilising several sources. BAU population is calculated both from an examination of the past trends by the POCACITO team, information from the literature and data and projections obtained from Oxford Economics. Data was obtained from Oxford Economics on household consumption for the EE-MRIO work and included projections on several indicators until 2030. Hence this was used to inform the projections (see Appendix 1, Harris et al 2016).

Since population numbers from Oxford Economics and from Landscan differ due to different data sources, we applied the expected percentage increase from 2012 to 2050 from Oxford Economics to population numbers from Landscan resulting in an expected population number for 2050 for each city for the BAU and the PC scenarios.

For the BAU scenario, we assumed that urban change from 2012 to 2050 would follow the same spatial patterns as the change from 2000 to 2012. This assumption was operationalized as follows.

Based on the historical development we assumed, that the proportion of population increase from 2000 to 2012, which resulted in urban spread would be the same for 2012 to 2050. E.g. from 2000 to 2012 population in Copenhagen increased by 55,705. In the same period, urban spread comprised 12.78 km² covering a population increase of 16,029 or 28.78 % of the total population increase. The population projection for Copenhagen shows and increase of 324,105 by 2050 for the BAU scenario. Consequently, we assume that 28.78 % of this increase or around 92,000 will result in urban spread, while the remaining increase will result in a densification. I.e. for Copenhagen, the BAU scenario results in an urban spread of 74.36 km². The same method was applied to quantify densification and dis-densification. In order to localize these types of urban change, we applied an automated cellular model (Fuglsang et al. 2013). Principally, the underlying assumption of this model is that future change is most likely to take place at the same locations or proximate to the same locations as historically. In practice, for each cell, we calculated the probability of undergoing one of the change types based on the cell's proximity to the same change type from 2000 to 2012. Based on this probability, each cell was assigned a change type, until the expected quantity in terms of km² of this change type was reached. In terms of urban spread, the only spatial restriction we used was that urbanization would not occur within Natura2000 designated areas or within sea. Other spatial restrictions, which of course exist, were not applied, since these would need city specific information and hence restrict the replicability of the study. For the PC scenario, the only assumption we applied, was that population increase would not result in urban spread, but only lead to densification and that no dis-densification would occur.

For both the BAU and the PC scenario, population changes within the different types of urban change were calculated by multiplying cells population number in 2012 with the expected percentage increase for the change type from 2012 to 2050 and adding it to the 2012 population.

III.III.I RECREATIONAL BENEFITS FROM URBAN GREEN AREAS

The recreational use of forests and urban green parks is an important non-market ecosystem service. Their economic valuation can play an important role in understanding their value and for planning the conservation of these important ecosystems. Changes in the recreational services have been assessed based on both supply and demand factors, which include site attributes, geographical location, socioeconomic characteristics and heterogeneity in the site selection.

The study focuses on modelling the impact of the PC2050 scenarios on the recreational service provided by urban green areas in the case study cities of Copenhagen and Malmö. The aim is to undertake a value function transfer of the preferences and demand for recreation from Copenhagen to the Malmö region under current conditions (baseline) and to adjust these based on scenarios of the number of people and where they may live in the twin city-region under BAU and PC2050 in 2050. The results indicate how changes in future urban planning may influence values of the sites in each municipality of the twin case study areas.

METHODOLOGY

For the twin case study cities of Copenhagen and Malmö, a monetary valuation study is conducted on Copenhagen and a benefit transfer made to Malmö. The monetary valuation approach is a spatially explicit Random Utility Model (RUM), which is based on travel cost methodology. A travel cost approach values the access to a site based on observed trade-offs between visit frequencies and travel distance and the estimation of a demand function for accessing a given site. The RUM adds to the travel cost framework by modelling multi-sites in a spatially explicit manner and can be used for studying how the probability of choosing a site is dependent upon site characteristics as well as the costs of accessing the site. In the RUM framework, an individual makes his/her choice between the sites on a single choice occasion, where the individual compares the characteristics of alternative sites, including the travel costs of going there, and then choosing the site that maximises utility. RUM is useful when a large number of choices are available and the site substitution is important.

The benefit transfer approach is based on a completed national RUM analysis of urban and rural nature recreation sites in Denmark, where the value of access to individual sites have been assessed in terms of value per hectare of sites within municipalities in Denmark. The transfer of value per hectare was adjusted to the Malmö case based on population density only and scenarios of population density under a BAU and a post carbon future. Simple linear regression was applied to the values per hectare per municipality and the population density of Denmark. This relationship was then used to predict the recreational values based on the different scenarios of population densities of Malmö and Denmark.

Previous research in Denmark using this method has shown no significant income effect on the probability of selecting a site, whereas the distance and number of people are strong predictors for site values.

DATA

An existing dataset on recreational values of natural habitats and urban parks in Denmark conducted by the Danish Economic Council is used for the study (Bjørner, Jensen, & Termansen, 2014). This national dataset consists of 1911 respondents aged 18 and above. Nature sites larger than 50ha outside cities were included as well as large urban parks (>20ha) in the five largest cities in Denmark (Copenhagen, Aarhus, Odense, Aalborg and Esbjerg). In total 2399 sites have been identified based on BASEMAP (Levin, Rudbeck Jepsen, & Blemmer, 2012) of which 98 were urban parks and 76 coastal points. For the capital region in Denmark, a total of 141 sites are included of which 133 are not linked to urban areas, 17 are urban and peri-urban sites and 8 are coastal points (beaches). The inclusion of the peri-urban sites and sites further away can help to reduce bias in the model.

The dataset included data on characteristics of the recreation areas, survey data on the choice of the latest site of visit and the total number of trips made during the past 12 months and a distance matrix of home addresses of the respondents and the sites, unit costs of travel.

The population data was derived from Landscan data for 2012. Landscan is a global dataset for population data at a resolution of 1x1km. The population density was calculated using the total adult population and the total area (ha) of each municipality.

III.IV SOCIO – ECONOMIC ASSESSMENT

The approach for the socio-economic assessment needed to be simplified due to data limitations and because it needed to cover ten case study cities within the scope of the project. Initially it was desired to cover energy, buildings and transport in the assessment.

For transport, we initially investigated assessing the investment costs for public transport but this proved difficult for several reasons. Firstly, the scenarios were not detailed enough in terms of stipulating what were the actual public transport requirements, and whether trains, buses, trams or other were required. In addition, collecting the data and information needed to perform a detailed transport study was beyond the scope of the project.

However, three approaches were investigated to circumvent this. The first focussed on utilising previous studies on the requirements and costs. Several studies were identified but they proved to be based on very individual circumstances and no robust method to transfer this to the case study cities was identified.

One approach that was therefore investigated was to attempt to standardise the costs based on a standard/normalised transport approach. Bus rapid transport (BRT) was chosen as an example and the approach was to attempt to cost the BRT system required to provide a certain level of service (e.g. buses per capita) or to achieve a % mode of public transport. Again, since cities are so individual there was no way to do this without more detailed information on spatial distribution of the population and the current public transport network.

A further approach investigated was to utilise abatement costs from previous similar studies, such as the mini-Stern review of Leeds (see Gouldson et al. 2012) from the New Climate Economy research. This too was based on local data and national energy prices for the UK and could not be easily utilised without building our own abatement costs model, which was beyond the scope of the project.

Finally, we considered using GAINS, the analytical air pollution and climate modelling tool. This however, would only give an indication at a national level, which would be difficult to transfer representatively to the local situations of the case study cities.

Hence it was decided not to pursue the calculation of investment costs (and therefore also the benefits) for transport.

III.IV.I INVESTMENT COSTS

The methodology for assessing the investment costs for energy and buildings are described in the following sections.

ENERGY

For energy it was decided to focus on the investment costs required for renewable energy to support the requirements of the BAU and PC2050 scenarios. There are four main renewable energy sources that were mentioned in the scenarios and considered for this analysis: wind, solar, hydro and geothermal. In general we assume an average investment cost of energy to 2050 based on 25% of the investment being made in each of the years: 2020, 2030, 2040 and 2049.

For wind, costs were derived from the IEA Wind Roadmap (IEA, 2009), and using an average figure to 2050 of 1400 EUR/kW (which is based on a decreasing cost to 2050). To calculate the amount of wind capacity required in MW to produce the annual quantity needed, we used local capacity factors derived principally from IEA annual wind reports (www.ieawind.org).

For solar we used an average solar PV system cost of 581.25 EUR/KWp up until 2050. This was derived from using data and deceasing cost projections up until 2050 from Fraunhofer ISE (2015) (and based on the steps of 25% investment costs described above).

The solar capacity required to provide the annual quantity of solar energy per GWh in 2050 was based on local conditions and calculated using the JRC tool and interactive map "Photovoltaic Geographical Information System" (JRC 2016).

We calculated the capacity required (in MW) for both fixed systems and 2-axis tracking systems and took an average between the two values, assuming that approximately 60% would be tracking and 40% fixed systems. The 2-axis tracking systems maximise the energy obtainable from the sun by optimally adjusting the angle of the solar panel to the sun, as opposed to fixed systems which do not move and are therefore less effective.

Hydro power and geothermal power were not as commonly stipulated and were based on available figures (as some projects were already being started under BAU) or using figures from the IEA roadmap for geothermal (IEA, 2011a).

BUILDINGS

For buildings we focussed on the costs of renovating the existing building stock. For consistency, but also due to lack of data and information on the buildings in each of the cities, the cost calculations were based on two factors. The first was that different renovations costs were applied to each city based on the level of renovation and the resulting improvement in energy efficiency. This was based on a study by "Buildings Performance Institute Europe" (BPIE 2011) who established average European costs for different levels on renovation as shown in Table 6.

Table 6: Renovation types and their average cost estimates

DESCRIPTION (RENOVATION TYPE)	FINAL ENERGY SAVING (% REDUCTION)	INDICATIVE SAVING (FOR MODELLING PURPOSES)	AVERAGE TOTAL PROJECT COST (€/M2)
Minor	0-30%	15%	60
Moderate	30-60%	45%	140
Deep	60-90%	75%	330
nZEB*	90% +	95%	580

(- Near Zero Emission Building) (source BPIE, 2011)*

The level of improvement for each case study city was obtained from the assumptions that were used in the calculation of the energy use for each of the cities. This in turn came from an interpretation of the PC2050 scenario (and the vision and milestones, see "Report on Stakeholder Workshops", Breil et al. 2015).

Secondly, the floor area for the residential and service commercial area for each city was calculated based on national averages obtained from Entranze (2008). The renovation cost of the cities were then calculated by multiplying these two factors together.

III.IV.II BENEFIT ANALYSIS

The approach of the benefit analysis is intended to be indicative only and provide a comparison of potential cost-benefits of achieving a post-carbon scenario.

The benefits are divided into those which can be quantified and those which are presented in a qualitative way. There are many potential benefits that are reported in the literature that could be included, some of which are listed in Table 7.

However, many of these benefits could not be directly quantified or transferred to the case study cities. The methodology therefore will focus on the following aspects:

1. Health benefits of reduced pollution.
2. Reduced energy expenditure (qualitative).
3. Jobs created from renewable energy.
4. Jobs created through building renovation.

The approaches to these are discussed below.

Table 7: Benefits of different aspects of a post-carbon city

	Costs	Benefits
Energy	• Energy source – wind, solar, geo etc • Energy efficient equipment	• Reduced air pollution • Potential of reduced energy costs • Indirect benefits – e.g. reduced air pollution • Jobs – manufacturing: 7.5 - 69 jobs/MW; and operation: O.2 – 5.5 jobs /MW (IRENA, 2013)
Transport	• Electric car and vehicle infrastructure • Public transport	• Reduced congestion • Reduced noise • Health and wellbeing from reduced air pollution • Health and fitness from cycling or walking – and catching public transport • $1 billion spending = 36,000 jobs, $3.6 bn of output and $1.8 bn of GDP (Rode and Floater,

		2014; pg 16 secondary reference)
Buildings	• Renovations • New buildings nZEB, ZEB etc	• Reduced energy costs • Jobs– 17 jobs per million EUR invested (Ürge-Vorsatz *et al.* 2010) and 12 -17 jobs (Meijer et al 2012) • Improved indoor air quality – e.g. through mechanical ventilation

HEALTH BENEFITS FROM REDUCED AIR POLLUTION

In our approach we utilise costs of premature deaths from air pollution as calculated in a report by WHO Regional Office for Europe, and OECD (2015). They have calculated the economic cost as a percentage of GDP, which can be transferred to the case study cities as the 2050 GDP have been calculated as part of the quantification.

We therefore applied these percentages to the cities with the following procedure:

1. The final % of GDP for premature deaths for the scenarios was calculated based on the degree to which BAU or PC2050 reduced the use of fossil fuels compared to the base year.
2. A linear decline/increase was assumed between the starting percentage and the final percentage, and a percentage calculated for each year.
3. For each year the cost of the scenarios is calculated by multiplying these calculated percentage s by the yearly GDP.
4. A fixed cost, assuming no improvement from 2018, for each year is calculated based on the 2010 percentage of GDP in the above table.
5. Discounted benefits are then calculated based on the difference between the figures obtained in point 3 from the fixed cost calculated in point 4.
6. The cumulative costs are then obtained by the sum of 2018 to 2050, from which the discounted costs and benefits are calculated.

Table 8: Economic cost of premature deaths from air pollution (APMP + HAP) as a percentage of GDP per country in the WHO European, 2005 and 2010

	Economic cost of premature deaths from APMP + HAP US$ (millions)		Economic cost of premature deaths from APMP + HAPas a % of GDP (at PPP)	
	2005[1]	2010[2]	2005[1]	2010[2]
Croatia	9 844	9 035	14.26	10.8
Czech Republic	22 834	20 901	10.03	7.4
Germany	154 382	144 715	5.82	4.5
Denmark	5 955	6 283	3.22	2.7
Italy	98 612	97 193	5.73	4.7
Portugal	7 885	9 205	3.40	3.2

Spain	42 124	42 951	3.46	2.8
Sweden	3 219	3 641	1.04	0.9
Turkey	50 639	70 386	6.48	6.0
1. OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8- 2. OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8, and adjusted for post-2005 income growth and inflation.				

(Source: WHO Regional Office for Europe, and OECD 2015)

The results are presented for a range of discount rates, using low discount rates (0.8%, 1.0% and 1.2%). It should be noted that lower discount rates are used for benefits compared to the costs, to give reasonable relevance in the perspective of a far-sighted social planner to potential future benefits.

REDUCED ENERGY EXPENDITURE (QUALITATIVE)

The energy use for BAU and PC2050 scenarios was calculated as part of the quantification of the main elements of the scenarios that included population, transport modes, and GDP etc. Knowing the difference in energy use between the scenarios also gives an indication of the difference in energy costs. Calculation of the actual costs of energy and the differences in the scenarios, due to differences in energy sources is extremely difficult and would be somewhat contentious. In general, energy prices are expected to rise by 2050, particularly fossil fuels and especially petroleum products for transport. On the other hand, prices for renewable energy are expected to fall relative to fossil fuels. This difference will be magnified if a European–wide price is placed on carbon emissions, which could be a reality by 2050.

Hence it is felt that the best method to assess the differences in energy costs of the scenarios is through a qualitative approach. Therefore we suggest a percentage difference in energy costs between the scenarios based on energy use and energy sources.

JOBS CREATED FROM RENEWABLE ENERGY

There have been several attempts to quantify the number of jobs created through the implementation of renewable energy and its use. We use a range of figures calculated by IRENA (2013) for a range of technologies and life cycle stages as shown in Table 9. The analysis is only intended to be indicative, based on the most reliable figures available.

Table 9: Employment estimates for different RET's for OECD countries

	MANUFACTURING, CONSTRUCTION AND INSTALLATION (PER MW)	OPERATION AND MAINTENANCE (PER MW)
Wind onshore	8.6	0.2
Wind offshore	18.1	0.2
Solar	18	0.2

	MANUFACTURING, CONSTRUCTION AND INSTALLATION (PER MW)	OPERATION AND MAINTENANCE (PER MW)
Hydro	7.5	0.3
Geo	10.7	0.4

(source: IRENA, 2013)

JOBS CREATED THROUGH BUILDING RENOVATION

Similarly, several pieces of research have attempted to quantify the number of jobs created through the renovation of buildings to increase energy efficiency and therefore reduce energy use. As shown in Table 7 two sources Ürge-Vorsatz *et al.* (2010) and Meijer *et al.* (2012) both agreed on a figure of between 12-17 jobs per million EUR invested in building renovation. It was not possible to disaggregate this figure into mining, manufacturing of products, design, engineering and onsite construction. As Meijer *et al.* (2012) note there will be an indirect effect on jobs, such as the supply of related products for the construction industry. However, there may also be job losses due to the reduced energy in sectors that generate and distribute energy to buildings. We therefore take the conservative number of 12 jobs per MEUR invested in renovation.

IV INDIVIDUAL CITY RESULTS AND ANALYSIS

This section presents the results of the quantification of impacts for each of the ten case study cities. It consolidates the work of WP5 on modelling the business as usual (BAU) and post carbon (PC 2050) scenarios and quantifying the impacts. It should be noted that the BAU scenario is primarily developed from a continuation of current trends with consideration of current projects. Whilst PC2050 is developed from an interpretation of the vision, action and milestones developed in the stakeholder workshops. It is therefore a judgement based on the consistency and robustness of supporting actions to the desired post-carbon state, and not a quantification of an idealistic state (for further information see Harris et al, 2016).

For each city the results are divided into the following sections:

1. Key Performance Indicator assessment and qualitative analysis
2. Quantitative analysis
    a. Energy and GHG
    b. MRIO – footprint impacts
3. Eco-system services
    a. Land use cover changes (eco-system services)
    b. Recreational benefits from urban green areas (assessing eco-system services)
4. Socio – economic assessment
    a. Investment costs
    b. Cost-benefit analysis
5. Gaps and risks

This follows the structure presented in the methodology section which should be referred to for additional information.

IV.I BARCELONA

IV.I.I INTRODUCTION

In the BAU 2050 scenario the population of Barcelona municipality has risen only slightly to 1.7 million. Energy use is at a similar level to what it was before the financial crisis. Following a return to growth in GDP after 2014 Barcelona's energy consumption continued to grow again. This growth was countered by energy efficiency policies to a certain extent, but a continuing electrification of society almost cancelled these out. However, energy production has improved with an increase of renewable and local energy sources. The overall efficiency per km of transport has improved due to a shift to electric mobility but transport volumes have risen slightly. An early ambition to attain 100% of renewable energy was not met with concerted action and there was a tendency to rely on regional nuclear energy, which still supplies over 50% of the electricity supply.

Barcelona in the PC 2050 scenario is a city that has undergone a remarkable transformation with the majority of buildings being extremely energy efficient and equipped with solar panels. A focus on increasing density and incentives to relocate from the suburbs has increased the population to two million inhabitants. Transport energy has declined due to the increased reliance on public transport network and on electric/hydrogen only transport. A fossil fuel ban on city transport in 2035 saw a shift to predominantly electric mobility.

The current energy use trends for Barcelona were used with caution because they closely followed a potential fallout from the financial crisis. The energy use was actually growing until 2006. After 2008 the GDP dropped. Within the municipality the energy growth is consistent with the population growth from 2001 until 2006. Data from Oxford Economics shows that GDP returns to steady growth in 2014. Most of the decline comes in the transport and industry sectors, which is probably due to the financial crisis. This is in line with the provincial trend as well suggesting that people travelled less to the city from the provinces[5].

The sectoral breakdown of GDP shows that the service industry has grown by almost 10% points, whilst industry has declined. This leads us to suggest that with a recovering GDP, energy consumption could increase again. The transport share could also recover to the level it had before the financial crisis.

Due to lack of data therefore we assume a BAU 2050 energy consumption similar to 2005 with a greater share covered by the service sector. The service sector has continued to grow GDP whilst decreasing energy consumption. At the Province level the population does not grow any further according to projections from Oxford Economics. According to projections in the EU Energy Trends 2050 (Capros, 2014) the growth in the final energy demand for Spain is in line with the population growth at 14.6% and 14.5% respectively. According to Barcelona Energy and Climate Plan the electricity share has increased from 37,2% to 44.3%, and we also expect a continuation of this electrification trend.

Therefore we assume that the:

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[5] http://www.diba.cat/documents/471041/24663576/emissions+in+Barcelona_july+14.pdf/34110b21-ca61-4da6-acc2-d4f83695fc2a

- service sector continues to grow to 2050 but improves efficiency - therefore similar energy consumption in total

- industry sector recovers to 2005 levels with slightly increased efficiency 5%.

- residential sectors increase in electrification cancels out efficiency increases therefore remaining fairly similar.

IV.I.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

The KPI assessment for Barcelona is provided in Table 10. It summarises the current trends of the KPI's and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable). A summary of the KPI's current trends and the expected outcomes under the scenarios is given below.

ENVIRONMENTAL KPI'S

For biodiversity no trends can be observed due to the lack of data availability. In addition, no measures were identified as being planned (i.e. therefore influencing BAU) and no measures were suggested in the PC2050 scenario. For energy use and intensity, the current trend is heavily affected by the financial crisis and it is therefore hard to draw conclusions. In the PC2050 scenario several energy efficiency projects are planned and therefore the energy intensity can be expected to improve. The current trend for carbon emissions intensity is decreasing, which is expected to continue in both the BAU and PC2050 scenario. These are discussed further in the quantification section. On a sector basis there are particularly high decreases in the transport and industry sector for GHG emissions that is most likely related to the financial crisis.

The air quality in Barcelona is undergoing a positive trend with the number of pollution threshold exceedance days approaching zero. The development can be expected to continue in both the BAU and PC2050 scenario and by 2050 no days of exceedance are expected.

Current trends show a small increase in the use of public transportation, primarily shifting from car use. In the BAU scenario only minor changes are expected. In the PC2050 scenario several measures will be taken resulting in a relatively drastic decrease in private car use with increases in public transportation and walking/biking.

The generation of waste has been decreasing in recent years and this can be expected to continue in both 2050 scenarios, although there were no measures proposed under PC 2050. However, there is an ambitious target of 100% treatment and recycling in PC2050.

ECONOMIC KPI'S

Despite the financial crisis there is a steady increase in the level of wealth with the strength of the Barcelona economy continuing. This is expected to continue in both scenarios, but with improved performance under PC2050. There is also a low indebtedness level but the data is only available for a short period. The research and development intensity is low at 1.19%-1.94% (2008-2010) but again the data is only available for a short period.

The business survival rate has decreased significantly from 90% to 69% (2008 to 2010) which is of concern, but there are not enough data points to indicate a trend or facilitate modelling to 2050. This is also exacerbated by the fact that Spain was particularly affected by the financial crisis, which is likely not to affect the circumstances by 2050.

SOCIAL KPI'S

Unemployment has increased dramatically from 6% in 2002 to 23.7% in 2012 leading to some concern, but again it is impossible to project to 2050 from these figures. This is also true for the share of population at risk of poverty, which has also increased from 2.4% to 17.7% during 2004 to 2013.

There is some gender inequality in the tertiary education rates which are greater for males at 37.7% than for females at 31.9% in 2013, although both have increased from around 27% in 2003.

Table 10: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Barcelona

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Percentage	28% (2012)	No data on trend	N/a	N/a
	Energy	Energy intensity variation rate	toe/euro toe	(2003-2012) 28.47 to 23.83 1.6 Mtoe to 1.4 Mtoe	- 16.3%	+	++
		Variation rate of energy consumption by sectors	Percentage	From 2003 to 2012	Residential 2003 – 2012: -2.4% Services 2003 – 2012: + 1.97% Industry 2003 – 2012: -21.25% Transports 2003 – 2012: -18.16%		
	Climate and Air Quality	Variation rate of carbon emissions intensity	ton CO_2/euro ton CO_2	(2003-2012) 84.77 to 60.95 4.72 to 3.69 MT	Decrease (-28.1%) -	+	++
		Carbon intensity per person	ton CO_2 eq. / capita	3.06 to 2.27	-25.9%	+	++
		Variation rate of carbon emissions by sector	ton CO_2	From 2003 to 2012	Residential: - 4,85% Services: - 1,86% Industry: - 16,78% Transports: - 18%	++	++
		Exceedance rate of air quality limit values	Nº	19-2 (2003-2012), 5 in 2013	Annual variations, but still decrease	++	++
	Transport and mobility	Variation share of sustainable transportation	Percentage	From 2004 - 2014	Public: 34.9% to 39.7% Private: 33.3% to 26.1% Walk and cycle: 31.7% to 34.1%	0	++
	Waste	Variation rate of urban	kg/person/day 2003 to 2014	1.44-1.26 kg/person and day	1.44-1.26 kg/person and day	++	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
		waste generation					
		Variation rate of urban waste recovery	Percentage	Waste to recycling :30.4%-36.11% (2006-2014) Organic waste amounts: 86914-122508 tonnes/year (2007-2012)	Waste to recycling :30.4%-36.11% (2006-2014)	++	++
	Water	Water losses variation rate	m^3/person/year	Data only provided in percent for a single year (17.9% in 2013)	**Water use** reduced 2001 to 2014 129.6 to 101.1 L/cap/day	N/a	N/a
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	No data	-	N/a	++
		Urban density variation rate	Nº/km^2	No data	-	N/a	N/a
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person	23,400-28,300 EUR (2001-2011; peak in 2007; purchasing power standard indicator)	Increase, sharp drop during crisis	++	++
		Variation rate of GDP by sectors	Percentage	Data missing	No data	N/a	N/a
		Employment by sectors variation rate	Percentage	Trend of decline in industry, construction and services (2005-2012). Significant drop in primary section in 2008 which recovered over 2009-2012.		N/a	N/a
		Business survival variation rate	Percentage	90%-69% (2008-2010)	Limited data points and only effects of financial crisis	N/a	N/a
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	Data missing	-	N/a	N/a
		Indebtedness level variation rate	Percentage of city's GDP	1.19%-1.94% (2008-2010)	-	N/a	N/a
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	1.33%-1.51% (2004-2012)	Increase, but possibly due to drop in GDP	N/a	N/a
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage	Diagram Men: 6.8%-23.7% (2001-2012) Women: 12%-22.5% (2001-2012)	Large increase in unemployment	--	N/a
		Variation rate of poverty	Percentage	2.4%-17.7% (2004-2013; share of population in poverty risk)	Large increase	--	N/a

SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
	level					
	Variation rate of tertiary education level by gender	Percentage	Male: 27.2%-37.7% (2003-2013) Female: 26.8%-31.9% (2003-2013)	Increase	+	N/a
	Variation rate of average life expectancy	Average Nº	80.0-82.2 (2003-2012)	Increase	++	++
Public services and Infrastructures	Variation rate of green space availability	Percentage	65.5%-64.4%% (2003-2010) 59.8%-62.1% (2011-2013; area changed)	No significant change?	+	+
Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes	Yes	++	++

Legend	Explanation for scenario projection compared to current situation
++	Likely very positive
+	Likely positive
0	Likely neutral or similar to current situation
-	Likely negative
--	Likely very negative

IV.I.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

The energy sources and quantities for the baseline year 2005 and the BAU and PC2050 scenarios are shown in Table 11. The PC2050 shows a higher transition to electrification of society with the large majority of energy being derived from low carbon sources such as nuclear and renewable energy. All transport is electric or low carbon due to a ban on fossil fuelled transport in 2035. Public transport increases to 50% of modal balance. This assumes a massive increase in local solar energy as well as an equally large expansion of wind and hydro sources.

ENERGY SOURCE	2008 (GWH)	BAU (GWH)	PC2050 (GWH)
Nuclear	13791	**5516**	**5516**
Coal	246		
Gas	11759	5109	1102
LPG	246	246	
Liquid fuels	3786	2272	
Hydro and wind	924	2000	3000
Solar thermal	31	490	800
Solar PV	0	100	2623
Biomass	0	50	1465
Hydrogen	0		147
Total	**30784**	**15783**	**14654**
Per capita (MWh)	**19.24**	**9.28**	**7.33**

Table 11: Energy production by source for 2008, BAU and PC2050 for Barcelona

The associated GHG emissions are shown Figure 9 showing that the majority of emissions in 2008 and BAU are clearly the result of the use of natural gas in heating and electricity production. In BAU the total GHG emissions are reduced by 27% compared to 2008. Emissions from transport are reduced by 40%. It should be noted that these figures do not include emissions from waste and the quantities may be higher in comparison to local estimates due to life cycle assessment emission factors being used (which is why emissions from nuclear energy are shown). In the PC2050 scenario total emissions are reduced by 84%, but there is still some use of gas which accounts for 70.5% of emissions (even though gas use is reduced by almost 91% compared to 2008).

Figure 10 compares the GHG emissions per capita for 2008 and the BAU and PC2050 scenarios. It highlights a considerable drop in per capita emissions in PC2050 to 350kgCO_2e compared to over 2.5 tonnes in 2008. Under BAU emissions also drop to 1.84 tCO2e per capita.

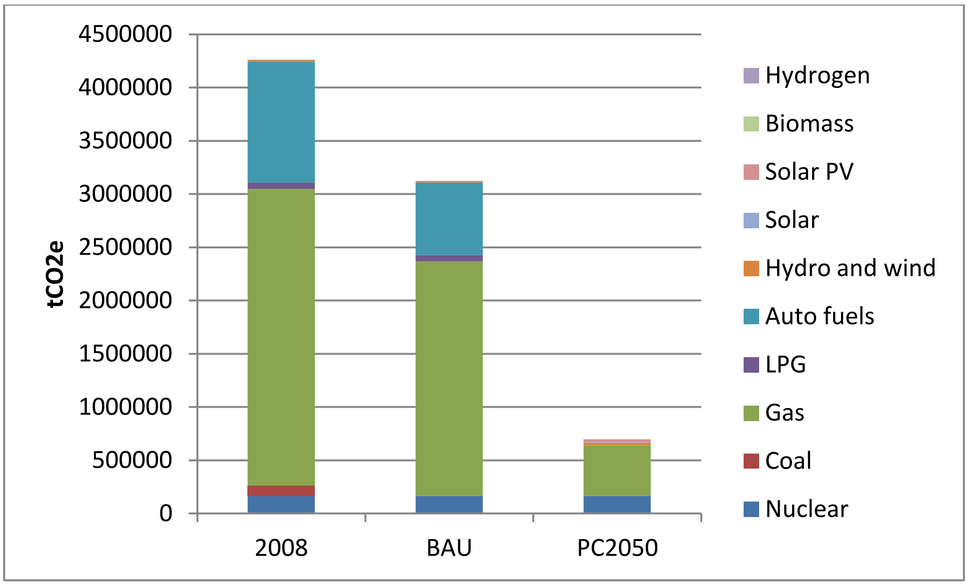

Figure 9: GHG emissions associated with energy sources for Barcelona for 2008, BAU and PC2050

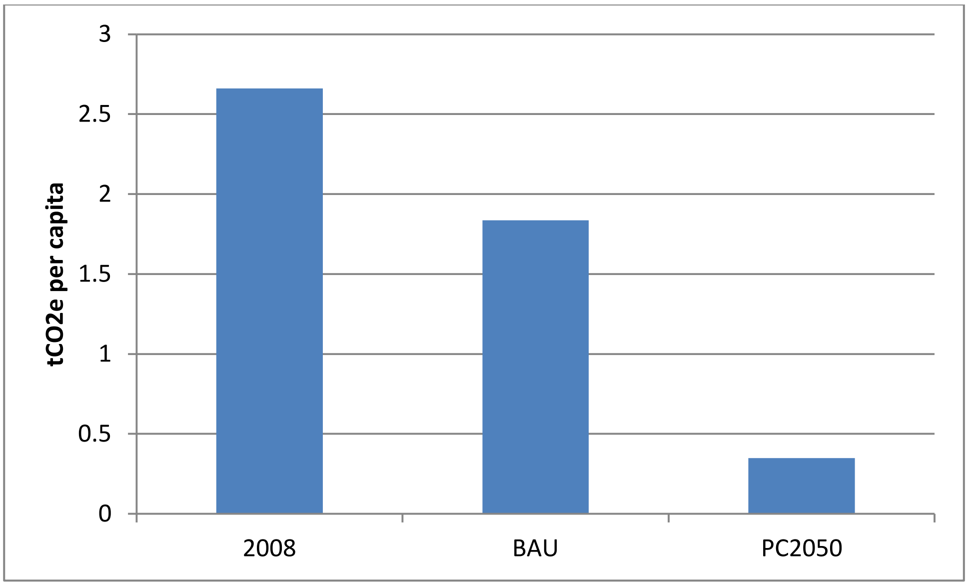

Figure 10: GHG emissions per capita for Barcelona Municipality for 2005, BAU and PC2050

MRIO – FOOTPRINT IMPACTS

POCACITO also relies upon an economic based multi-regional input-output (MRIO) approach to enable the consumption footprint of the cities to also be assessed (supply chain and city). To this end, we utilise an existing environmentally extended MRIO database called EXIOBASE or CREAA. (Tukker et al. 2013). The most current data available within this database is from 2007, which is therefore used as a baseline year. In POCACITO the environmental footprint of a city is defined as the sum of impacts associated with both household spending and government expenditure. These two aspects account for the majority of environmental impacts caused by final demand within cities.

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 11, the direct GHG emissions that occur in the city are compared with the indirect emissions.[6] It shows that the total GHG footprint increases under both the BAU and PC2050 scenarios. This is fundamentally linked to the projected increase in GDP and the resulting increase in consumption. Hence despite expected improvements in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase. The figure also shows that despite reductions in direct emissions for PC2050 the overall GHG emissions still rise considerably under PC2050.

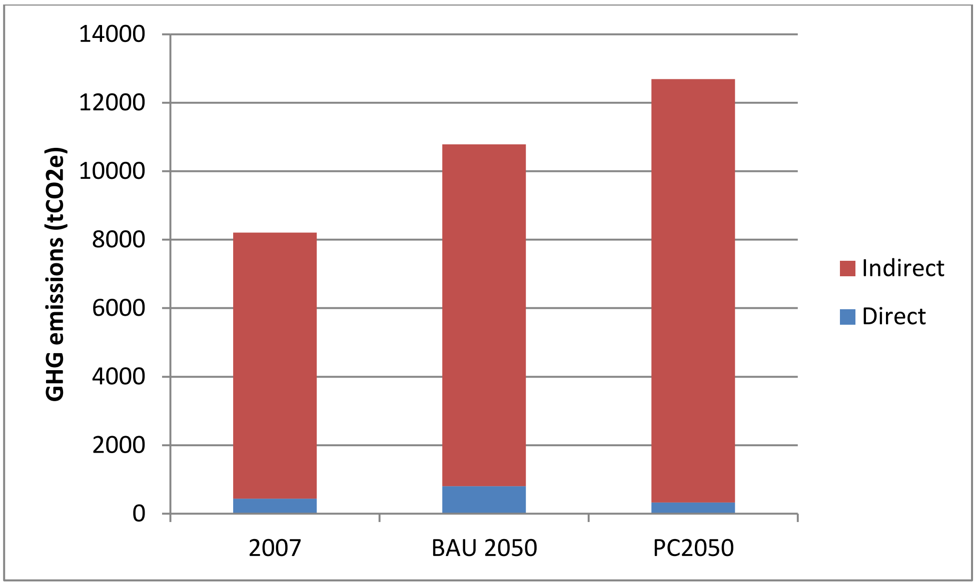

Figure 11: Direct and indirect GHG emissions for Barcelona for 2007, BAU and PC2050

Figure 12 compares the product groups responsible for GHG emissions , and shows that in both BAU and PC2050 the share of “other services” and “other goods and materials” increase considerably. Emissions caused by housing and food are also expected to increase under PC2050, whilst “transport fuels, equipment and services” and “electricity and heat fuels” decrease. This highlights that there is a reduction in local emissions from transport and electricity, but this is counteracted by increases in “other goods and services” due to increases in consumption, linked to a strong growth in GDP.

The other impacts of photochemical oxidation, acidification and eutrophication show a similar rise as shown in Table 12.

[6] The direct emissions are not the same as those calculated in the above section or in typical emission profiles reported by cities, because factors such as electricity are included under indirect. This stems from the underlying Exiobase model in which direct only accounts for direct emissions of the household or government (e.g. from burning gas).

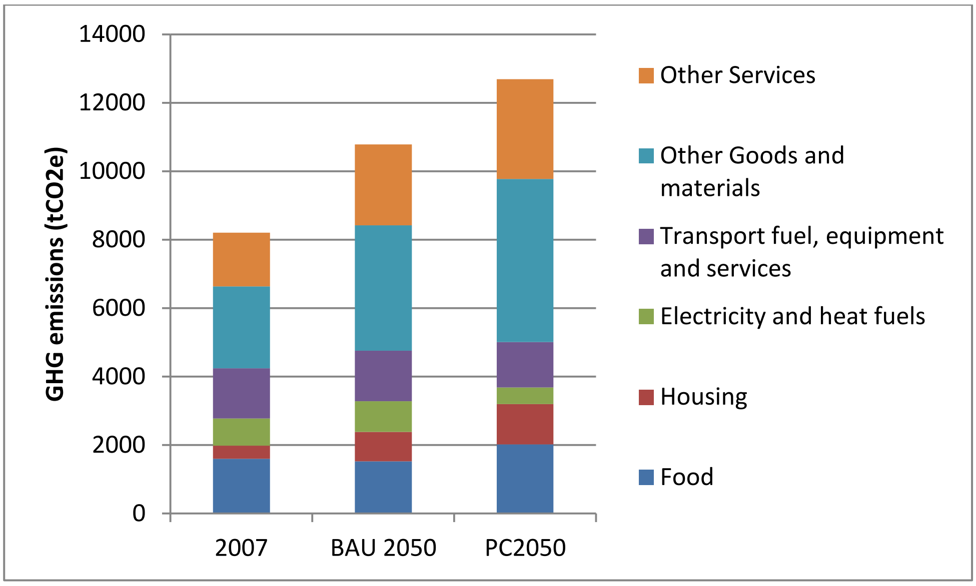

Figure 12: The contribution of product groups to the GHG footprint for 2007, BAU and 2050 for Barcelona

Table 12: Environmental impacts for 2007 and the scenarios for Barcelona

				% INCREASE FROM 2007	
	2007	**BAU**	**PC2050**	**BAU**	**PC2050**
Global warming (kg CO2 eq)	8207.7	10781.1	12683.7	31%	55%
Photochemical oxidation (kg ethylene eq)	2.3	2.7	3.0	18%	32%
Acidification (kg SO2 eq)	42.5	43.4	53.7	2%	26%
Eutrophication (kg PO4--- eq)	17.5	19.9	26.2	14%	50%

Figure 13 further illustrates the other impact categories and the contribution of the product groups contribute to the impacts. Most noticeable from this is that “other goods and materials” is dominant for all scenarios, with over 30% of the impact for photochemical oxidation and acidification. Food however is clearly the most significant contributor to the eutrophication impact.

In summary, the impacts of the scenarios mimic the anticipated rise in GDP and household spending expected. Despite improvements in the efficiency of the background production systems of 2050 and improvements in the energy efficiency and energy production of the cities energy supply, this is outweighed by the expected increase in consumption.

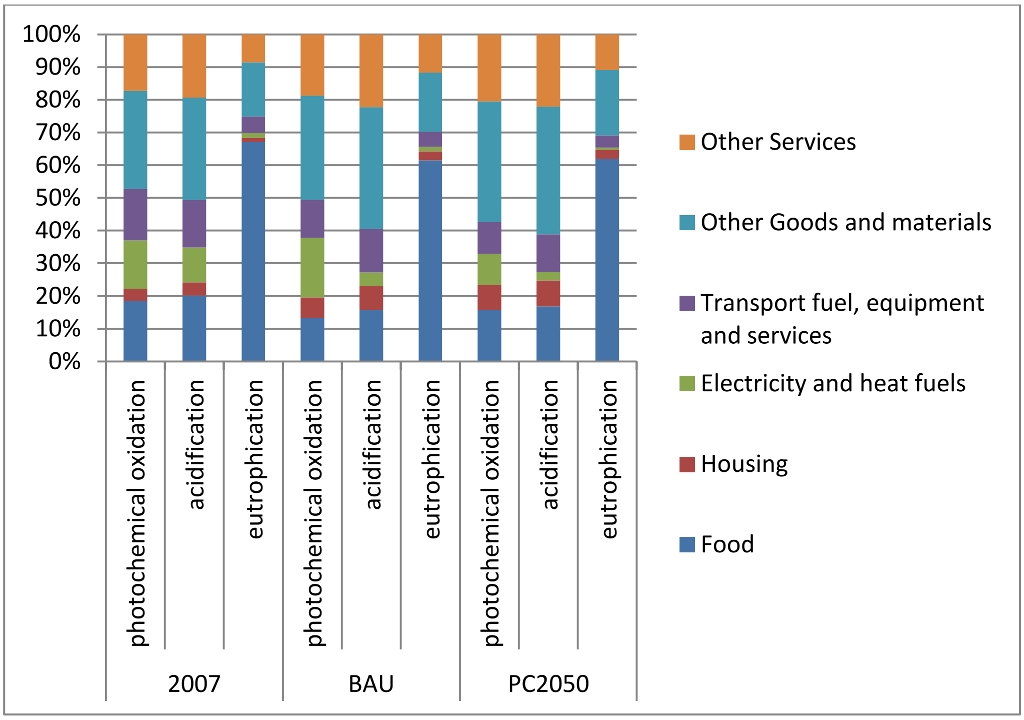

Figure 13: Comparison of other impacts for Barcelona for 2007, BAU and PC2050

IV.I.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 the population of the Barcelona Province increased by 849,900 inhabitants or 19.0 % and urban land increased by 199.9 km² or 32.9 % (Annex II, Table 86). According to the BAU scenario, by 2050, population will decrease by 281,700 or 5.3 %. However, the use of land for urban development (sprawl) will still increase by 161.0 km² or 19.9 %. According to the PC2050 scenario the population will increase by 75,000 inhabitants or 1.4 %. Since the PC2050 scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Barcelona, between 2000 and 2012, urban spread accounted for 199.9 km² with a population increase of 550,845 inhabitants. In the same period, urban areas with no population change accounted for 79.5 km². Urban areas with population densification accounted for 338.8 km² and a population increase to 1,513,493 dwellers. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 189.3 km² and a population decrease of 1,214,455 inhabitants. In summary, the development from 2000 to 2012 was characterized by a significant total population increase, a considerable urban spread, and consequently, a loss of non-urban land, and at the same time by densification (population increase) in a considerable part of the city and dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 161.0 km² with a population increase of 444,721. Urban land with no population change accounts for 121.3 km² while urban areas with a population increase (densification) account for 451.2 km² and a population increase of 752,169 dwellers. Urban areas with a population decrease (dis-densification) account for 235.1 km² and a population decrease of 1,475,608. In summary, the BAU scenario indicates, that in spite of a slight population decrease, a considerable urban spread as well as densification is will take place, while other areas will be characterised by population decreases (dis-densification). Since our assumption for the PC2050 scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 75,000 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 14 and Figure 15 shows spatial patterns of historic and projected urban change for Barcelona. Between 2000 and 2012 the central parts of the city were primarily characterised by a population decrease (dis-densification). Densification (population increase) took place in the suburbs, while areas with urban spread were located at the fringe of the city. For the BAU scenario, patterns of urban development until 2050 largely match the historical changes. The central part of the city is characterised by population decreases and the suburbs by densification. Urban spread is taking place at the fringe of the city. For the PC scenario, population increase is largest in the central part of the city. The entire city is characterised by population densification, except of some airport areas and areas with infrastructure, which did not contain any population in 2012.

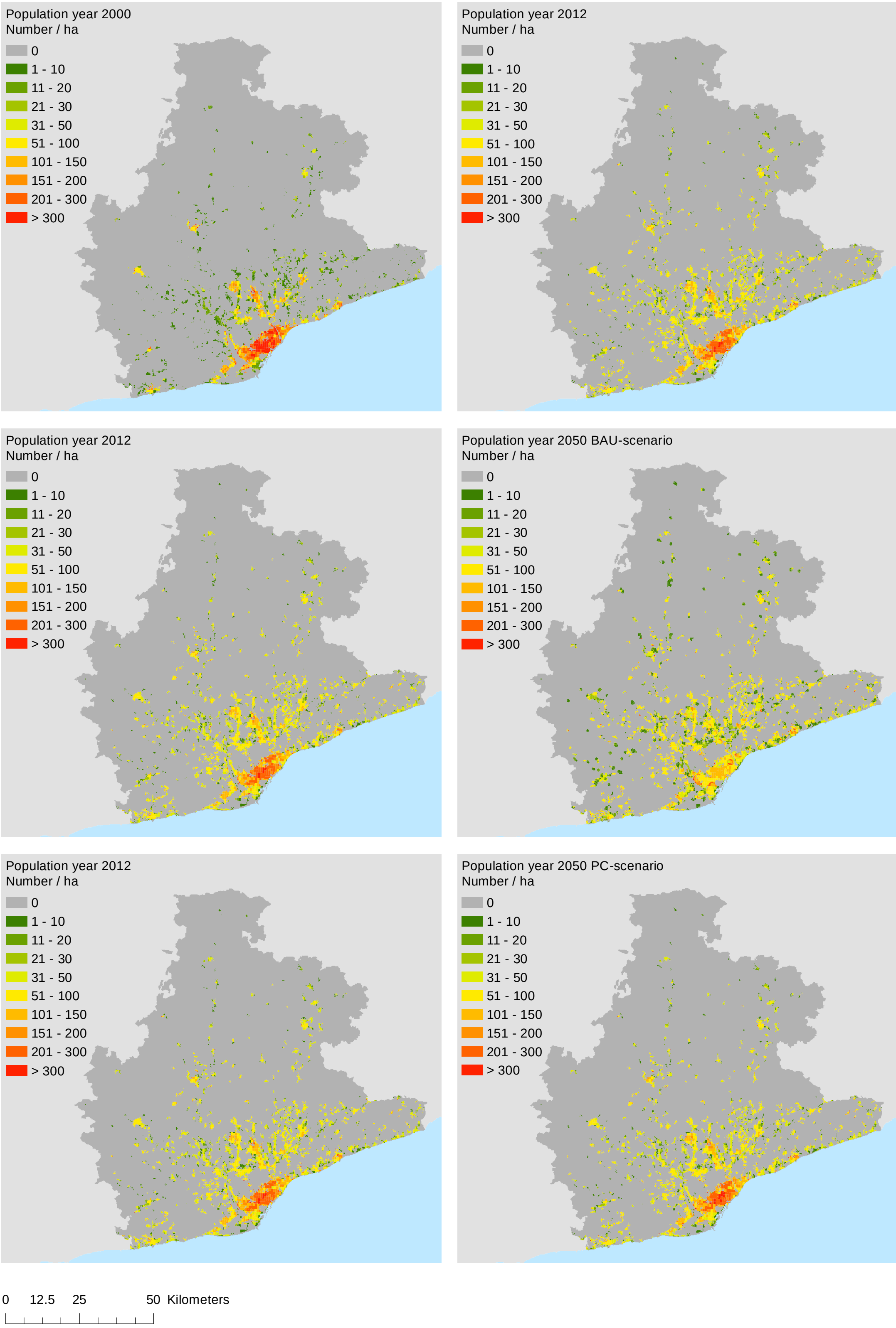

Figure 14: Population and urban change for 2000-2012, and BAU and PC2050 for Barcelona

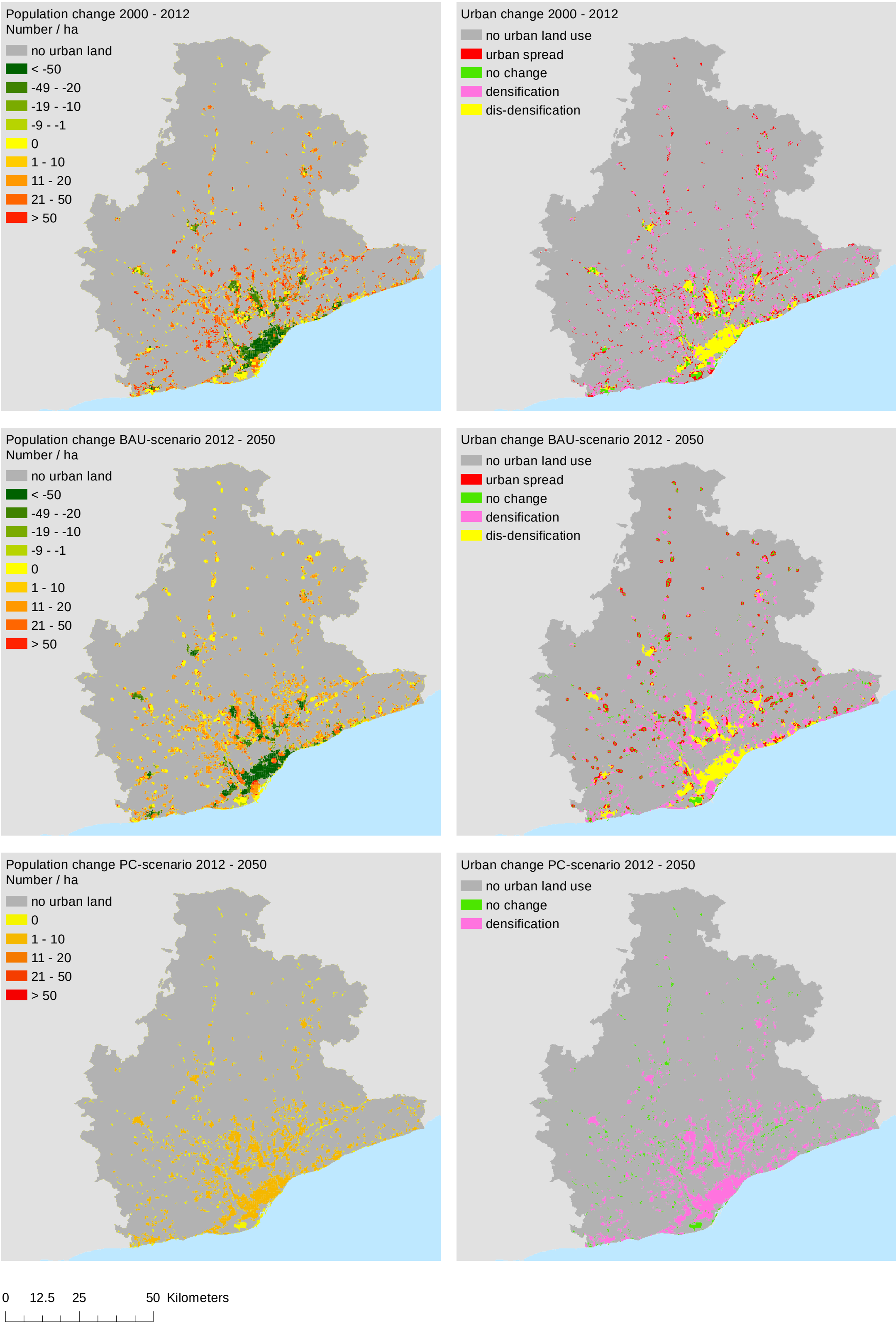

Figure 15: Population and urban change for 2000-2012, and BAU and PC2050 for Barcelona (cont'd)

IV.I.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050 for each scenario are shown in Table 13. The total costs of PC2050 are 3.6 MEUR compared to 1.3 MEUR for BAU. However, the table also shows that these costs would represent only 0.31% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 13: Investment costs for BAU and PC2050 Scenarios for Barcelona

Energy	MEUR (2016)
BAU	851
PC2050	2 120
Total costs for fossil free energy	2 599
Building renovations	
BAU	3 617
PC2050	8 441
Total costs (Energy and buildings)	
BAU	4 469
PC2050	10 562
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.15%
PC2050	0.31%

This translates into the following discounted costs as shown in Table 14 at various discounted rates from 2018 to 2050.

Table 14: Net costs for scenarios investments at different discount rates (MEUR) for Barcelona

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV[7])	3 775	2 792	2 157
PC2050 Costs (NPV)	8 921	6 597	5 097

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Barcelona are estimated at 1,882 billion MEUR/year based on the 2010 cost of 2.8% of GDP for Spain provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net of benefits of BAU and PC2050 at different discount rates are shown in Table 15. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and

[7] Net Present Value

PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050.

Table 15: Cumulative cost savings (2018-2050) due to reduced mortality in the scenarios, and for no air pollution by 2050 (EUR millions NPV) for Barcelona

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	20 037	19 178	18 362
PC2050	37 712	36 063	34 497
No air pollution	38 533	36 881	35 311

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 53. Potential jobs for renewable energy are modest with 310 ongoing jobs from operation and maintenance, but contribute to nearly 24,000 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 82,002.

Table 16: Benefits of PC2050 scenario compared to BAU for Barcelona

Additional PC2050 Jobs	MCI	O&M
Renewable energy	23665	310
Building renovation	82002	

REDUCTION IN ENERGY COSTS

Due to limitations in data availability and the scope of the project the energy costs of the scenarios could not be compared with the current costs. However it is possible to provide a semi-quantitative and qualitative indication of the costs.

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 7.2% lower. Currently (2013) Barcelona has only 3.1% renewables in its energy mix and this is expected to increase to 16.7% in BAU and 58.3% in PC2050. Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 7.2% reduction of costs in PC2050 due to reduced energy consumption (in absence of rebound effects) and a further reduction related to the 41.6% additional renewable energy (the latter depending on the actual costs of renewable energy).

IV.I.VI GAPS AND RISKS

The most prominent gaps for Barcelona under the current PC2050 scenario are as follows:

ENERGY AND ENVIRONMENT

There is an assumed continued reliance on nuclear power to supply the majority of the electricity. This is due to challenges of providing enough renewable energy at the city level, but also because nuclear is already a low carbon option. However, due to the shortfall in developing significant quantities of renewable energy there is a need for a high input of natural gas, which is responsible for the majority of GHG emissions. The current trends for self-provision of renewable energy are not significant to make a significant impact under BAU.

The projected per capita GHG emissions for PC2050 are among the lowest of the case study cities at only 340 $kgCO_2e$ per capita, but with total emissions of almost 700,000 tonnes the city is still far from an absolute zero carbon target. This is mainly due to the reliance on gas for some heating and electricity generation. There are still major weaknesses in the provision of sufficient quantities of renewable energy (due primarily to a lack of consistent and robust actions and milestones from the scenario workshops).

In order to close these gaps there is a need to provide an additional 1102 GWh of energy from renewable energy. This is slightly more than the 953 GWh that were supplied in 2008 from renewable energy.

The data availability to assess biodiversity was low but this was not addressed in the PC2050 vision or actions and hence should be considered in the strategic paper. Although waste reduction was not addressed in the PC2050 vision, there was an ambitious target for waste recovery and recycling. This should be further supported in the strategic paper along with actions for the circular economy (see below).

SOCIO-ECONOMIC

The KPI analysis showed that the business survival rate has decreased significantly from 90% to 69% (2008 to 2010) which is of concern, but there are not enough data points to indicate a trend or facilitate modelling to 2050. This is also exacerbated by the fact that Spain was particularly affected by the financial crisis, which is likely not to affect the circumstances by 2050.

Unemployment has increased dramatically from 6.8% in 2002 to 23.7% in 2012 leading to some concern, but again it is impossible to project to 2050 from these figures. This is also true for the poverty level which has also increased from 2.4% to 17.7% during 2004 to 2013.

There is some inequality in the tertiary education rates which are greater for males at 37.7% than for females at 31.9% in 2013. But both have increased from around 27% in 2003.

The cost benefit analysis showed that the PC2050 scenario would cost 6,597 MEUR compared to 2,792 MEUR for the BAU scenario (Net Present Value and using a discount rate of 3%). This represents only 0.15% of the cumulative GDP (from 2018 to 2050) for BAU and 0.31% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be a very significant 36,063 MEUR (NPV with discount rate of 1%).

URBAN SPRAWL

Under BAU although the population of Barcelona Province is projected to decrease by 281,700 or 5.3 %, the use of land for urban development (sprawl) will still increase by 161.0 km² or 19.9 % on the account of non-urban land.

We have assumed within the PC2050 that densification will occur and no urban sprawl will occur. However, the BAU scenario highlights the potential for significant urban sprawl that requires addressing in low carbon strategy of the city (e.g. also to be laid out in the POCACITO strategic paper). Hence the strategy should address two aspects. Firstly, it should address the potential for an increase in population under PC2050 within the municipality and plan for densification. However, there is also a role for Barcelona Municipality to encourage further movement of the Province population to the municipality. This is in order to reduce the risk of further urban sprawl but also to capitalise on the additional sustainability benefits of densification such as improved energy efficiency and reduced transport infrastructure and public services.

CIRCULAR ECONOMY AND CONSUMPTION

The potential for improvements in the impact of consumption are currently not well addressed in the PC2050 scenario. Options include increasing the facilities for reuse (e.g. through provision of locations to leave unwanted good for reuse) and repair (such as repair cafes), but also to support businesses and innovation in this area.

The EE-MRIO footprint analysis suggests that under PC2050 there is a risk that the total GHG emissions footprint of the city will increase by 55% to 12.6 tCO_2e per capita. This is despite the territorial emissions decreasing by 87% to 0.3 tCO_2e per capita. This is largely caused by a large increase in GDP which will potentially cause increased spending and consumption. This emphasises the need for policies to address lifestyles and consumption and promote a more circular economy.

IV.II COPENHAGEN

IV.II.I INTRODUCTION

Copenhagen is a growing city and well known as a leading sustainable city having been placed highly in the Siemens Green City Index for several years and winning the 2014 European Green Capital Award. The City of Copenhagen set forth its vision and plans to be CO_2 neutral by 2025 in its *Copenhagen Climate Plan Climate* (City of Copenhagen 2009). The majority of the population is less than 49 years old. The population has increased by 23 percent within the last twenty years from 471,300 inhabitants in 1995 to 581,000 in early 2015 (City of Copenhagen, 2015). Copenhagen has an extensive district heating system that covers 98% of homes. A major factor in the move to carbon neutrality is therefore the switch from fossil fuels to biomass in order to fuel and support the district heating network.

Since the City of Copenhagen did not actively take part in the POCACITO workshop programme the BAU and PC2050 scenarios were built up using a combination of local strategy and vision documents, the expert knowledge of the case study leaders and supplemented with interviews of local stakeholders. In addition, since Copenhagen has in any case already developed a post-carbon vision and plan, this forms the basis for the quantification of the scenarios. In BAU we assume that the 2025 vision has been achieved but that transport is still primarily fossil based. The major difference in PC2050 we assume that the transport is no longer fuelled by fossil fuels and is 100% electric, based on renewable energy.

In the Copenhagen BAU scenario the population has continued to increase and the dense city centre now has a population of 838,000. The housing and buildings are all heated through district heating which is fuelled almost entirely by biomass. The biomass is combusted in combined heat and power plants which also supply more than a third of the electricity. The remainder is supplied by wind energy, with an excess of electricity being supplied to the grid, whilst some is stored in storage facilities for peak loads. Transport is still dominated by private cars although cycling is a close second, which are the only major emissions of the city.

In PC2050 the population is slightly higher at 866,000 which has been addressed through density rather than sprawl. The quality of life is central and is promoted by nurturing blue and green spaces, low carbon mobility, safe neighbourhoods, sustainable built infrastructure, smart technology and novel forms of participation that jointly invite citizens to have active urban lives and shared activities in city spaces. Copenhagen is also a regional city, with strong networks to adjacent cities on Zealand and in Scania, in particular Malmö.

IV.II.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 17 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable). A summary of the KPI's current trends and the expected outcomes under the scenarios is given below.

ENVIRONMENTAL

Regarding biodiversity, Copenhagen has relatively large areas of protected land at about 20% for the city area, however due to low data availability no trends can be observed. For energy intensity the trend is positive, showing a decrease during the last ten years. The largest energy consuming sector is trade and services followed by private households and public institutions. In both the BAU and PC scenario more energy efficient buildings will contribute to reducing energy use, resulting in further reductions in energy intensity.

The carbon emission intensity has almost been halved during the last ten years. Several measures have been suggested for the future, such as further renewable energy and electrification of the transport sector for which the future development most likely will be very positive. A similar development can also be seen for the carbon intensity per person; however in this case the reduction is slightly smaller, although the suggested measures will probably lead to a positive development in both the BAU and the PC scenario. Sector-wise, emission reductions can be noticed for transport, while increases can be seen for industry and energy and work machines and tools. The air quality in Copenhagen has improved in terms of PM 2.5 while the levels of PM10 and NO2 have been increasing. With future electrification of the transport sector the levels can be expected to improve in both the BAU and the PC scenario. Due to low data availability no trend can be seen for transport and mobility. However, several positive measures are suggested for the future probably resulting in a reduced car use.

Waste generation has been decreasing during recent years, whilst recycling has increased and waste incineration reduced. This is considered a positive development and is expected to continue under both the BAU and the PC scenario.

ECONOMIC

The level of wealth is high in Copenhagen and it has been increasing during the last ten years by 28% in the municipality and 33% in the capital region. According to the future projection the increase will continue, with a slightly higher increase in the PC2050 scenario. Services accounts for almost four fifths of the GDP whilst industry accounts for the majority of the remainder. Employment numbers are also increasing within the service sector whilst industry-related employment is decreasing. The economy of the municipality is strong, with decreases in both the budget deficit and in the indebtedness level. The development is expected to continue both in the BAU and the PC scenario, as a result of the increasing wealth in the city.

SOCIAL

The variation rate of unemployment level by gender is held fairly constant at approximately 7% equally distributed between the two genders. No trend can be seen due to relatively high annual variations. The variation rate of poverty level has been decreasing between 2000 and 2010 and the improvement is expected to continue in both the BAU and PC scenario. The trend for the level of tertiary education in the population was only available for women and shows a positive trend. The level for women was already relatively high at 35% in 2006 and increased by 6% to 41% in 2012. Finally, the average life expectancy has also increased during the by 1.6 years from 2004 to 2013.

Table 17: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Copenhagen

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Green or blue area City Wider area	City: 20% Wider area: 36.6%	No trend available	+	+
	Energy	Energy intensity variation rate	GWh / EURO 2005-2014	2005: 0.168 2014: 0.140	-17%	+	+
		Variation rate of energy consumption by sectors	Percentage of electricity and heating 2013	Public institutions: 21.1% / 7.9% Private households: 28.7% / 66.8% Trade and services: 41.3% / 21.9% Industry: 6.6 / 3.3% Building and construction: 2.2% / 0%	No trend available		
	Climate and Air Quality	Variation rate of carbon emissions intensity	Ton CO_2/ million euro 2005-2014	2005: 58.7 2014: 35.9	-39%	++	++
		Carbon intensity per person	Ton CO_2 / Capita 2005-2013	2005: 4.69 2013: 3.35	-29%	++	++
		Variation rate of carbon emissions by sector	kTon CO_2 2005-2012	Work machines and tools 50.0 – 74.0 Industry and energy 734.0 – 1158.4 Road transport 489.0 – 348.4 Transport & other 45.6 – 25.3	Work machines and tools +48% Industry and energy +57.8% Road transport -28.8% Transport & other -44.5%		
		Exceedance rate of air quality limit values	Annual mean value 2009-2012 µg/m3	PM 2.5 18-15 PM10 30-31 NO2 50-55	-17% +3.5% +10%	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
	Transport and mobility	Variation share of sustainable transportation	Percentage 2012	Cycle 26% Bus, train, metro 21% Cars 33% Walking 20%	No trend available	+	+
	Waste	Variation rate of urban waste generation	Ton per capita/year	2007 1.77 ton/cap 2010 1.56 ton/cap	-0.21 ton/cap	+	+
		Variation rate of urban waste recovery	Percentage	Recycling rate 2006-2012: 55% - 58% Incineration rate 2006-2012: 41% - 37%	Recycling rate +3% Incineration rate -4%	+	+
	Water	Water losses variation rate	m3/person/year	N/a	N/a	N/a	N/a
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	N/a	N/a	+	+
		Urban density variation rate (buildings)	Nº of buildings/ km2 2010	313.9	No trend available	N/a	N/a
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person GDP/cap (EUR)	Capital Region 2003-2013: 42,000 - 56,000 Municipality 2003 -2013: 49 000 - 63 000	Capital Region +33% Municipality +28%	++	++
		Variation rate of GDP by sectors	Percentage 2013	Agriculture: 1.5% Industry: 21.7% Services: 76.8%	No trend available	N/a	N/a
		Employment by sectors variation rate	Percentage 2009 to 2013	N/a	Hotels and Restaurants +21.9% Education +13.5% Research & Development +9.3% Consultancy +9.2% Building and Construction -14.9% Transport -13.1% Telecommunications -9.8%	N/a	N/a

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
		Business survival variation rate	Percentage	N/a	N/a	N/a	N/a
	Public Finances	Budget deficit variation rate	Percentage of city's GDP 2005-2014	2005: - 0.6% 2014: -4.5%	-3.9%	+	+
	Public Finances	Indebtedness level variation rate	Percentage of city's GDP 2005-2014	2005: 3.3% 2014: 0.9%	-2.4%	+	+
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	N/a	N/a	+	+
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage 2007-2012 Male / Female	2007: 6.5 / 7.1 2012: 7.8 / 7.1	No trend available due to annual variations	+	+
SOCIAL	Social Inclusion	Variation rate of poverty level	Percentage	2000: 18.2% 2010: 14.5%	-3,7%	+	+
SOCIAL	Social Inclusion	Variation rate of tertiary education level by gender	Percentage (2006-2012)	(2006-2012) Male: n/a Female: 35%-41%	Female +6%	+	+
SOCIAL	Social Inclusion	Variation rate of average life expectancy	Average Nº 2004-2013	2004: 74.7 2013: 76.3	+1,6 years	+	+
SOCIAL	Public services and Infrastructures	Variation rate of green space availability	Recreational areas as percentage of total area City of Copenhagen	City:16.5% Capital region: 19.1%	No trend available	+	+
SOCIAL	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes		+	+

IV.II.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

The energy use and GHG emissions of the scenarios are compared with 2013 in Figure 16 and Figure 17 respectively. They show that the energy use is expected to rise in both BAU and PC2050 primarily due to the increasing population and the resulting increased consumption of households. Energy use in transport also rises in BAU but is reduced in PC2050 due to an increased move to sustainable transport modes and electric vehicles.

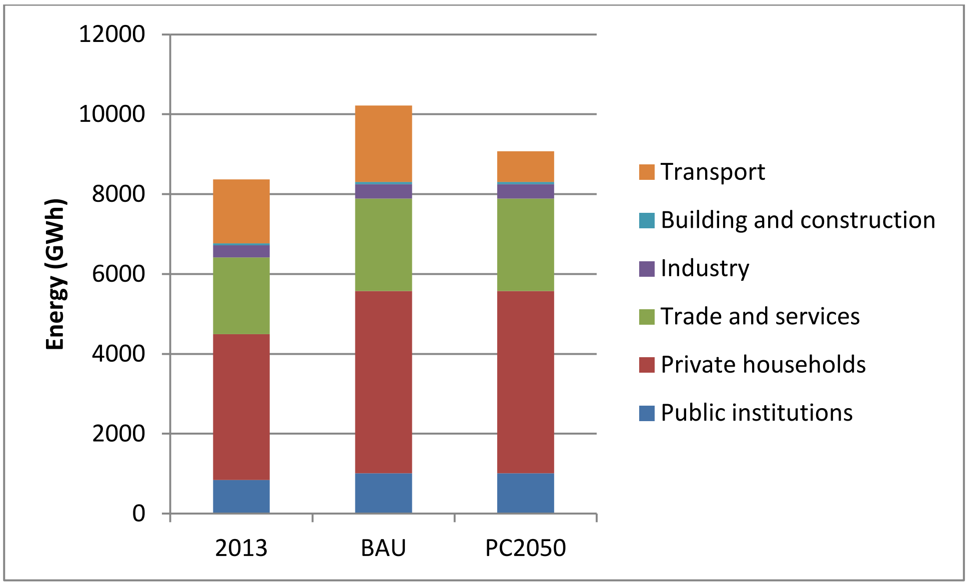

Figure 16: Energy use by sector for Copenhagen 2013, BAU and PC2050

Despite the increase in energy use, GHG emissions are reduced by 78.4% and 94.4% for BAU and PC2050 respectively, compared to 2010. This is due to a shift to biomass to fuel the district heating system (instead of coal and natural gas) and a large increase in wind power from the current 87 MW to 450 MW. There is however some small use of natural gas under both scenarios that accounts for the majority of the emissions under PC2050. In BAU the majority of GHG emissions come from the transport sector where 70% of the fleet is still fuelled by fossil fuels. In PC2050 we assume that fossil fuel based transportation has been banned from the city and electric vehicles (based on wind power electricity) are prevalent.

The figures are reported for the base year 2010 instead of 2013 above because detailed data for energy sources was only available for 2010. These may also be slightly higher than those reported by the City of Copenhagen because full life cycle emission factors are used. In addition, some figures reported by Copenhagen contained reductions applied to the emissions due to self-proposed renewable energy credits.

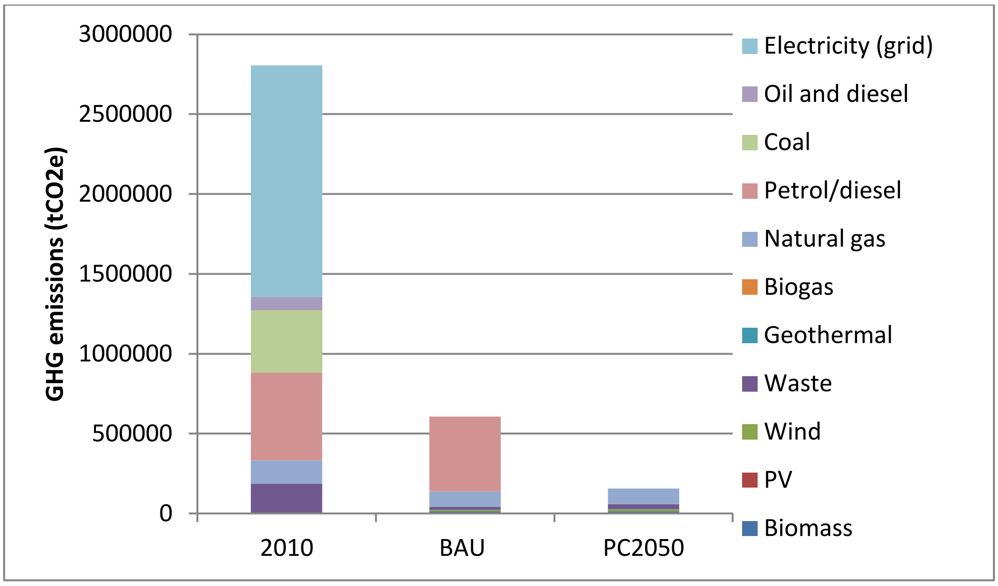

Figure 17: GHG emissions associated with energy sources for Copenhagen 2010, BAU and PC2050

Finally, Figure 18 presents a comparison of the per capita GHG emissions. It can be seen that both scenarios are close to post-carbon status, and PC2050 does not attain zero emissions due to a small use of natural gas in the cities heating, but also due to some life cycle emissions that are present in the emission factors. These may actually be slightly less in 2050 than in the current production and so actual emissions could be slightly less than is presented here, depending on future production techniques and raw materials.

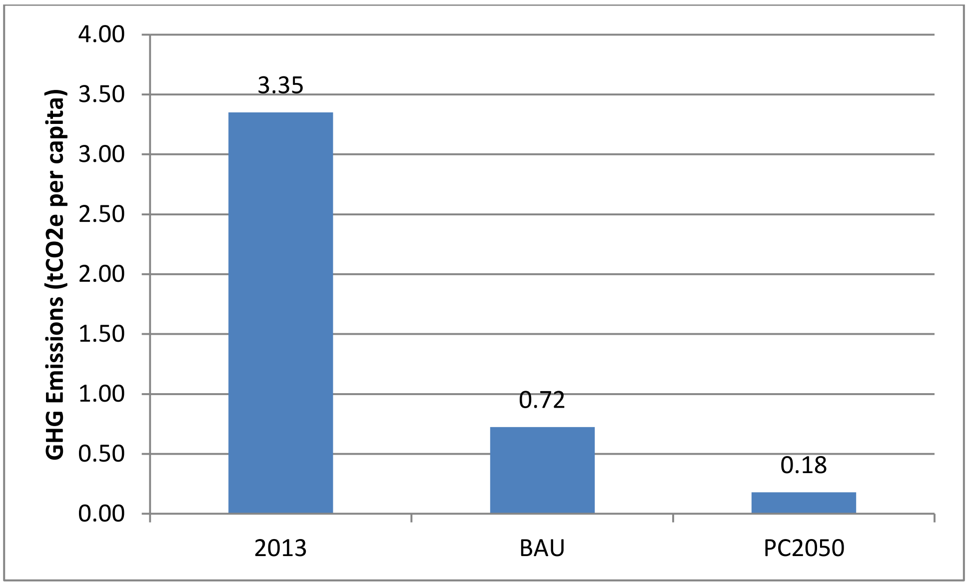

Figure 18: GHG emissions per capita for Copenhagen for 2013, BAU and PC2050

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 19, the direct GHG emissions that occur in the city are compared with the indirect emissions. It shows that despite direct emissions falling, indirect and overall emissions increase under both scenarios. This is related to the projected increase in GDP and the expected associated increases in consumption. Hence despite expected improvements in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase.

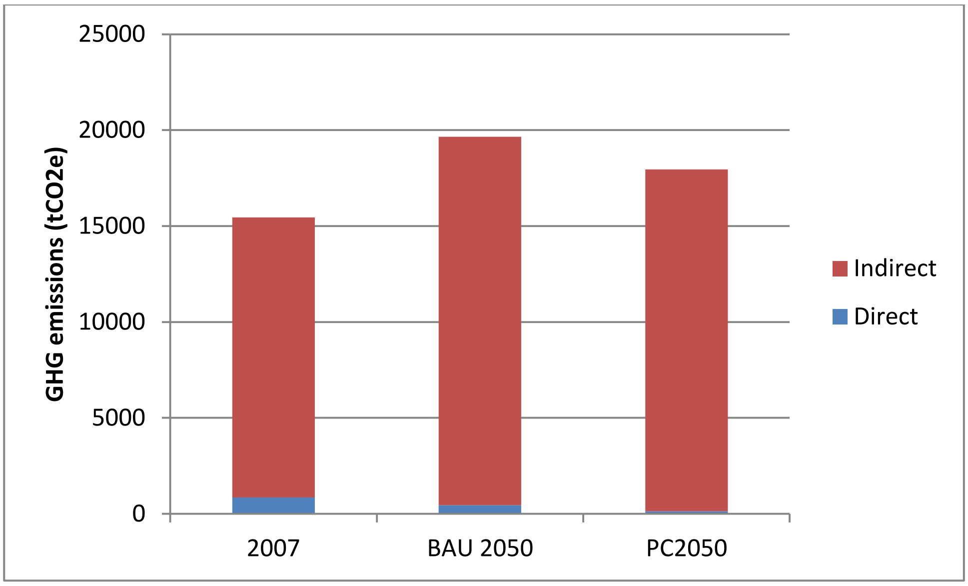

Figure 19: Direct and indirect GHG emissions for Copenhagen for 2007, BAU and PC2050

Figure 20 compares the contribution of the product groups to the GHG emissions for each scenario, and shows that in both BAU and PC2050 "other services" and "other goods and materials" increase considerably, whereas electricity and heat fuels decreases especially in PC2050. Transport also reduces under both scenarios but more so in PC2050.

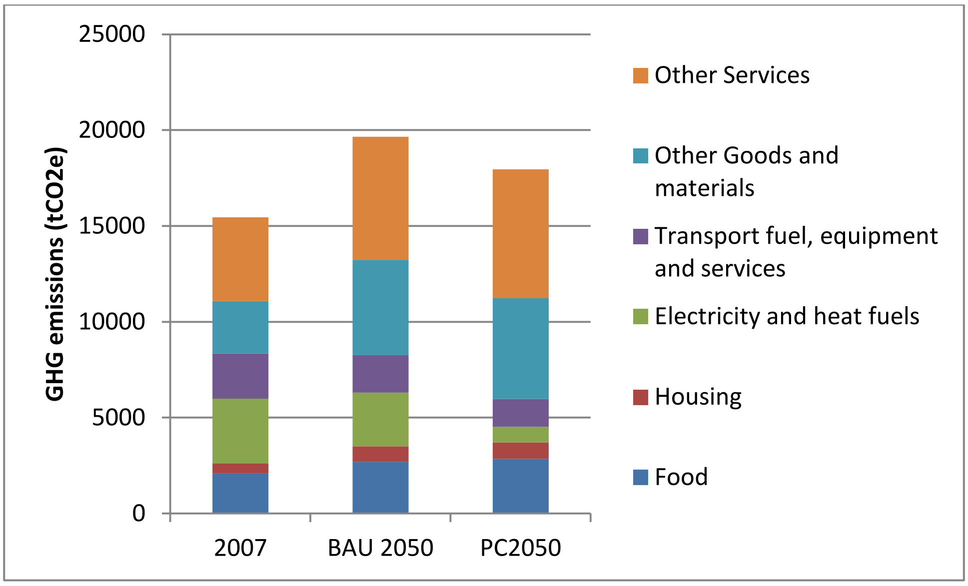

Figure 20: The contribution of product groups to the GHG footprint for 2007, BAU and 2050 for Copenhagen

The other impacts of photochemical oxidation, acidification and eutrophication show a similar rise as shown in Table 18. However, by proportion the rise of photochemical oxidation, 72% and 75% for BAU and PC2050 respectively, is somewhat higher than for the other values which typically rise around 20% (see Table 18). The reason is highlighted in Figure 21, which shows that the contribution of "electricity and heat fuels" to the photochemical oxidation impact greatly increases in both BAU and PC2050. This is probably due to the increase in the use of biomass for heating and electricity generation. However, due to the structure of the underlying Exiobase database and platform the actual increases in photochemical oxidation may be under represented. This is because no product group existed to adequately represent the use of biomass in district heating and hence the general product group "Products of forestry, logging and related services" was used. Unfortunately, this does not adequately reflect the nature of emissions from the burning of biomass which could be considerable depending on the technology utilised in 2050.

Table 18: Environmental impacts for 2007 and the scenarios for Copenhagen

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2 eq)	15450.5	19655.1	17952.6	127%	116%
Photochemical oxidation (kg ethylene eq)	4.1	7.0	7.1	172%	175%
Acidification (kg SO2 eq)	66.3	85.7	85.2	129%	128%
Eutrophication (kg PO4--- eq)	17.7	22.0	22.5	124%	127%

Figure 21 compares the contribution of the product groups to the other environmental impacts for 2007 and the scenarios. It shows that the main contributor to eutrophication is food, which is what we expect due to the use of fertilisers. For acidification the sector "other goods and materials" becomes more dominant in both BAU and PC2050 compared to 2007.

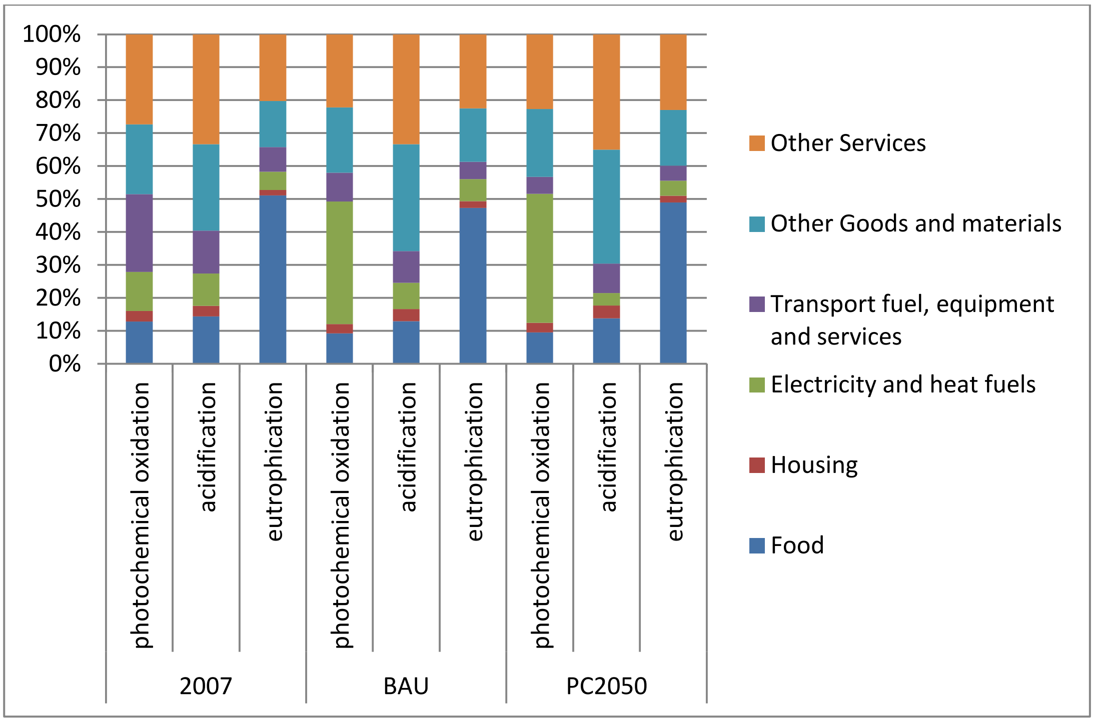

Figure 21: Comparison of other impacts for Copenhagen for 2007, BAU and PC2050

IV.II.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Copenhagen's population increased by 55,700 or 4.8 % and urban land increased by 12.8 km² (see Table 86 of Annex II). According to the BAU scenario, until 2050 population will increase by another 324,000 or 26.7 % and urban land will increase by 74.4 km² or 23.6 % on the account of non-urban land. According to the PC scenario, population will increase by 374,700 or 30.9 % by 2050. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Copenhagen, between 2000 and 2012, urban spread accounted for 12.8 km² with a population increase of 16,029. In the same period, urban areas with no population change accounted for 145.0 km². Urban areas with population densification accounted for 107.5 km² and a population increase of 241,476. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 49.6 km² and a population decrease of -201,800. In summary, the development from 2000 to 2012 was characterized by a total population increase, some urban spread, and consequently loss of non-urban land and at the same time by densification (population increase) in some urban areas and a dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 74.4 km² with a population increase of 92,963. Urban land with no population change accounts for 152.5 km² while urban areas with a population increase (densification) account for 112.1 km² and a population increase of 251,769. Urban areas with a population decrease (dis-densification) account for 50.3 km² and a population decrease of -20,752. In spite of the relatively limited urban spread from 2000 to 2012, the BAU scenario indicates, that the expected population increase until 2050 will result in quite a considerable urban spread and thus a loss of non-urban land while at the same time large parts of the urban land will be characterized by population increase (densification) and a lesser part by population decrease (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 374,700 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 22 and Figure 23shows spatial patterns of historic and projected urban change for Copenhagen. Between 2000 and 2012 population increase was most pronounced in the central part of the city. Patterns of urban development are characterised by densification in the city centre and in its surrounding and in some parts of the city's suburbs. Parts of the city's suburbs were also characterised by no change or dis-densification (population decrease) while urban spread was primarily taking place in the western outskirts. For the BAU scenario, patterns of urban development until 2050 are characterised by large areas of urban spread, primarily in the western outskirts. Densification is primarily taking in the city centre and its surroundings, while dis-densification is taking place in parts of the suburbs. For the PC scenario, population increase is largest in the central part of the city. Almost all of the city is characterised by population densification, except of some harbour and airport areas, which did not contain any population in 2012.

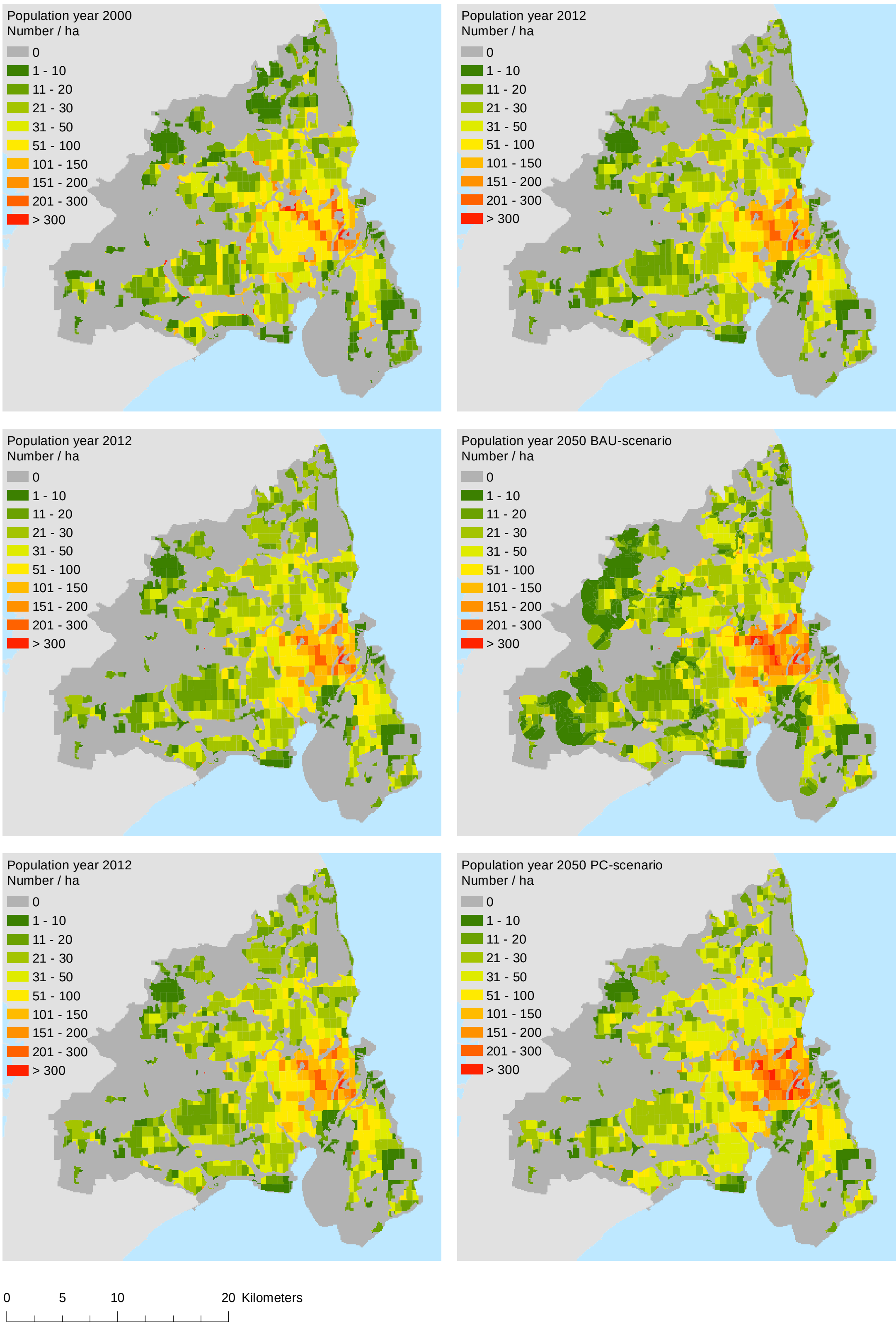

Figure 22: Population and urban change for 2000-2012, BAU and PC2050 for Copenhagen

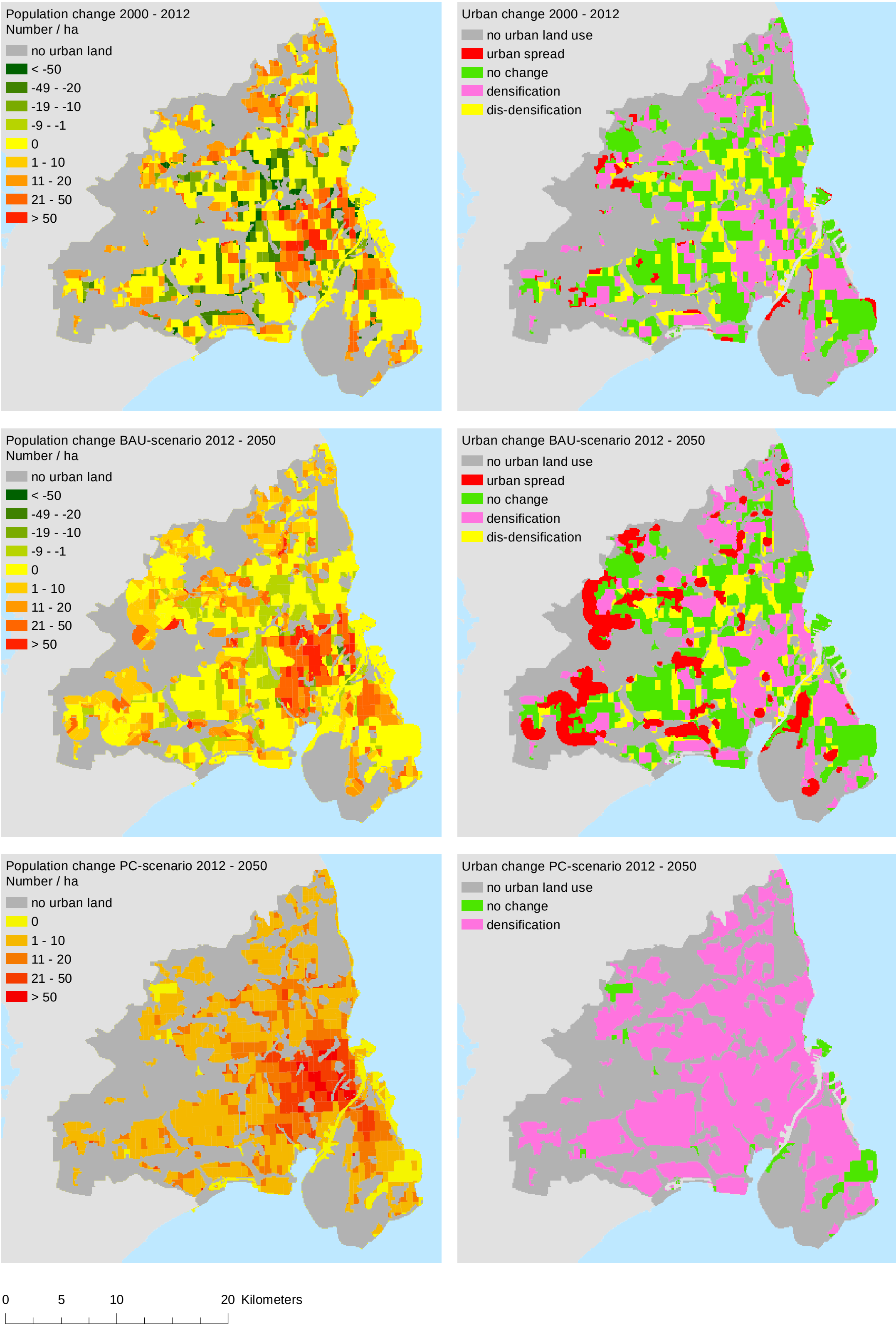

Figure 23: Population and urban change for 2000-2012, BAU and PC2050 for Copenhagen (cont'd)

IV.II.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 19. The total costs of PC2050 are 7,039 MEUR compared to 3,667 MEUR for BAU. However, the table also shows that these costs would represent only 0.35% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 19: Investment costs for BAU and PC2050 Scenarios in Copenhagen

Energy	MEUR (2016)
BAU	1 300
PC2050	1 514
Building renovations	
BAU	2 368
PC2050	5 525
Total costs (Energy and buildings)	
BAU	3 668
PC2050	7 040
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.18%
PC2050	0.35%

This translates into the following discounted costs as shown in Table 20 comparing various discounted rates from 2018 to 2050.

Table 20: Net costs for scenarios investments in Copenhagen at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	3 098	2 291	1 770
PC2050 Costs (NPV)	5 946	4 397	3 397

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Copenhagen are estimated at 1,059,797,068 EUR/year based on the 2010 cost of 2.7% of GDP for Copenhagen provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net of benefits of BAU and PC2050 at different discount rates are shown in Table 21. The table shows the benefit or cost of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050.

Table 21: Cumulative cost savings (2018-2050) due to reduced mortality in the Copenhagen scenarios, and for no air pollution by 2050 (€ millions NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	-2 299.19	-2 199.36	-2 104.49
PC	2 613.77	2 499.44	2 390.83
No air pollution	46 573	45 006	43 509

The modelling of potential air pollution costs included biomass into the calculations as biomass energy production facilities can also emit considerable pollution. Both scenarios for Copenhagen utilise significant biomass for energy production but the extent of emission controls that will be installed in 2050 is not known. Therefore the figures in Table 21 represent a worst case scenario and benefits should in fact be much higher, and more towards the benefits of "no air pollution". Therefore in Table 22 the benefits of the scenarios are calculated assuming that no air pollution occurs as a result of biomass combustion.

Table 22: Cumulative cost savings (2018-2050) due to reduced mortality assuming no air pollution from biomass combustion (€ millions NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU (biomass excluded)	18 939.46	18 117.09	17 335.67
PC2050 (biomass excluded)	23 738.85	22 700.44	21 714.01

Therefore it can be seen that the potential net benefits of PC2050 of 22.7 MEUR (using a discount rate of 1%) far outweigh the net costs even though only the benefits of reduced air pollution were considered.

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 53. Potential jobs for renewable energy are modest with 115 ongoing jobs from operation and maintenance, but contribute to nearly 9,600 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 53674.

Table 23: Benefits of PC2050 scenario compared to BAU for Copenhagen

Additional PC2050 Jobs	MCI	O&M
Renewable energy	9563	115
Building renovation	53674	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU due to a reduced energy consumption of 11%. This is primarily due to transport in PC2050 being fossil fuel free but also increased energy efficiency of buildings through deeper renovation. Currently (2010) Copenhagen has 21.1% renewables in its energy mix and this is expected to increase to 80.8% in BAU and 95.6% in PC2050. Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

However, there is a risk both to energy security and cost with the amounts of biomass projected under both scenarios representing 61.2% and 67.7% in BAU and PC2050 respectively.

In summary, there is potential for 11% reduction of costs in PC2050 compared to BAU due to reduced energy consumption and a further reduction related to the 15% additional renewable energy.

IV.III GAPS AND CONCLUSING COMMENTS

In summary, Copenhagen is likely to remain one of the most sustainable cities in Europe, and indeed in the world both through BAU or PC2050. Due to the limited participation of Copenhagen in the POCACITO project, the analysis was conducted differently due to the unavailability of an actual POCACITO PC2050 scenario, which should be taken into account when reading the discussion below. Because Copenhagen already has a 2025 carbon-neutral target (apparently disregarding transport) we have utilised this and assumed that the only difference between BAU and PC2050 is that under PC2050 transport is predominately electrified and carbon neutral.

ENERGY AND GHG EMISSIONS

A major facet of Copenhagen is its district heating system which will be fuelled predominately through biomass under both BAU and PC2050. However, due to this there is a risk of increased air pollution which could be detrimental to local air quality depending on the extent of pollution control technology. There is also a strong focus on wind energy leading to the lowest GHG emissions of our case study cities of 0.7 tCO_2e per capita under BAU and 0.18 tCO_2e per capita under PC2050. Hence even under PC2050 there are some GHG emissions due to life cycle impacts (i.e. GHG emissions within the life cycle of the energy sources) and an assumed small requirement of natural gas needed to supplement energy requirements.

Currently, there is a lack of clarity and information of the approach to transport of the City of Copenhagen, which has filtered through into the BAU assumption that some fossil fuel transport will remain.

URBAN SPRAWL

The KPI analysis showed that Copenhagen has a high percentage of protected green areas (about 20%) although due to data limitations a trend was not discernible.

Through the land use analysis it was shown that during the years 2000 to 2012 Copenhagen's use of land for urban purposes increased by 12.8 km^2 driven by a population increase of 55,700. Following this trend, under BAU there is a projected increased of urban land area of 74.4 km² or 23.6 % due to a population increase of 324,000. Hence under PC2050, with a potential population increase of 374,700 there is the risk of significant encroachment of non-developed land unless densification becomes a specific part of future policy.

SOCIO-ECONOMIC

The KPI analysis showed that the social conditions of Copenhagen, including poverty level, equality, life expectancy and education have experienced positive trends in recent years. This is expected to continue under both BAU and PC2050.

The cost benefit analysis showed that the PC2050 scenario would cost 4,397 MEUR (NPV with discount rate of 3%) compared to 2,291 MEUR for BAU. This represents only 0.18% of the cumulative GDP (from 2018 to 2050) for BAU and 0.35% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 2500 MEUR (NPV with discount rate of 1%).

If air pollution is reduced to zero by 2050 (i.e. through best available pollution control of biomass combustion) at a linear rate, the expected net benefits compared to no action are expected to reach 45,000 MEUR. The implementation of PC2050 could also stimulate significant job growth across the supply chain of almost 10,000 jobs due to the renewable energy and 53,600 due to building renovations.

CIRCULAR ECONOMY AND CONSUMPTION

There is currently a limited emphasis within the Copenhagen strategy on consumption and the circular economy. Options include increasing the facilities for reuse (e.g. through provision of locations to leave unwanted good for reuse) and repair (such as repair cafes), but also to support businesses and innovation in this area.

The EE-MRIO footprint analysis suggests that despite local GHG emissions and impacts decreasing by 96% under PC2050 to 0.8 tCO_2e per capita, there is a risk that the total footprint impacts of the city will increase by 16% to 17.9 tCO_2e per capita. This is largely caused by the continuing increase in GDP which will potentially cause increased spending and consumption. This emphasises the need for policies to address lifestyle and consumption and promote a more circular economy.

IV.IV ISTANBUL

IV.IV.I INTRODUCTION

This document consolidates the work to date of POCACITO on modelling the business as usual (BAU) and post carbon (PC 2050) scenarios for Istanbul and quantifying the impacts. It should be noted that the BAU scenario is primarily developed from a continuation of current trends with consideration of current projects, whilst PC2050 is developed from an interpretation of the vision, action and milestones developed in the stakeholder workshops. It is therefore a judgement based on the consistency and robustness of supporting actions to the desired post-carbon state, and a not a quantification of an idealistic state (for further information see Harris et al, 2016).

In the BAU scenario the population of Istanbul continues to grow rapidly reaching 19.8 million (from 13.9 million in 2012), whilst in PC2050 the population grows more slowly reaching 18.9 million in 2050.

Energy use is forecast to grow in both scenarios, both due to the growing population and increasing energy use, in particular electricity use (due to increasing income levels).

However, the assessment, particularly around energy use and GHG emissions was difficult due to insufficient data. Although adequate national data was also difficult to identify, it was sufficient to form the basis of the approximation for energy use in Istanbul.

Similarly with Istanbul, the conditions in Turkey are particularly difficult to project due to a lack of data but also due to the very dynamic conditions with high growth and changing life styles.

IV.IV.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 24 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable).

It shows that ecosystem protected areas and green spaces have increased and biodiversity is likely to increase under PC2050 due to more green buildings, the integration of built and natural environment, and the protection of biologically important areas. Energy intensity has decreased when measured in terms of energy per GVA (gross value added) but data limitation prevents discerning a clear trend. The general growth in energy use is most likely due to an increase in GVA, and it is difficult to say whether the decrease in energy intensity will continue under either scenario.

In terms of air quality the current trend in Istanbul is positive regarding NOx but unchanged for PM10’s. In the BAU scenario further improvements seem unlikely. In the PC scenario the exceedance of air pollution threshold levels will probably be lower as a result of an increased use of electric and hybrid vehicles and use of renewables for transport.

Due to low data availability no trend can be established for sustainable transport under BAU. However since no major measures have been put forward, we assume that the transportation modes will probably have similar shares as today, both in the PC and BAU scenario.

The current trend for waste shows increasing waste generation and is expected to continue in both the BAU and PC scenario. However, waste recovery is improving but is still at a low level. The increase will probably continue, especially in the PC scenario, but it will most likely not reach European levels. Overall water use and management has greatly improved with high quality sewage treatment and recovery of water.

There was no data available on the status of energy efficient buildings, but few improvements are expected under BAU. In the PC scenario increasing use of solar energy and energy efficient buildings will have positive impacts. Urban density is discussed in the land use section below.

There is a high economic growth rate which is expected to continue. The service sector is likely to further increase its share on GDP whilst industry is expected to drop under both scenarios. However, there appears to be an increasing and highly variable indebtedness level which could be of concern.

On a positive note, unemployment and the poverty level appear to be decreasing and tertiary education increasing. This is expected to continue under both scenarios. However, there is some inequality with a higher unemployment rate amongst the female population.

Table 24: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Istanbul

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Percentage	39 498 – 52 212 (2004-2014)	+32.1%	+	++
	Energy	Energy intensity variation rate	toe/euro toe	0.023 – 0.020 toe/euro GVA (2008-2012) Not available	-13% N/A	-	0
		Variation rate of energy consumption by sectors	Percentage	Residential & services: +12 points Transportation: +4 points Industry: -1 points Agriculture: +3 points Others: -18 points (2003-2008)	Too little data to draw any conclusions	N/A	N/A
	Climate and Air Quality	Variation rate of carbon emissions intensity	ton CO_2/euro ton CO_2	0.315 – 0.246 ton CO2 eq. / 1000 dollars GVA No data	-0.069 No data	0	+
		Carbon intensity per person	ton CO_2 eq.	3.25 – 3.31 (2006-2010)	+1.8%	-	+
		Variation rate of carbon emissions by sector	ton CO_2			N/a	N/a
		Exceedance rate of air quality limit values	Nº	SO_2: 0 – 0 (2010-2012) NO_2: 35 – 0 (2010-2012) PM_{10}: 157 – 173 (2010-2012) $PM_{2.5}$: 0 – 0 (2010-2012)	Improvement in NO2, no difference in PM10.	0	+
	Transport and mobility	Variation share of sustainable transportation	Percentage	54% (2008) Pedestrian, cycling, public transit	No data on trend (incomparable data points)	0	0
	Waste	Variation rate of urban waste generation	kg/person/year	$4.67*10^9 – 5.69*10^9$ kg/year (2005-2012)	No data per person.	-	-

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
		Variation rate of urban waste recovery	Percentage	0.48% - 2.62% (2006-2011)	+2.14 points (2006-2011)	+	+
	Water	Water losses variation rate	m^3/person/year	2001: 35.3% 2012: 24.11	-	+	+
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	Number of LEED building (2009 – 2014: 2 - 40	-	+	+
	Buildings and Land Use	Urban density variation rate	Nº/km^2	637.93 – 677.51 (2009-2011)	+6.2%	N/A	N/A
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person	7 943 – 13 865 dollars GVA/person	+74.6%	++	++
ECONOMY	Sustainable economic growth	Variation rate of GDP by sectors	Percentage	Agriculture/Industry/Services (2007-2011): 0.2%/27.5%/72.3% - 0.2%/27.4%/72.5%	No significant changes	N/A	N/A
ECONOMY	Sustainable economic growth	Employment by sectors variation rate	Percentage	Agriculture/industry/services (2004-2009): 0.8%/42.6%/56.7% - 0.3%/37.9%/61.8%	Number of people working in services increases, working in industry decreases	N/A	N/A
ECONOMY	Sustainable economic growth	Business survival variation rate	Percentage	No data	No data	ND	ND
ECONOMY	Public Finances	Budget deficit variation rate	Percentage of city's GDP	No data	No data	ND	ND
ECONOMY	Public Finances	Indebtedness level variation rate	Percentage of city's GDP	7.8% - 9.5% (2006-2012)	Significant variations (max in 2010: 31.7%)	0	0
ECONOMY	Research & Innovation dynamics	R&D intensity variation rate	Percentage	0.63% - 0.69% (2010-2011)	No clear trend but very low rate currently	-	-
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage	Male: 11.7% – 10.1% (2004-2012) Female: 14.9% – 14.4% (2003-2012)	No trends. Significant variations	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
		Variation rate of poverty level	Percentage	21% - 17.4% (2006-2012)	Significant variations	+	++
		Variation rate of tertiary education level by gender	Percentage	Male: 3.92% – 5.71% (2008-2012) Female: 3.14%-4.98% (2008-2012)	Increase	+	+
		Variation rate of average life expectancy	Average Nº	77.8-77.2 (2012-2013)	No trend may be identified		
	Public services and Infrastructures	Variation rate of green space availability	Percentage	5.65% - 9.09% (2004-2012)	+3.44 points	+	++
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes, but not CO2	-	0	0

IV.IV.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

Istanbul's energy use is characterised by a high growth rate and a dynamic situation with especially high growth in the electricity demand. Since Turkeys energy use is still fairly low on a per capita basis, compared to other countries, this is assumed to be due to rising GDP and increasing consumption in general.

The energy use of Turkey also has a high growth rate and high imports of primary energy, with domestic production accounting for only 29% of the total primary energy supply in 2010 (Tamzok 2010). Natural gas accounts for 32% of total primary energy, whilst the largest domestic source is coal with 53.9% of domestic production (Tamzok 2010).

Electricity use in Turkey is reported to have increased by over 78% in a decade to 235,000 GWh of electricity in 2013 (Daily News, 2014). Some research estimates that by 2050 the electric energy demand for Turkey will be approximately 1,2 million GWH (Yumurtaci and Asmaz, 2004). Despite a high potential for renewable sources there is a recent push for nuclear and coal due to the high growth in energy demand.

Due to poor data for Istanbul the energy use and trends were first calculated and adapted from national energy data. Some data was available on electricity use in Istanbul with 36,800 GWh of electricity being used in 2013 (Daily News, 2014). The national figures shown in Table 25 were used as a basis to help understand the trend in energy use in Istanbul. It was assumed that agriculture would not be significant within the Istanbul metropolitan area.

Table 25: Energy use by sector in Turkey

TURKEY	2003	2008
Industry	33.0%	32.0%
Services Residential	24.0%	36.0%
Transport	16.0%	20.0%
Agriculture	4.0%	7.0%
Others	23.0%	5.0%

(Source: Ministry of Energy and Natural Resources)

The PC2050 scenario was quantified using BAU as a basis and then applying several assumptions based on an interpretation of the stakeholder vision workshop and the corresponding actions and milestones. These were based on the actions and development foreseen in each of the sectors The industrial sector is seen as only improving by 20% its energy efficiency due to weak actions and milestones. Meanwhile we assume the following energy efficiency improvements: residential 40% due to efficiency and insulation; services 40% due also to efficient appliances and efficient buildings; and transport 40% due to a shift to electric vehicles. This translates into a much lower energy use for PC2050 of 224,000 GWh.

However, a key document subsequently identified was the 2010 GHG Inventory of Istanbul Metropolitan Area (GTE Carbon and ERM 2013). In this document the GHG emissions for Istanbul were calculated to be 43.83 $MTCO_2e$ for the year 2010. However, this included waste emissions and industrial process emissions which are not included in the POCACITO analysis. Therefore, subtracting these gives the 2010 GHG emissions as 26.87 $MTCO_2e$

Reverse engineering was used to help calculate the emission factors used in the inventory and the energy consumption which was used (as this was not available in the document).

These figures were then used to calculate new energy consumption figures for the two scenarios, as well as GHG emissions. However, because no trend on energy use was available from the GHG Inventory, trend coefficients were developed based on the national energy trends, Istanbul's population and GDP projections. The base trend coefficient was 3.24 (meaning energy use in each sector is expected to grow 3.24 times) based on the total growth in GDP. This is then adjusted by different factors for each scenario based on the expected efficiency or reductions (see Annex 1 - Assumptions for further details).

The comparison of energy consumption for 2010 and the two scenarios is shown in Figure 24. This highlights the large growth in energy use, following recent trends, particularly in the residential sector and is the result of high population growth and improving GDP per capita.

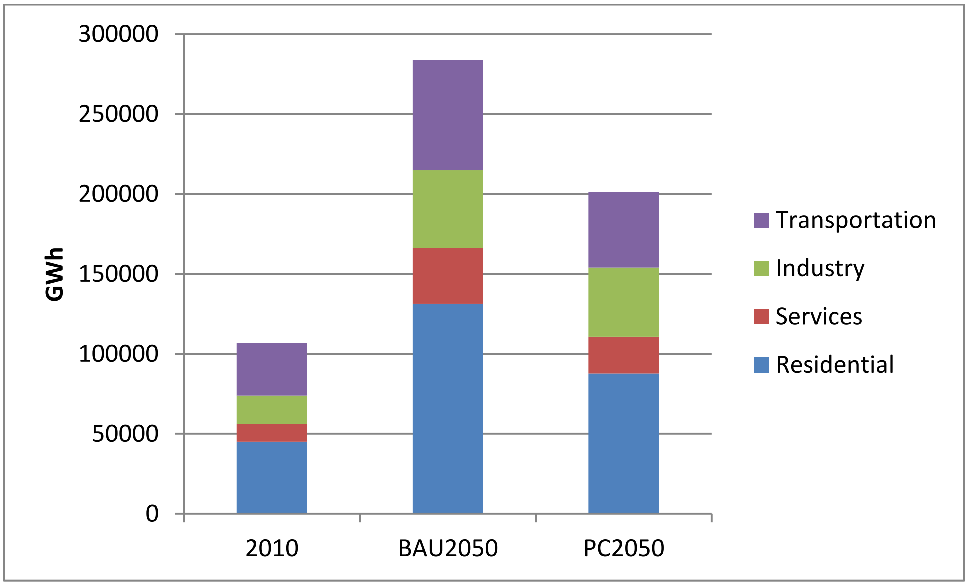

Figure 24: Energy consumption for Istanbul by sector for 2010, BAU and PC2050

Similarly, Figure 25 highlights a strong growth in GHG emissions for BAU, but also a growth of 52% in total emissions under PC2050. However, PC2050 does see a reduction in per capita emissions to 2.96 TCO_2e compared to 3.31 TCO_2e in 2010, and 5.01 TCO_2e under BAU.

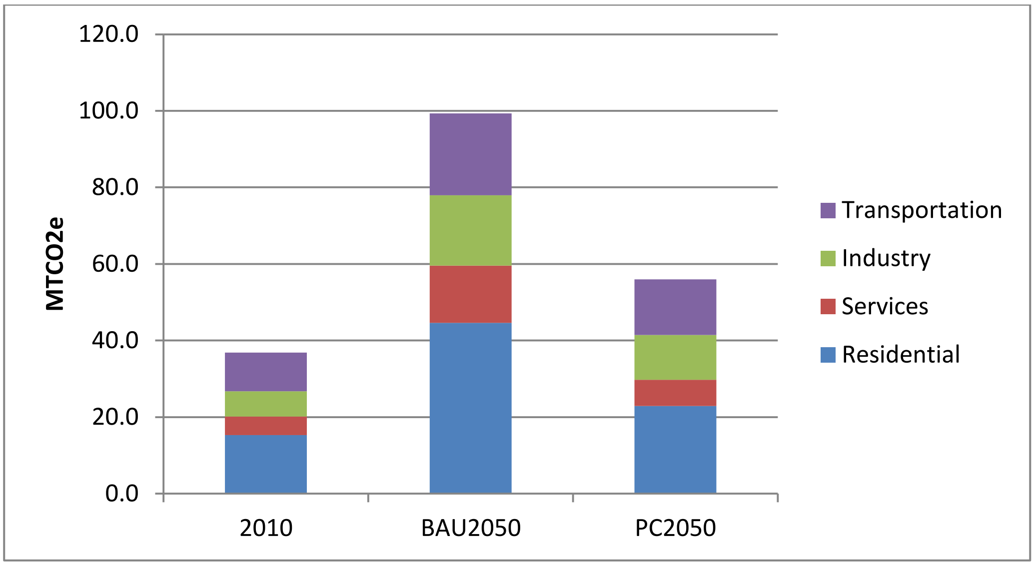

Figure 25: GHG emissions for Istanbul for 2010, BAU and PC2050

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the projected scenarios are shown below. In Figure 26 the direct GHG emissions per capita that occur in the city are compared with the indirect emissions. It shows that the total GHG footprint increases under both the BAU and PC2050 scenarios. This is fundamentally linked to the significant increase in GDP by 2050 and a corresponding increase in consumption. Hence despite expected improvements in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions therefore increase. The figure also shows that both direct and indirect emissions increase. PC2050 is projected to be higher in emissions than BAU due to a higher GDP being achieved.

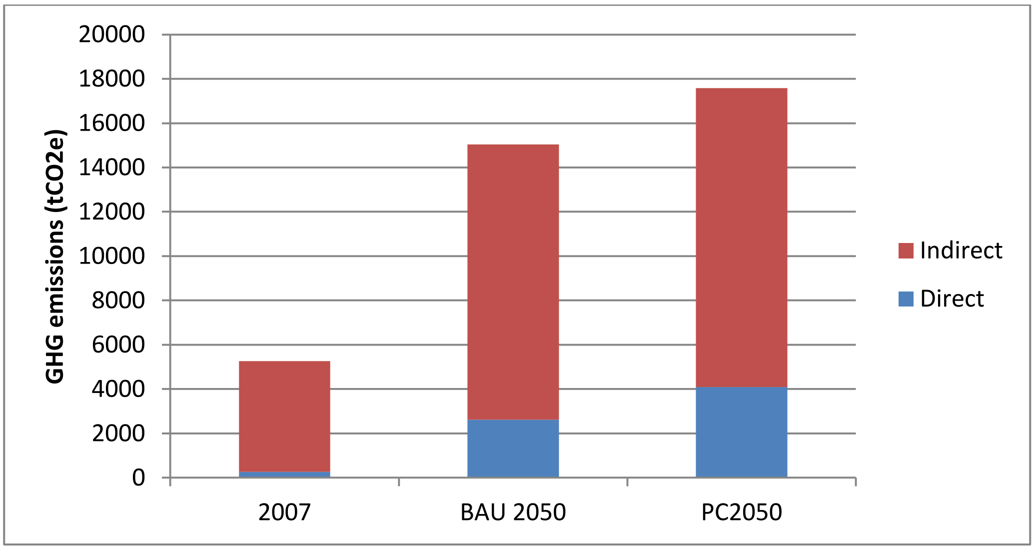

Figure 26: Direct and indirect GHG emissions for Istanbul for 2007, BAU and PC2050

Figure 27 compares the contribution of different product groups to the total carbon footprint. It shows that the most significant increases are for "other goods and materials" and "electricity and heat fuels". This supports the notion that the increases are caused by increased affluence leading to increases in energy use and spending on goods and materials.

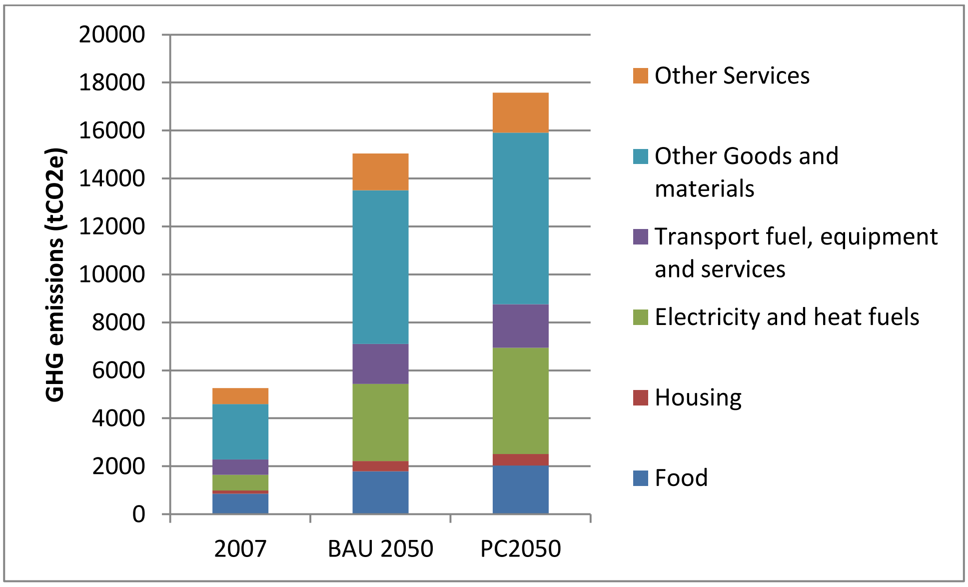

Figure 27: The contribution of product groups to the GHG footprint for Istanbul for 2007 and 2050

The other impacts of photochemical oxidation, acidification and eutrophication show a similar rise as shown in Table 26. This is further elaborated in Figure 28 which shows the contribution of the product groups. The large increase in eutrophication is associated with food consumption.

Table 26: Environmental impacts for 2007 and the scenarios for Istanbul

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2 eq)	5259	15038	17583	286%	334%
Photochemical oxidation (kg ethylene eq)	2.0	4.2	4.4	217%	224%
Acidification (kg SO2 eq)	34.7	78.1	86.2	225%	249%
Eutrophication (kg PO4--- eq)	6.1	13.7	15.5	225%	255%

The contribution of the product groups to each of the impact categories remains fairly constant from 2007 to each of the scenarios. The most significant contributor of acidification comes from consumption of "other goods and materials".

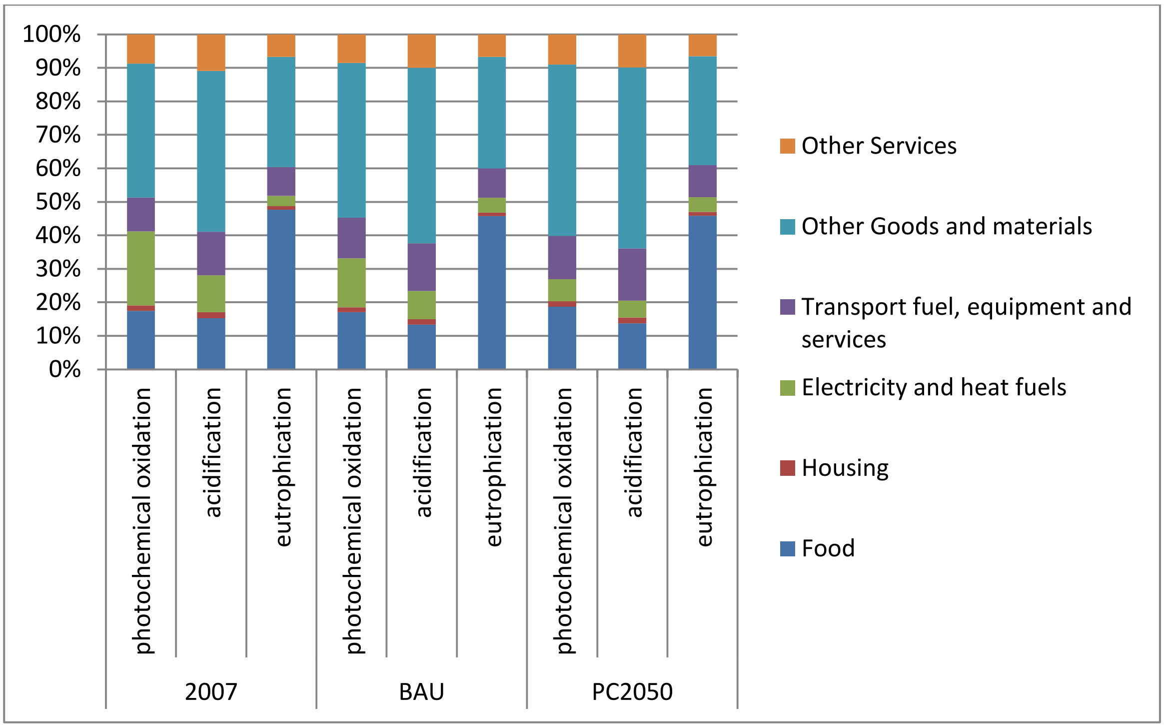

Figure 28: Contribution of the product groups to other impact categories for Istanbul for 2007, BAU and PC2050

IV.IV.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Istanbul's population increased by 3,415,600 or 40.3 % and urban land increased by 214.9 km² or 24.3 % (see Annex II, Table 86). According to the BAU scenario, by 2050 the population will increase by a further 5,268,300 or 44.3 % and urban land will increase by 331.5 km² or 30.1 % on the account of non-urban land. According to the PC scenario, population will until 2050 increase by 4,498,000 or 37.8 %. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Istanbul, between 2000 and 2012, urban spread accounted for 331.5 km² with a population increase of 850,417. In the same period, urban areas with no population change accounted for 133.0 km². Urban areas with population densification accounted for 592.5 km² and a population increase of 3,953,475 inhabitants. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 161.7 km² and a population decrease of -1,388,254. In summary, the development from 2000 to 2012 was characterized by a significant total population increase, a considerable urban spread, and consequently loss of non-urban land and at the same time by extensive densification (population increase) in some urban areas and a less extensive dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 331.5 km² with a population increase of 1,310,424. Urban land with not population change account for 171.1 km² while urban areas with a population increase (densification) accounts for 743.1 km² and a population increase of 4,958,841. Urban areas with a population decrease (dis-densification) account for 187.9 km² and a population decrease of -1,000,923. The BAU scenario indicates that the expected significant population increase until 2050 will result in a considerable urban spread and thus a loss of non-urban land while the at the same time large parts of the urban land will be characterized by population increase (densification) and a lesser part by population decrease (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 374,700 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 29 and Figure 30 show spatial patterns of historic and projected urban change for Istanbul. Between 2000 and 2012 patterns of urban development are characterised by densification in the city centre and in its surrounding and in some parts of the city's suburbs. A considerable part of the city's centre at the eastern bank of the Bosporus was characterised by a dis-densification (population decrease). Urban spread was primarily taking place in the northern outskirts.

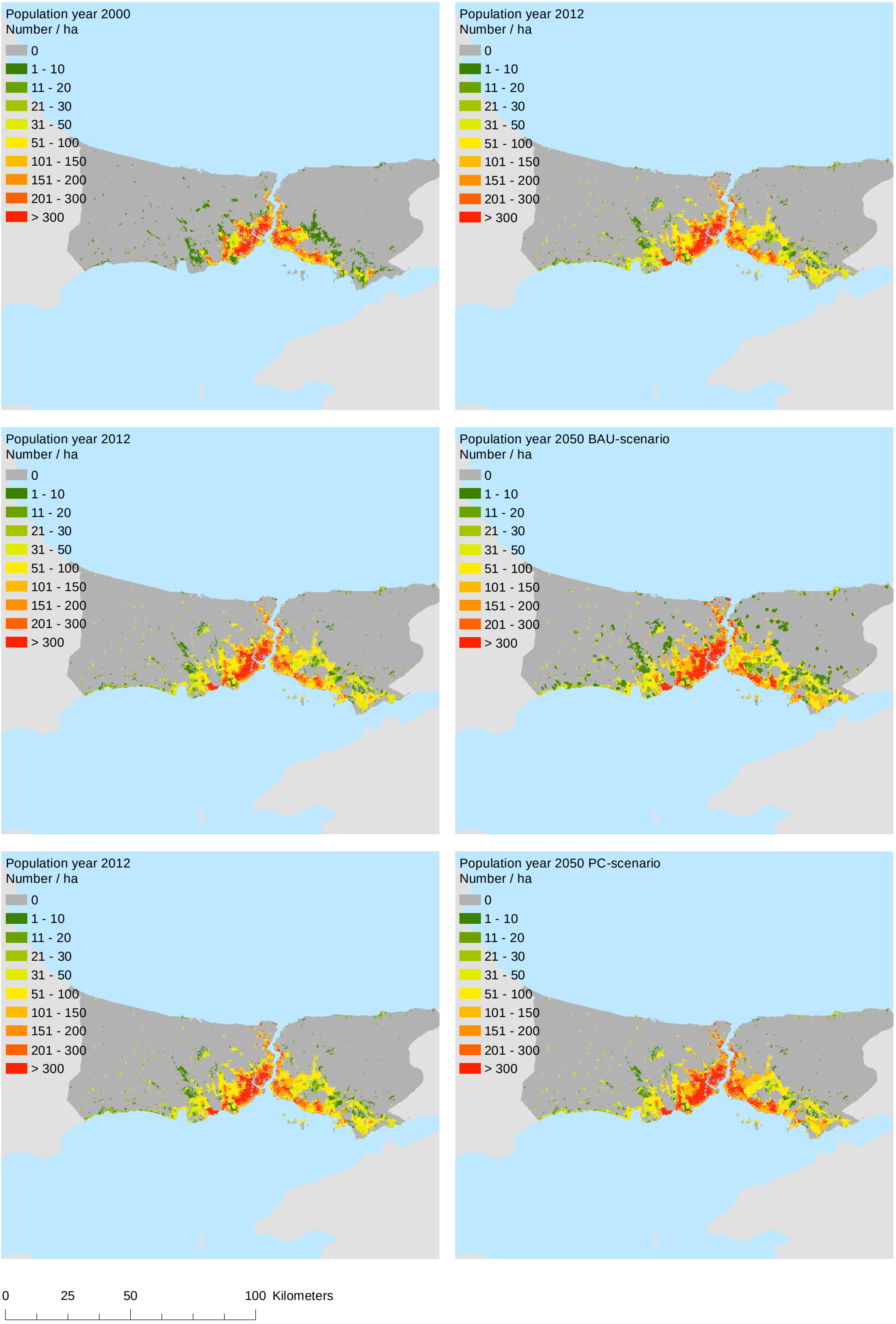

Figure 29: Population and urban change for 2000-2012, BAU and PC2050 for Istanbul

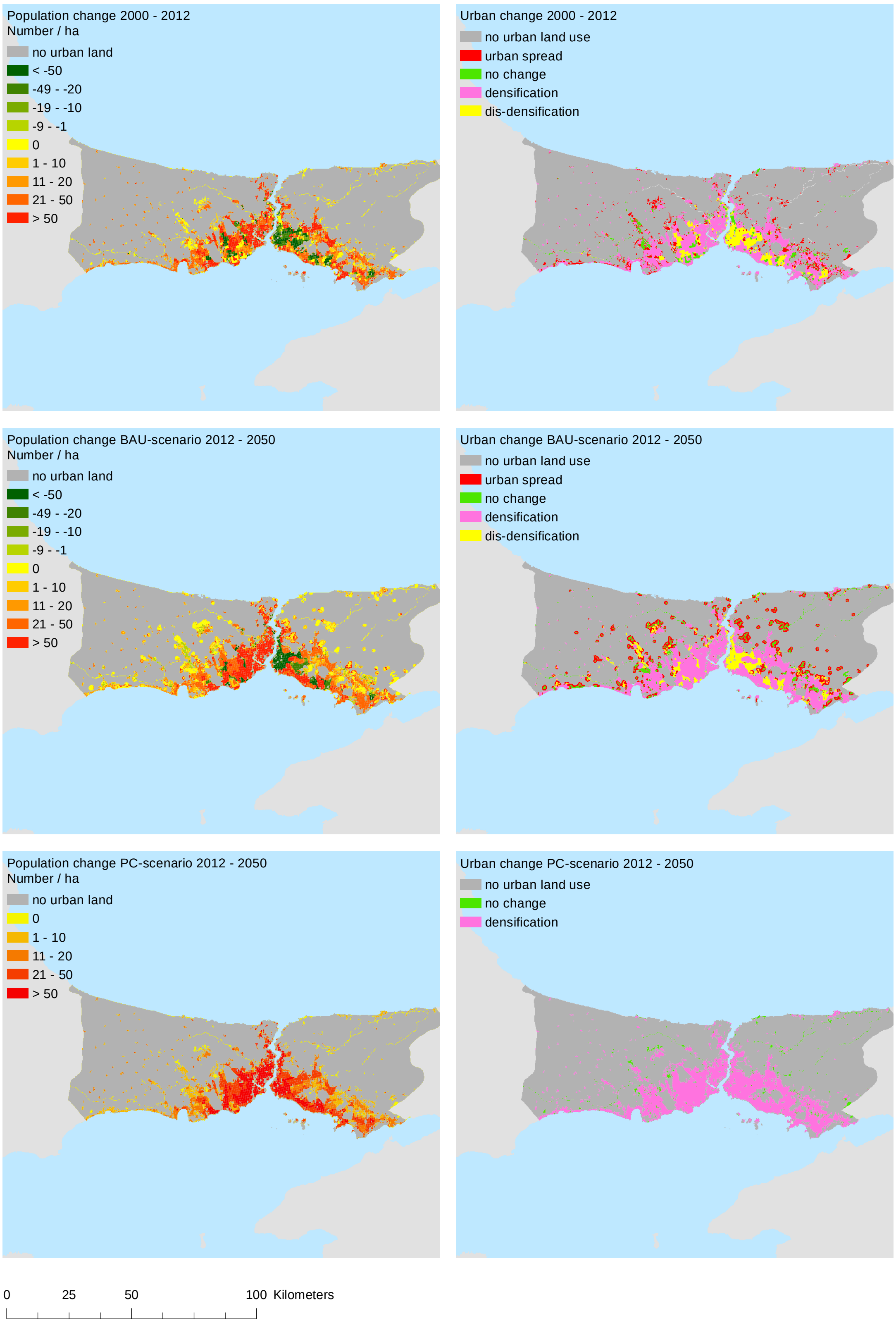

Figure 30: Population and urban change for 2000-2012, BAU and PC2050 for Istanbul (cont'd)

For the BAU scenario, patterns of urban development until 2050 are characterised by large areas of urban spread, primarily at the fringe of the city. Densification is taking place all over the city, while dis-densification is taking place at the eastern bank of the Bosporus and in some other parts of the city. For the PC scenario, population increase is largest in the central part of the city. Almost the entire city is characterised by population densification, except of some areas with infrastructure, which did not contain any population in 2012.

IV.IV.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050 for each scenario are shown in Table 27. The total costs of PC2050 are 52,532 MEUR compared to 31,448 MEUR for BAU. However, the table also shows that these costs would represent only 0.45% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 27: Investment costs for BAU and PC2050 Istanbul Scenarios

Energy	**MEUR (2016)**
BAU	6 300
PC2050	27 384
Total costs for fossil free energy	80 655
Building renovations	
BAU	25 148
PC2050	25 148
Total costs (Energy and buildings)	
BAU	31 449
PC2050	52 532
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.28%
PC2050	0.45%

This translates into the following discounted costs as shown in Table 28 at various discounted rates from 2018 to 2050.

Table 28: Net costs for Istanbul scenarios investments at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	26 564	19 644	15 178
PC2050 Costs (NPV)	44 373	32 814	25 353

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Istanbul are estimated at 12,324 MEUR/year based on the 2010 cost of 6.0% of GDP for Turkey provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net present value of benefits or costs of BAU and PC2050 at different discount rates are shown in Table 29. The table shows the benefit or cost related to the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050.

Under both BAU and PC2050 the costs of air pollution are expected to rise considerably compared to 2010 levels, at 438.7 billion EUR and 94.7 billion EUR, respectively. If current levels of air pollution remained constant at 2010 levels the net cost of air pollution would be 674.8 billion EUR and 698.8 billion EUR for BAU and PC2050 respectively. The costs of BAU and PC2050 are additional to this and hence the net cost of air pollution by 2050 is expected to be significant.

Table 29: Cumulative cost savings (2018-2050) due to reduced mortality in the scenarios, and for no air pollution by 2050 (€ millions NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	-458 742	-438 731	-419 718
PC2050	-99 103	-94 711	-90 540
No air pollution	321 727	307 692	294 358

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is massive and is summarised in Table 30. Potential jobs for renewable energy amount to 4649 ongoing jobs from operation and maintenance, but contribute to nearly 332,000 jobs along the value chain from manufacturing to installation. The number of jobs created from the renovation of buildings is significant at 427,500.

Table 30: Benefits of PC2050 scenario compared to BAU for Istanbul

Additional PC2050 jobs	MCI	O&M
Renewable energy	331500	4649
Building renovation	427500	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 29.1% lower. Currently (2013) the renewable fraction of energy sources for Istanbul is estimated to be about 10%, which is similar to Turkey's amount. This is expected to remain static under BAU as coal and nuclear power are utilised to meet the increasing energy demand. Under PC2050 the renewable fraction is projected to be 35%. Hence there is the potential for greater energy security and lower risks due to the volatility of fossil fuel prices under PC2050.

In summary, there is potential for 29.1% reduction of costs in PC2050 due to reduced energy consumption and a further reduction related to the 25% additional renewable energy

IV.IV.VI GAPS AND CONCLUDING COMMENTS

ENERGY

In considering the energy and GHG projections, one must consider that the quality of data available for Istanbul is quite poor, and that the trends of high energy growth stem from analysing national data. However, there is no evidence to suggest that Istanbul itself would not experience high energy demand growth due to the high population and GDP growth as stated above (e.g. with electricity consumption growing 78% in a decade).

The current PC2050 pathway falls short of achieving post-carbon status due to weak actions and milestones. In addition, due to the high energy demand growth rate, there is a danger that what may be viewed as the "easiest" or cheapest solution (i.e. fossil fuels) may be adopted. This is evidenced in the recent push for 80 coal power stations by 2023 and is compounded by the Ministry of Energy and Natural Resources "coal strategy" which seeks reduced reliance on energy imports through full utilisation of lignite and hard coal reserves (IEA Clean Coal Centre, 2014). In other words, careful planning of energy supply and improvement in energy and resource efficiency is required in order to avoid BAU, or worse, becoming a reality.

There is currently a massive gap in the supply of renewable low carbon energy for the city even in the PC2050 scenario. This is as a major challenge as the quantity of electricity required to even supply 30% of electricity in 2050 is very large at 14 TWh.

The proposed actions and milestones are viewed as insufficient to achieve post-carbon status. For example, the targets of 70% clean energy in industry was not seen as realistic as there were insufficient actions and milestones proposed to support it. In addition there was no target set or proposed for the residential or service sectors for renewable energy.

Under the PC2050 scenarios, there is currently a reliance on (national) grid electricity which poses a large risk due to the nature of the electricity supply in Turkey, which is moving more towards coal, with plans for another 80 power stations by 2019.

In 2013 renewable power accounted for 11.8% of Turkey's gross inland consumption (Eurostat, 2015), but this is unlikely to rise significantly under current plans.

SOCIO-ECONOMIC

On a positive note the economic and social indicators are likely to continue in a positive direction under both scenarios. However, the projected large increases in population pose significant challenges to quality of life and social equality.

The cost benefit analysis showed that the current PC2050 scenario would cost 32,814 MEUR (NPV with discount rate of 3%) compared to 19,644 MEUR for BAU. However, this represents only 0.28% of the cumulative GDP (from 2018 to 2050) for BAU and 0.45% for PC2050. Meanwhile due to continuing air pollution, even under PC2050 there would be a cost of 94,711 MEUR (NPV with discount rate of 1%)due to premature deaths caused by air pollution.

However, the significant cumulative GDP that is projected under PC2050 suggests that there is economic scope for an improved PC2050 plan with increased energy efficiency measures and renewable energy.

URBAN SPRAWL

In recent years (2000 to 2012) urban land has increased by 214.9 km² or 24.3 % in Istanbul driven by a large population increase of 3,415,600, The land use analysis demonstrated that if this trend continues, as in BAU, the urban land will increase by 331.5 km² or 30.1 % due to a population increase of 5,268,300. Even though the population increase under PC2050 is slightly less at 4,498,000 there is none the less a risk of increasing encroachment on non-urban land, which requires a strong policy of densification if this is to be limited.

CIRCULAR ECONOMY AND CONSUMPTION

The potential for improvements in the impact of consumption are currently not well addressed in the PC2050 scenario.

The EE-MRIO footprint analysis suggests that under PC2050 there is a risk that the total GHG emissions footprint of the city will increase by 234% to 17.6 tCO_2e per capita. This is despite the territorial emissions only increasing by 12% to 2.96 tCO_2e per capita.

These increases are largely caused by a large increase in GDP which will potentially cause increased spending and consumption. This emphasises the need for policies to address lifestyles and consumption and promote a more circular economy.

IV.V LISBON

IV.V.I INTRODUCTION

The population of Lisbon municipality was 547,733 in 2011 and 2,042,477 for Greater Lisbon. There has been a recent decrease in the population of the municipality as people have located in the suburbs. This has exacerbated the transport challenges as the population of the municipality increases on workdays to almost 900,000 people, with the predominant mode of transport being the car.

Under BAU the population of Lisbon will continue to decline and there will be 526,000 residents in the municipality in 2050, whilst greater Lisbon has also declines from 2.02 million in 2014 to 1.96 million in 2050. Energy use increases only marginally and is still dominated by the transport and service sectors.

In the PC2050 scenario Lisbon in 2050 is a carbon neutral smart city with more people, more jobs and an excellent quality of life. It is an attractive, creative, sustainable and start-up city with 585,000 inhabitants (municipality). It is a city growing in density with increasing energy productivity. The total energy use decreases considerably due to 50% of vehicles being electric and due to improved building efficiency by 30% in the services and residential sectors. Electric vehicles account for about 50% of the motor transport, but oil is still widely used and accounts for 28% of the final energy demand.

IV.V.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 31 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable). A summary of the KPI's current trends and the expected outcomes under the scenarios is given below.

ENVIRONMENTAL

The biodiversity protected areas have recently increased. The Biodiversity Strategy 2020 suggests that there is good potential for this area to be improved in the future, but no additional measures were suggested in PC2050.

Energy intensity has decreased which has probably been aided by the increasing contribution of the service sector to the GDP and a decrease in the industrial sectors contribution. With the increased building efficiency and electrification of cars under PC2050, in addition to an improving national energy mix, this is likely to continuing improving considerably.

There is a current trend of decreasing carbon intensity, which can be expected to continue in both the BAU and the PC2050 scenario. However, the local renewable energy contribution in Lisbon has only recently risen to around 1 MW of capacity in solar (in 2013) and progress has been slow. The carbon intensity is therefore predicted to increase much more significantly under PC2050 than BAU but there is still room for improvement under PC2050 to facilitate a move to carbon neutrality.

The air quality trend in Lisbon is positive and the number of exceedance days of air quality thresholds is decreasing. With further measures in the PC2050 scenario the decrease can be expected to continue.

The recent trend in transport has been quite negative with an increase in transport energy and the use of private cars. Measures have been taken which probably can influence the development, however neither in the BAU or PC scenario any drastic increase in sustainable transportation can be expected.

As for waste, the current trend shows decreasing waste generation, which can be expected to continue. However, no major additional measures have been suggested and only minor decreases can be expected in both the BAU and the PC scenario. Surprisingly there has recently been a decrease in waste recovery and no measures have been put forward under PC2050 to improve the situation.

The situation of water losses in Lisbon's distribution system has improved and it can be expected to improve further under both scenarios, although water has not been specifically addressed under PC2050.

For buildings the current trend is positive with the number of energy efficient buildings increasing substantially. In the BAU scenario this increase can be expected to continue. In the PC scenario measures will be taken to reach a target that 100% of all new buildings are "Nearly net zero energy buildings" which, as long as it is reached, will have positive effects.

Urban density in addition to population density appears to be decreasing, the latter of which is an issue for Lisbon's sustainability in general.

ECONOMIC

On the economic front the level of wealth has shown a steady increase and is therefore expected to continue under BAU, whilst PC2050 is expected to be slightly higher. With the development of the circular economy there is potential for the industry sector to increase under PC2050, with an increase in employment.

There has recently been a high level of indebtedness for Lisbon City Council but this seems to have improved greatly since the financial crisis. This therefore is not seen as a specific concern under either scenario. The R&D intensity was increasing until the financial crisis but was still quite moderate even at its peak of 2.5%.

SOCIAL

For the social indicators one concern is the high level of unemployment particularly for males. There was only national level data available for the poverty level which has been increasing in the last nine years. Tertiary education has shown a significant decrease for males which is of concern.

Finally, on a positive note the amount of green space has grown significantly in the last five years and life expectancy continues to grow.

Table 31: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Lisbon

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Percentage Geographical level: Municipality Source: Lisbon City Council	Calculated to be 0.0% - 1.5% (2003-2012)	+1.5 points	+	+
	Energy	Energy intensity variation rate	toe/euro toe Geographical level: NUT III Source: INE, DGGE	$5.922 \times 10^{-5} – 5.334 \times 10^{-5}$ (2003-2012) 2.339 Mtoe – 2.441 Mtoe (2003-2012)	-9.9% +4.3%	+	++
		Variation rate of energy consumption by sectors	Percentage Geographical level: Municipality Source: INE; DGGE	Industry: +45.8% Agriculture: +31.8% Services: +0.5% Transport: +25.4% Residential: -10.5% (2008-2012)	Increases in three sectors. No change in services, and residential decreased		
	Climate and Air Quality	Variation rate of carbon emissions intensity	ton CO_2/euro ton CO_2 Geographical level: NUT III Source: INE; APA (www.apambiente.pt/)	$151.8 \times 10^{-6} – 118.1 \times 10^{-6}$ (2005-2009) Greater Lisbon – 7.507.507,70 Ton CO_2 (2005) Greater Lisbon – 6.366.261,01 Ton CO_2 (2009)	-22,2% -15,20%	+	++
		Carbon intensity per person	ton CO_2/per capita Geographical level: NUT III Source: INE; APA	3,76 Ton CO_2 per capita (2005) 3,13 Ton CO_2 per capita (2009)	-16,76%	+	++
		Variation rate of carbon emissions by sector	ton CO_2	**No data available**	No data available	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
		Exceedance rate of air quality limit values	Nº Geographical level: Municipality Source: APA	O_3: 11.8 – 5.3 (2003-2012) PM10: 76.3 – 25.4 (2003-2012) Only the pollutants that recorded exceedance rates on air quality limit values were considered in this indicator. Other pollutants (NO_2, SO_2 and $PM_{2.5}$) did not registered exceedance rates for air quality limit values.	O_3: -55.1% (2003-2012) PM_{10}: -66.7% (2003-2012) Other pollutants (NO_2, SO_2 and $PM_{2.5}$) remain null values in terms of exceedance rates.	+	++
	Transport and mobility	Variation share of sustainable transportation	Percentage Geographical level: Municipality Source: INE, Census,	59% - 51% (2001-2011)	-8.0%	0	+
	Waste	Variation rate of urban waste generation	kg/person/year Geographical level: Municipality Source: INE	648.6 - 561.4 (2009-2013)	-13% (2009-2013)	+	+
		Variation rate of urban waste recovery	Percentage Geographical level: Municipality Source: INE	92.2 – 72.6 kg (2009-2013)	-21% (2009-2013)	-	-
	Water	Water losses variation rate	m^3/person/year Geographical level: Municipality Source: INE; EPAL	27.98 – 15.75 (2009-2013)	-43.7% (2009-2013)	+	N/a
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage Geographical level: Municipality Source: ADENE	The rate of buildings with A+ and A energy class was null in 2007 14% (2012)	Since the beginning of the certification process (2007), an exponential increase was observed in 2009, even in higher efficiency classes A and A+. In evolutive terms between 2007	+	++

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
					and 2012, there has been a significant evolution until 2009 and then a slight decrease.		
		Urban density variation rate	Nº/km^2 Geographical level: Municipality Source: INE	628.08 – 617.82 (2001-2011)	-1.63% (2001-2011)	+	+
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person Geographical level: NUT III Source: INE	About 18,400 – 19,500 (2004-2012)	No clear trend – maximum in 2008 and 2010, reduced since.	+	+
		Variation rate of GDP by sectors	Percentage Geographical level: NUT III Source: INE	Agriculture/Industry/Services (2003-2012): 0.21%/17%/83% - 0.20%/14%/86%	Share of services increases somewhat in Greater Lisbon, while industry decreases somewhat.	+	+
		Employment by sectors variation rate	Percentage Geographical level: NUT III Source: INE	Agriculture (2003-2011) – 0.70% - 0.46% Industry (2003-2011) – 18.99% - 13.92% Services (2003-2011) – 80.32% - 85.61%	Agriculture: - 0.24% Industry: - 5.07% Services: + 5.29% Number of people working in services increases, working in industry registered a slight decrease	+	+
		Business survival variation rate	Percentage Geographical level: NUT III Source: INE	5.7% – 6.7% (2008-2010)	+1 points	+	+
	Public Finances	Budget deficit variation rate	Percentage of city's GDP Geographical level: Municipality Source: PORDATA	Extremely volatile rates that goes from +200% in 2010 to -96% in 2013, achieving an average of +78% under this period.	Significant annual variation – 2012 was an extraordinary year of revenues.	+	+
		Indebtedness level variation rate	Percentage of city's GDP Geographical level: Municipality	79.3% - 4.5% (2010-2013)	Significant drop	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
			Source: Management Report 2013, Lisbon City Council				
	Research & Innovation dynamics	R&D intensity variation rate	Percentage Geographical level: NUT III Source: INE	1.1% - 2.5% (2003-2010)	Significant annual variation	+	+
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage Geographical level: NUT II Source: INE	Male 4% – 10% (2003-2012) Female 4% – 7.5% (2003-2012)	Increase in unemployment.	-	N/a
		Variation rate of poverty level	Percentage Geographical level: NUT I Source: Economic Inequality in Portugal, Carlos Farinha Rodrigues, 2012	5.0% - 12.0% (2003-2012)	Variation rate only available at national level and with negative fluctuations in 2005, 2007 and 2009.	+	+
		Variation rate of tertiary education level by gender	Percentage Geographical level: Municipality Source: INE, Census	About 21% - 32% (2001-2011) Male 33.2% - 11.0% (2005-2012) Female 10.3% - 9.4% (2005-2012) No data available for 2003-2005	+ 11% (2001-2011) A significant drop on male – 22.2% A slight decrease on female – 0.9%	-	0
		Variation rate of average life expectancy	Average Nº Geographical level: NUT III Source: INE	77.8 – 79.9 (2003-2012)	+2.1 years	+	+
	Public services and Infrastructures	Variation rate of green space availability	Percentage Geographical level: Municipality Source: Lisbon City Council	+ 27.88% medium rate 2004-2014 (including new or refurbished green spaces, and urban gardens) -0.72% medium rate > 2014 (including new or refurbished green spaces, and urban gardens)	+413% (2004-2008) Exponential increase of new and refurbished green spaces in the period 2009-2014	++	++
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description Geographical level: Municipality Source: Lisbon City Council	No	-	0	0

IV.V.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

The energy data available for the energy analysis of Lisbon was fairly limited and is derived from two main sources: energy data collected in POCACITO (initial assessments) and the Sustainable Action Plan for Energy (from the Covenant of Mayors programme (Lisboa E-Nova, 2010). This is supplemented with national data and projections from the EU Energy Trends 2050 report (Capros et al, 2014).

The energy data for 2008 and 2012, along with the projections for BAU and PC2050 is shown in Table 32. Figure 31 illustrates the energy consumption of the scenarios, highlighting the decrease in energy use under PC2050 due to improvements in energy efficiency in buildings and transport.

Table 32: Energy by sector for 2008, 2012 and the scenarios for Lisbon

(GWH)	2008	2012	BAU	PC 2050
Transport	4536	5688	5794	3187
Services	3354	3369	3320	2324
Residential	1448	1296	1308	916
Industry	258	377	391	312
Agriculture	43	56	56	56
Total	**9638**	**10786**	**10869**	**6795**

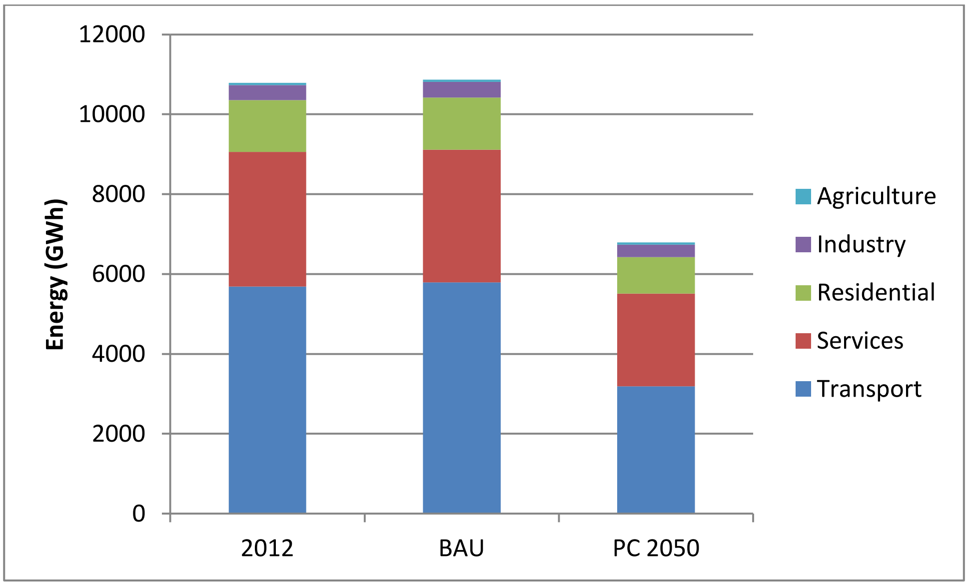

Figure 31: Energy use by sector for 2012, BAU and PC2050 for Lisbon

The GHG emissions by energy source for 2002 (from Lisboa E-Nova, (2010) and the projected emissions for the BAU and PC2050 scenarios are shown in Figure 32, which points to a strong improvement under BAU, but a very significant reduction under PC2050.

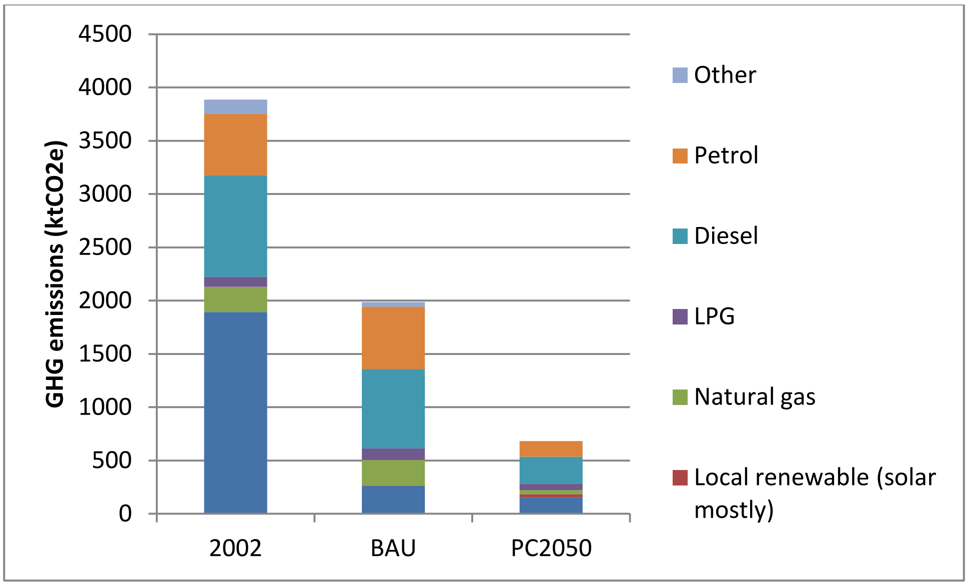

Figure 32: GHG emissions by fuel source for Lisbon for 2002, BAU and PC2050

This is primarily due to an increased amount of local renewable energy under PC2050 (from 5.5% under BAU to 41.2% in PC2050) supported by a move to more electric transport. There is also a general electrification of the energy system with electricity accounting for 70% of the energy. This is highlighted in Figure 33 which compares the energy source profile for 2002, BAU and PC2050. In PC2050 there is a significant drop in the amount of petrol and diesel used for transport. However, fossil fuel transport still accounts for 18.2% of the total energy and this translates into 46% of the total GHG emissions. Therefore to further enhance the move to a low carbon city, there is a need for effective policies that further reduce or eradicate the use of fossil fuelled transport.

The changes in GHG emissions for sectors are shown in Figure 34 emphasising the importance of the transport sector under both BAU and PC2050.

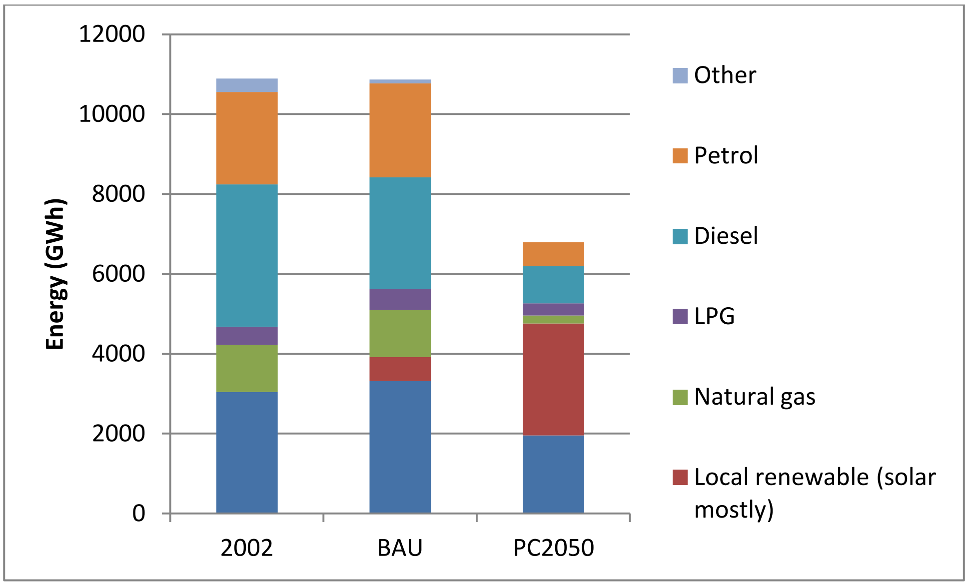

Figure 33: Energy source profile for 2002, BAU and PC2050 for Lisbon

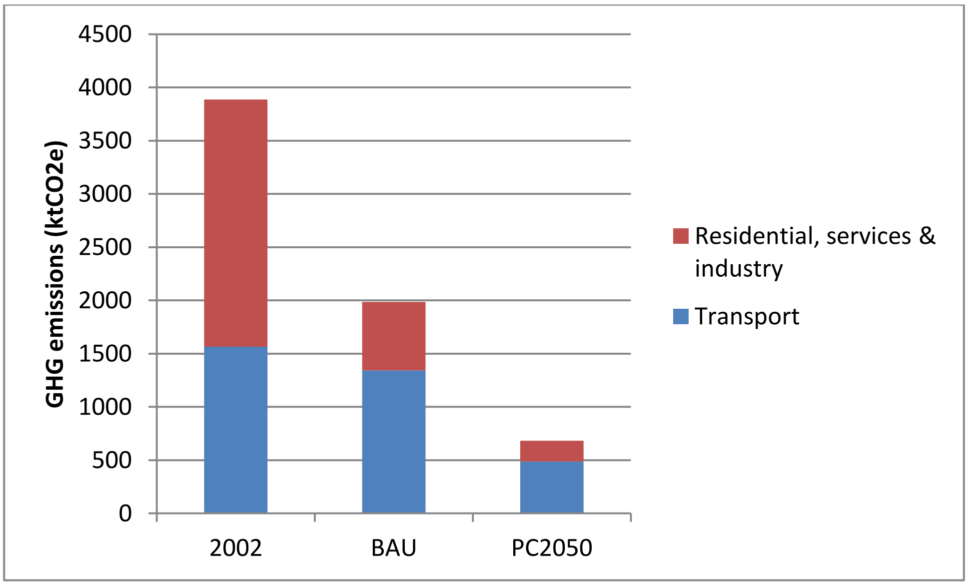

Figure 34: GHG emissions by sector for Lisbon for 2002, BAU and PC2050

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 35, the direct GHG emissions that occur in the city are compared with the indirect emissions. It shows that the total GHG footprint increases under both the BAU and PC2050 scenarios. This is fundamentally linked to the projected increase in GDP and the resulting increase in consumption. Hence despite expected improvements in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase. The figure also shows that despite reductions in direct emissions for PC2050 the overall GHG emissions still rise considerably under PC2050.

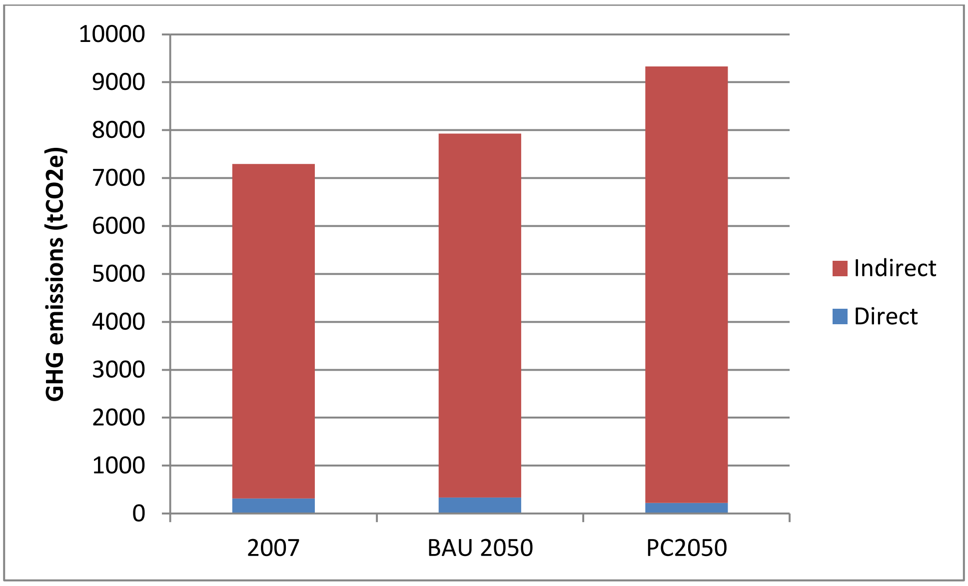

Figure 35: Direct and indirect GHG emissions for Lisbon for 2007, BAU and PC2050

Figure 36 compares the contribution of different product groups to the total carbon footprint. It shows that the contribution of "transport fuel, equipment and services" and "electricity and heat fuels" decreases for both scenarios. However, increases in the contributions of "other goods and materials", "food" and "other services" outweigh these decreases causing an overall increase in GHG emissions in both scenarios.

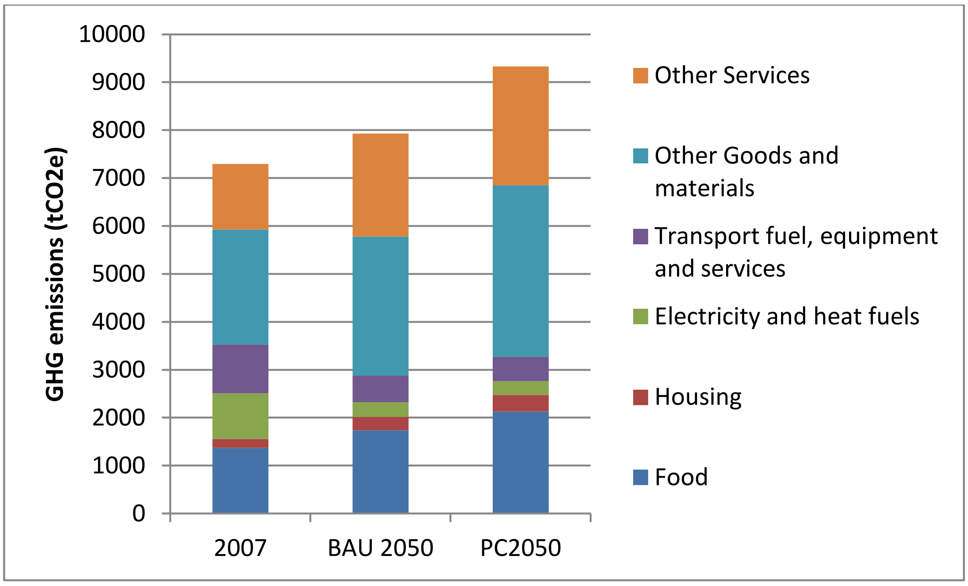

Figure 36: The contribution of product groups to the GHG footprint for Lisbon for 2007 and 2050

The other impacts of photochemical oxidation, acidification and eutrophication show a similar rise as shown in Table 33. This is further elaborated in Figure 37 which shows the contribution of the product groups. Again, the large increase in eutrophication is associated with food consumption.

Table 33: Environmental impacts for 2007 and the scenarios for Lisbon

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2 eq)	7296.6	7928.6	9331.6	9%	28%
Photochemical oxidation (kg ethylene eq)	2.5	2.5	2.3	4%	-7%
Acidification (kg SO2 eq)	38.7	36.1	42.8	-7%	11%
Eutrophication (kg PO4--- eq)	12.0	15.5	18.7	29%	56%

The contribution of "electricity and heat fuels" and "transport fuel equipment and services" both decrease under PC2050 for acidification and photochemical oxidation (particularly for electricity). On the other hand, the contribution on "other services" and "other goods and materials" increases its contribution in these categories, emphasising the increasing impacts of these consumption categories. Eutrophication is dominated by the food group as we would generally expect due to the high use of fertilisers in food production.

In summary, the impacts of the scenarios mimic the anticipated rise in GDP and household spending. Despite improvements in the efficiency of the background production systems of 2050 and improvements in the energy efficiency and energy production of the cities energy supply, this is outweighed by the expected increase in consumption.

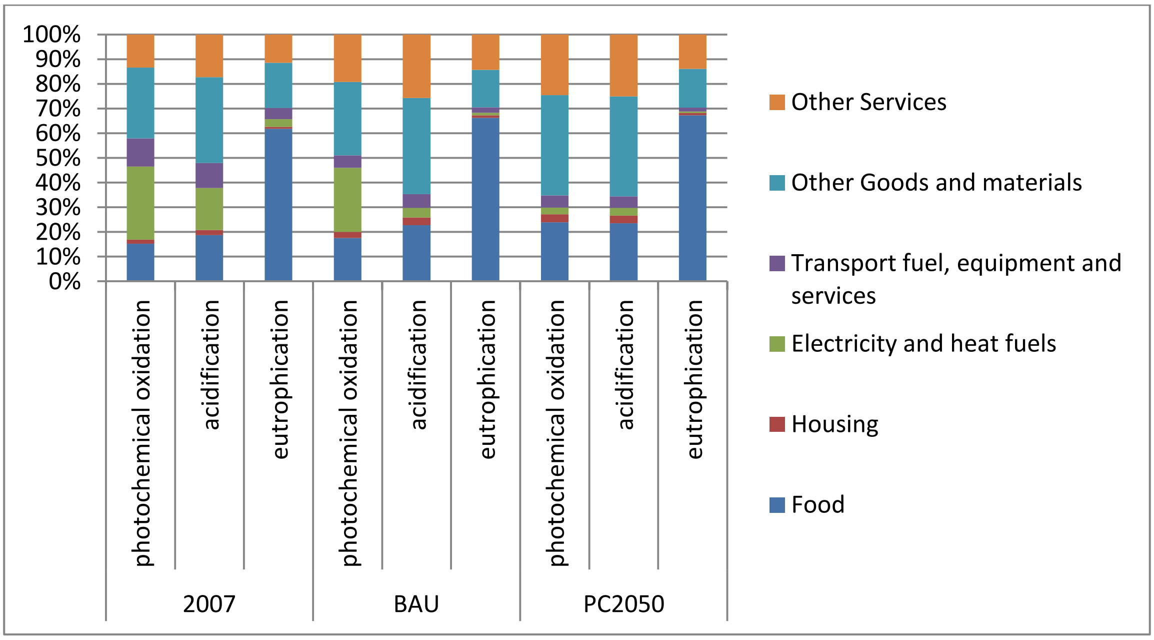

Figure 37: Contribution of the product groups to other impact categories for Lisbon for 2007, BAU and PC2050

IV.V.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

The analysis below for Lisbon includes the surrounding metropolitan NUTS III areas of Greater Lisbon and Setúbal Peninsula.

Population and land use changes

Between 2000 and 2012 Lisbon's population increased by 356,700 or 14.7 % and urban land increased by 135.6 km² or 28.7 % (Annex II, Table 86). According to the BAU scenario, by 2050 population will decrease by 96,900 or -3.5 %. However, urban land will still increase by 64.4 km² or 10.6 %. According to the PC scenario, population will until 2050 increase by 190,500 or 6.9 %. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Lisbon, between 2000 and 2012, urban spread accounted for 135.6 km² with a population increase of 230,132. In the same period, urban areas with no population change accounted for 115.2 km². Urban areas with population densification accounted for 251.1 km² and a population increase of 760,700. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 105.7 km² and a population decrease of 634,090. In summary, the development from 2000 to 2012 was characterized by a significant total population increase, a considerable urban spread, and consequently loss of non-urban land and at the same time by both extensive densification (population increase) in some urban areas and dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 64.4 km² with a population increase of 109,128. Urban land without population change accounts for 144.5 km² while urban areas with a population increase (densification) account for 329.6 km² and a population increase of 213,066. Urban areas with a population decrease (dis-densification) account for 133.5 km² and a population decrease of 419,067. The BAU scenario indicates that the expected slight population decrease until 2050 will still result in some urban spread and thus a loss of non-urban land while the at the same time large parts of the urban land will be characterized by population increase (densification) and others by population decrease (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 190,516 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 38 and Figure 39 show spatial patterns of historic and projected urban change for Lisbon. Between 2000 and 2012 patterns of urban development were characterised by decreasing population (dis-densification), primarily in the city centre. Population increase (densification) took mainly place in the suburbs and urban spread in the northern outskirts. For the BAU scenario, patterns of urban development until 2050 are characterised by some areas of urban spread, primarily in the outskirts of the city. The central parts of the city are characterised by population decrease (dis-densification) or no change, while the remaining part is characterised by densification. For the PC scenario, population increase is largest in the central part of the city. Almost the entire city is characterised by population densification, except some industrial areas and areas with infrastructure, which did not contain any population in 2012.

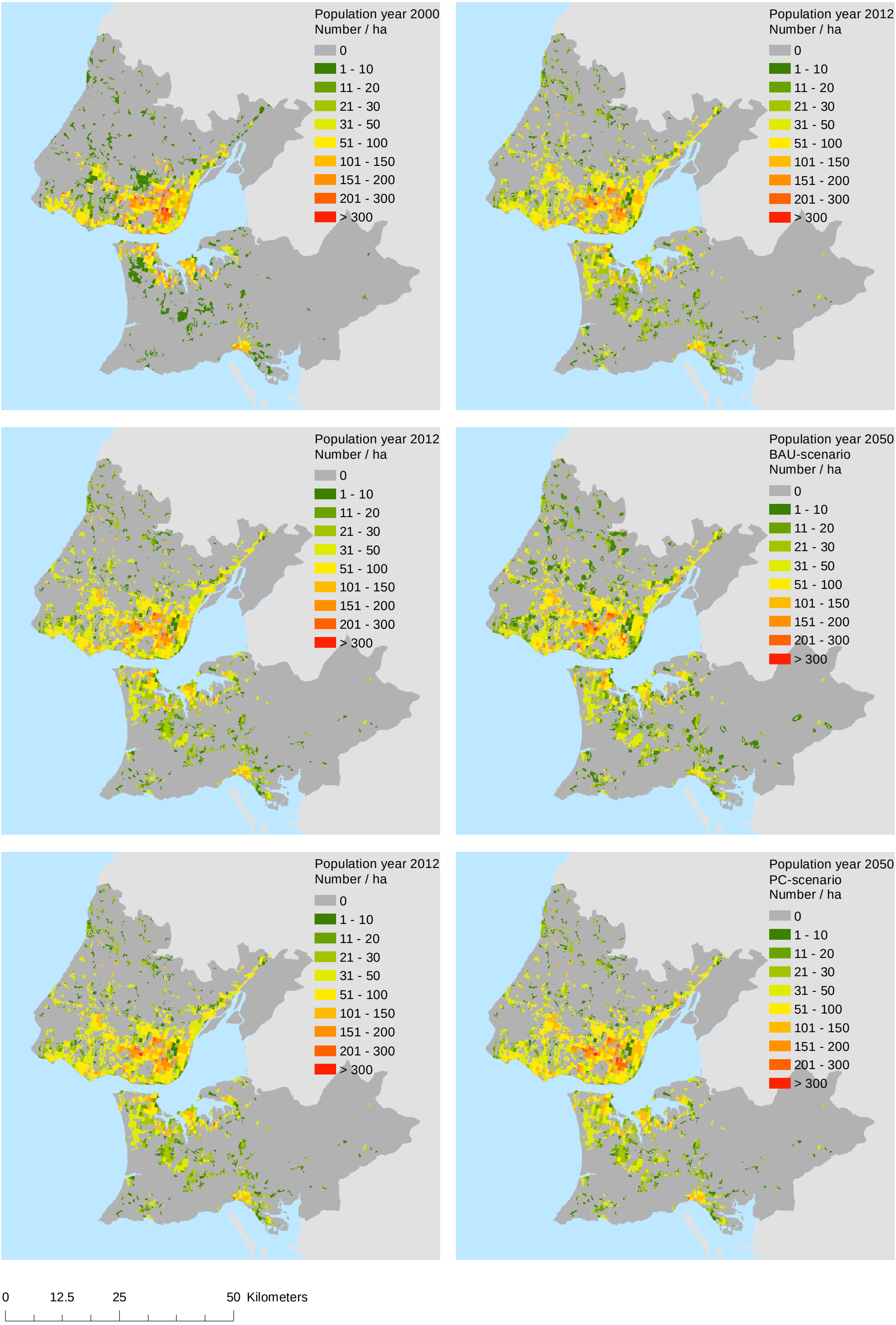

Figure 38: Population and urban change for 2000-2012, BAU and PC2050 for Lisbon

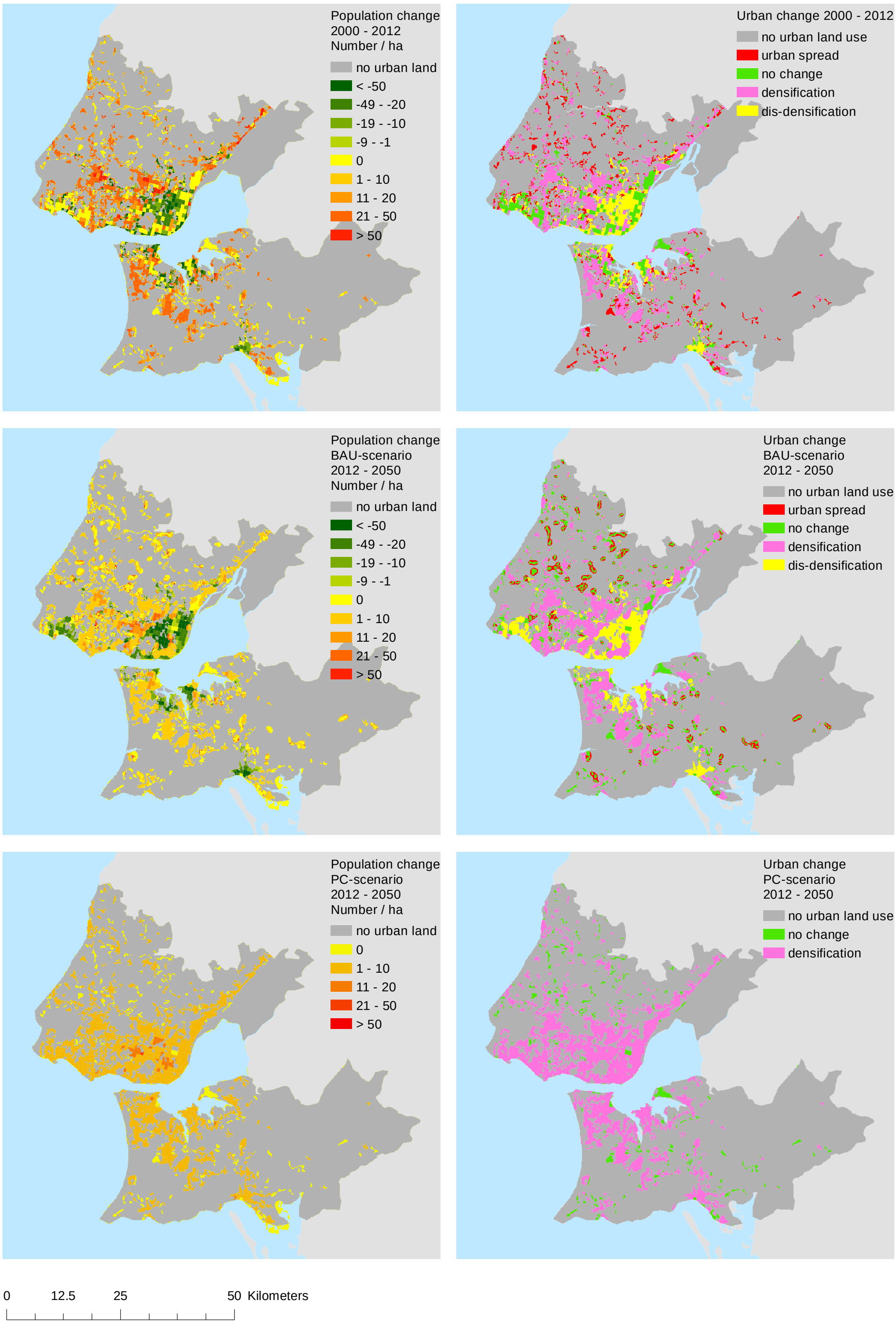

Figure 39: Population and urban change for 2000-2012, and BAU and PC2050 for Lisbon (cont'd)

IV.V.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050 for each scenario are shown in Table 34. The total undiscounted costs for PC2050 are 4,599 MEUR compared to 1,703 MEUR for BAU. However, the table also shows that these costs would represent only 0.69% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 34: Investment costs for BAU and PC2050 Lisbon scenarios

Energy	MEUR (2016)
BAU	261
PC2050	1 235
Total costs for fossil free energy	2 133
Building renovations	
BAU	1 442
PC2050	3 364 174 983
Total costs (Energy and buildings)	
BAU	1 703
PC2050	4 599
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.28%
PC2050	0.69%

Assuming a 3% discount rate, this translates into a net cost of 2,873 MEUR for PC2050 and 1,064 MEUR for BAU as shown in Table 35. The table shows a range of discounted rates (for the period 2018 to 2050).

Table 35: Net costs for Lisbon scenarios investments at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	1439	1064	822
PC2050 Costs (NPV)	3885	2873	2220

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Lisbon are estimated at 488.8 MEUR/year based on the 2010 cost of 3.2% of GDP for Portugal provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 36. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050. The table shows that there are significant benefits under BAU as air pollution is reduced (compared to today's air pollution) but these are dwarfed by the large benefits projected under PC2050. Considering only these benefits of 7,340 MEUR on their own, more than compensates for the 4,599 MEUR net costs of PC2050.

Table 36: Net benefits for Lisbon scenarios (2018-2050) due to reduced mortality, and for no air pollution by 2050 (MEUR NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	1 053	1 008	966
PC2050	7 669	7 340	7 027
No air pollution by 2050	9 207	8 817	8 447

INCREASED EMPLOYMENT

The potential for increased employment under PC2050 due to the use of renewable energy and building innovation is summarised in Table 37. Potential jobs for renewable energy are modest with 209 jobs from operation and maintenance, but contribute to nearly 15,000 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 32,700.

Table 37: Benefits of PC2050 scenario compared to BAU for Lisbon

Additional PC2050 Jobs	MCI	O&M
Renewable energy	14600	209
Building renovation	32700	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower energy costs than BAU as a result of increased energy efficiency meaning that energy consumption is 45% lower. Currently (2013) Lisbon has 15.3% renewables in its energy mix (mostly from grid electricity and not local) and this is expected to increase to 35.9% in BAU (5.5% locally with the rest from the grid) and 69.2% in PC2050 (41.2% locally). Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 45% reduction of costs in PC2050 due to reduced energy consumption and a further reduction related to the 33.3% additional renewable energy.

IV.V.VI GAPS AND RISKS

ENERGY AND GHG EMISSIONS

In both scenarios the GHG emissions per capita are considerably reduced from 6.89 tCO_2e per capita for the baseline year of 2002 to 3.77 and 1.16 tCO_2e per capita for BAU and PC2050 respectively.

Although the PC2050 emissions per capita are low compared to 2002, the total emissions are still 683,000 tCO_2e, and hence post carbon status is not reached. If the remaining fossil fuels used for transport and heating were supplied by renewable energy, there would be a requirement for an additional 2036 GWh/year supply. In addition, replacing the grid supplied electricity would require an additional 1960 GWh of supply. However, since the Portuguese electricity supply in 2050 is expected to be very low in carbon it may be more cost effective to utilise the national grid.

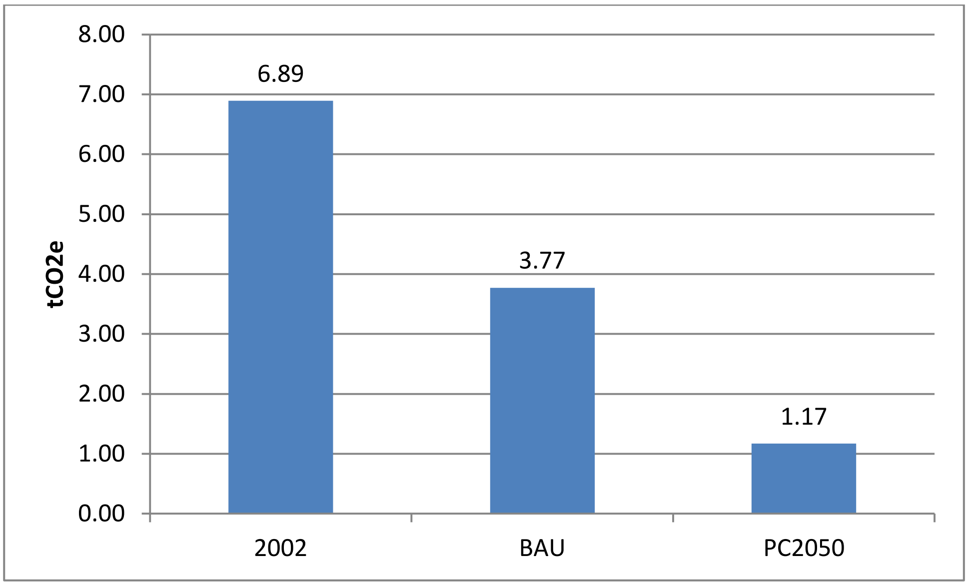

Figure 40: GHG emissions per capita for 2002, BAU and PC2050 for Lisbon

URBAN SPRAWL

A well-known issue with Lisbon in recent years has been the exodus of the population from the centre of Lisbon to the surrounding region. This is an issue which needs to be reversed and population density increased in the centre if a sustainable post-carbon status is to be reached by 2050. This is critical not only in reducing urban sprawl but in reducing the required transport energy and infrastructure investment in transport.

This is emphasised by the land use analysis which showed that even though a population decrease of 96,900 or -3.5 % is projected under BAU, there is still an expected increase in urban sprawl of 64.4 km^2 (or 10.6 %) and a corresponding reduction in non-urban land.

SOCIO-ECONOMIC

There is some concern over the poverty level, although this was only available at the national level. The strategy paper for Lisbon (e.g. as elaborated in the POCACITO strategy paper for Lisbon) should nonetheless address this and in particular ensure that disaggregated figures are available for Lisbon. In addition both the rising unemployment and decrease in tertiary education, particularly within the male population, are of concern.

The cost benefit analysis showed that the PC2050 scenario would cost 2,873 MEUR (NPV with discount rate of 3%) compared to 1064 MEUR for BAU. This represents only 0.69% of the cumulative GDP (from 2018 to 2050) for BAU and 0.28% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 7340 MEUR (NPV with discount rate of 1%).

CIRCULAR ECONOMY AND CONSUMPTION

The EE-MRIO footprint analysis suggests that despite local GHG emissions and impacts decreasing by 84% under PC2050 to 1.2 tCO_2e per capita, there is a risk that the total footprint impacts of the city will increase by 28%. This is largely caused by a large increase in GDP which will potentially cause increased spending and consumption. This emphasises the need for policies to address lifestyles and consumption and promote a more circular economy.

IV.VI LITOMĚŘICE

IV.VI.I INTRODUCTION

In the BAU 2050 scenario Litoměřice declines slightly in population to 23,500. A geothermal plant supplies all of the heating requirements of the city and some electricity, greatly reducing the carbon content of the energy supply. The service sector is the driving force of the local economy, but the GDP per capita at €16,700 is low by national standards of €31,700.

Under the PC2050 scenario Litoměřice has greatly reduced its GHG emissions and is a virtually energy self-sufficient city. A strong focus on energy efficiency measures has reduced the total energy requirements of the city. The population under PC2050 is also expected to remain at around 23,500. It is a compact city, with very little sprawl and most daily transit is done by walking, cycling and public transport. Individual car traffic has been eliminated from the city centre.

IV.VI.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 38 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable).

Due to poor data it is difficult to understand the current trend and therefore propose a potential BAU for many indicators. The lack of data also makes it difficult to understand the likely outcome under PC2050 in many cases. However, some trends can be seen.

Economic wealth per person has increased considerably from 2002 to 2011, suggesting the outlook is positive for both scenarios, although it is still low by European standards.

For both scenarios it is reasonable to assume that air quality will be good. Waste generation increased from 2013 to 2014– although there is not enough data to accurately identify a trend. One concern is the risk of poverty which seems to be increasing, but data was not available on specific percentages.

Table 38: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Litoměřice

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Percentage	92% (2013 and 2014)	No trend available	N/A	N/A
	Energy	Energy intensity variation rate	toe/euro toe	No data 22 256 (2013)	No trend available	+	+
		Variation rate of energy consumption by sectors	Percentage	Industry/housing/other (2013): 39%/50%/11%	No trend available	N/A	N/A
	Climate and Air Quality	Variation rate of carbon emissions intensity	ton CO_2/euro ton CO_2	Not possible to calculate 136 428 ton CO2 eq. (2013)	No trend available	+	++
		Carbon intensity per person	ton CO_2 eq. / capita	5.65 (2013)	No trend available	+	++
		Variation rate of carbon emissions by sector	ton CO_2 (2013)	Industry: 39 399 Transport: 30 604 Housing: 48 707 Other: 14 132	No trend available	N/A	N/A
		Exceedance rate of air quality limit values	Nº	O_3: 0 (2013) NO_2: 0 (2013) SO_2: 0 (2013) $PM_{2.5}$: N/A PM_{10}: 19 (2013)	No trend available	0	++
	Transport and mobility	Variation share of sustainable transportation	Percentage	74.5% (2013)	No trend available	0	++
	Waste	Variation rate of urban waste generation	kg/person/year	93.9 – 95.8 (2013-2014)	No trend available	0	++
		Variation rate of urban waste recovery	Percentage	34% - 35% (2013-2014)	No trend available	0	++
	Water	Water losses variation rate	m^3/person/year	No data		N/A	N/A
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	Data only for public buildings	No trend available	+	++
		Urban density variation rate	Nº/km^2	No data		+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person	About 6 500 – 11 900 EUR/person (2002-2011)	About +80%	++	++
		Variation rate of GDP by sectors	Percentage	-	Industry: +4.8% Agriculture: +3.7% Services: -1.6%	N/A	N/A
		Employment by sectors variation rate	Percentage	-	Agriculture: -28.9% Industry: -13.8% Services: +20.5% (2001-2011)	N/A	N/A
		Business survival variation rate	Percentage	No data	No data	N/A	N/A
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	-1.49% - +0.36% (2004-2011) High annual variations		N/A	N/A
		Indebtedness level variation rate	Percentage of city's GDP	No data		N/A	N/A
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	Variations between 0.21%-0.28% (2002-2011)	Annual variations	-	-
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage	Only graph. No data per gender.		N/A	N/A
		Variation rate of poverty level	Percentage	Significant annual variations	Appears to be increasing	-	0
		Variation rate of tertiary education level by gender	Percentage	Male: about 6.4% - 7.3% (2001-2011) Female: about 4.1% - 6.5% (2001-2011)	Increase	+	+
		Variation rate of average life expectancy	Average №	75.1-76 (2008-2013)	App. +0.9 year	+	+
	Public services and Infrastructures	Variation rate of green space availability	Percentage	9% (2013-2014)	No trend available	N/A	+
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	No		N/A	N/A

IV.VI.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

Geothermal energy is a major contributor of the energy supply in both BAU and PC2050, with the assumed development of the geothermal power station. In PC2050 a potential second geothermal plant is also built. The energy profile of 2013 and each scenario are compared in Table 39 and Figure 41, highlighting the increased contribution of geothermal energy in PC2050, but also the significant contribution of solar energy. However, under BAU a significant quantity of natural gas is also utilised in order to maintain the energy supply, particularly for industry. Due to a significant local policy drive to increase renewable energy production, electrical mobility is assumed to be encouraged through incentives such as exclusive access to parts of the city and free parking.

Table 39: Energy source profile for 2013 and the scenarios for Litoměřice

ENERGY SOURCE	2013	BAU	PC2050
Electricity from grid	17%	8.2%	0%
Coal/other	21%	0%	0%
Geo electricity	0%	9.2%	22.0%
Geothermal heat	0%	22.1%	18.9%
Natural gas	30%	22.4%	0%
Biomass – local and regional	1%	1.1%	1.5%
Biogas	0%	0.01%	0.01%
Solar thermal panels	0%	1.1%	0.8%
Photovoltaic panels	0%	0.2%	33.7%
Hydro power plant	0%	8.9%	12.2%
Transport (fossil fuelled)	30%	26.7%	10.9%
TOTAL	**100%**	**100.0%**	**100%**

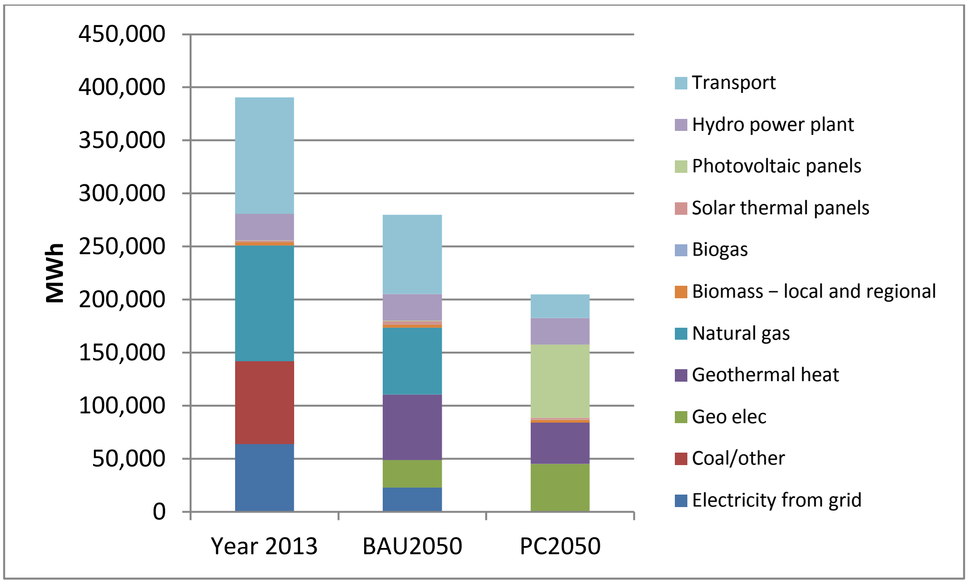

Figure 41: Contribution of energy sources to total energy supply for Litoměřice

The emissions of greenhouse gases (GHG) and the contribution of energy and transport sectors are shown in Figure 42. These highlight the large reduction in GHG emissions in BAU but particularly in the PC2050 scenario. Under PC2050 per capita GHG emissions have been significantly reduced to only 0.36 tCO_2e, compared to 2.08 tCO_2e in BAU, as shown in Figure 43.

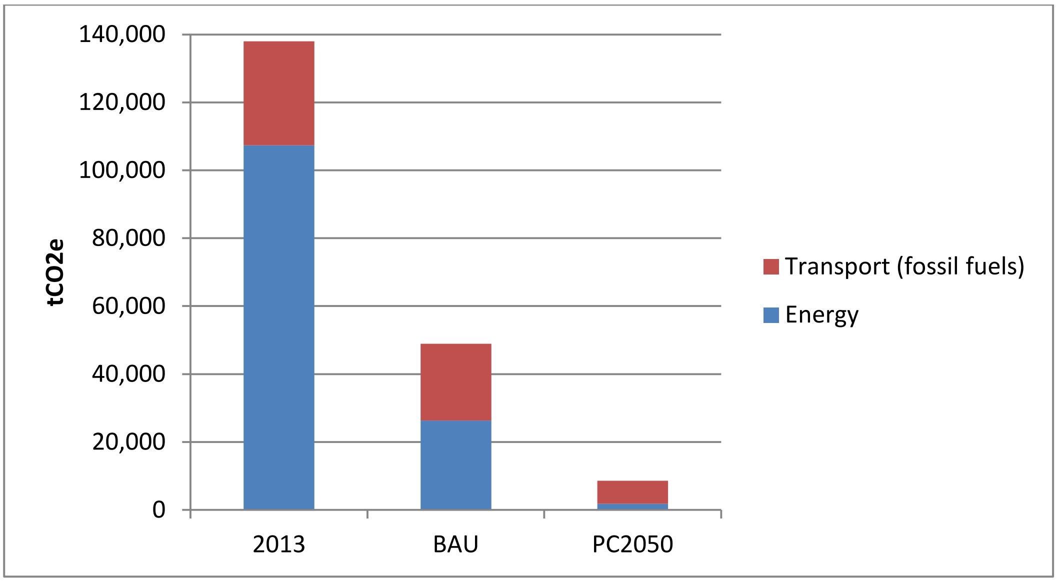

Figure 42: GHG emissions for Litoměřice

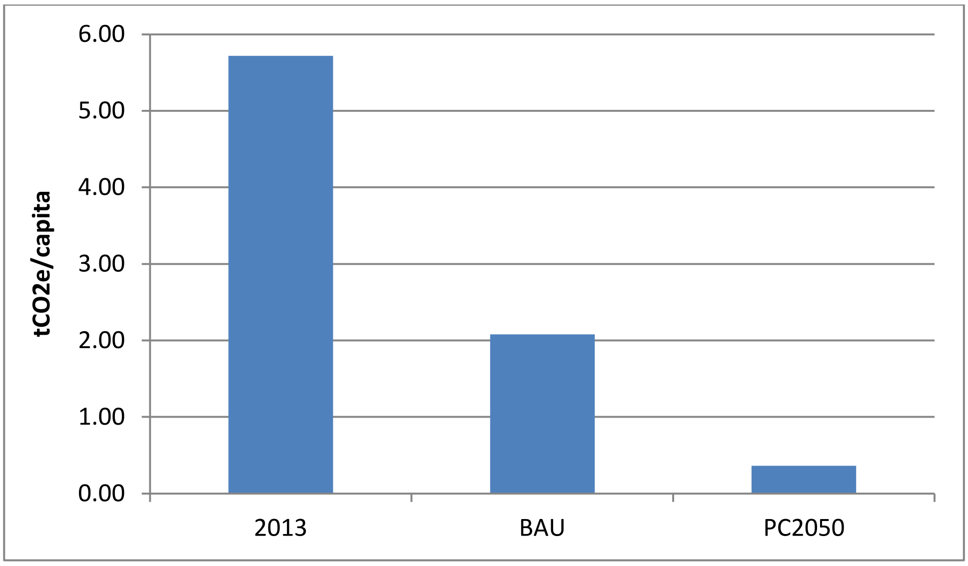

Figure 43: Emissions per capita for Litoměřice for 2013 and the scenarios

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 44, the direct GHG emissions that occur in the city are compared with the indirect emissions. It shows that direct emissions remain fairly static but total emissions increase in both BAU and PC2050 scenarios, because there is a significant increase in indirect emissions.

This is related to the projected increase in GDP and the expected associated increases in consumption. Hence despite expected improvements in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase.

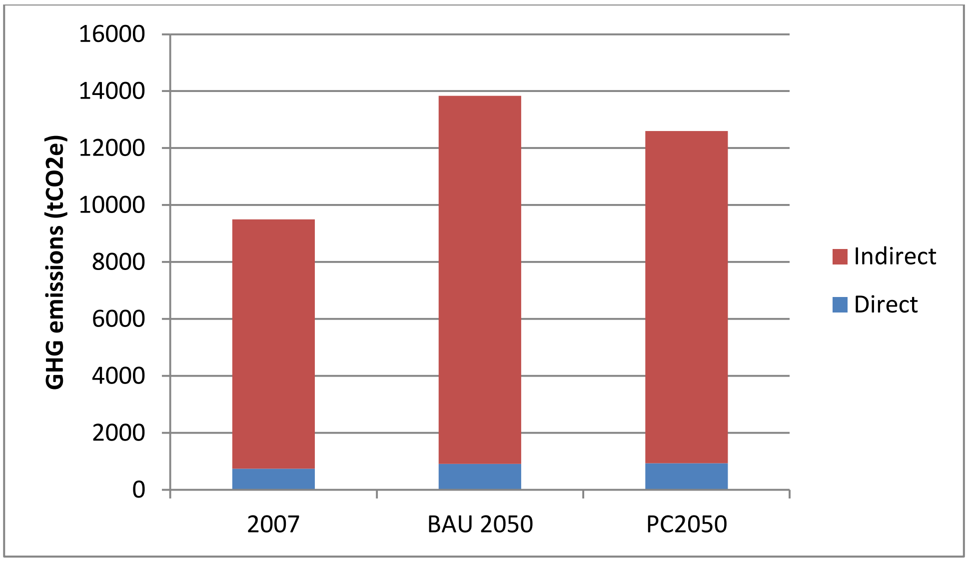

Figure 44: Direct and indirect GHG emissions for Litoměřice for 2007, BAU and PC2050

Figure 45 compares the contribution of the product groups to the GHG emissions for each scenario. It shows that in both BAU and PC2050 “other goods and materials” increase considerably, whereas “electricity and heat fuels” decreases especially in PC2050. There are also increases for “other services”, “transport fuel, equipment and services”, “food” and “housing” in both scenarios. In PC 2050 the overall footprint is reduced compared to BAU primarily due to larger decreases in “electricity and heat fuels” as well as smaller increases for transport.

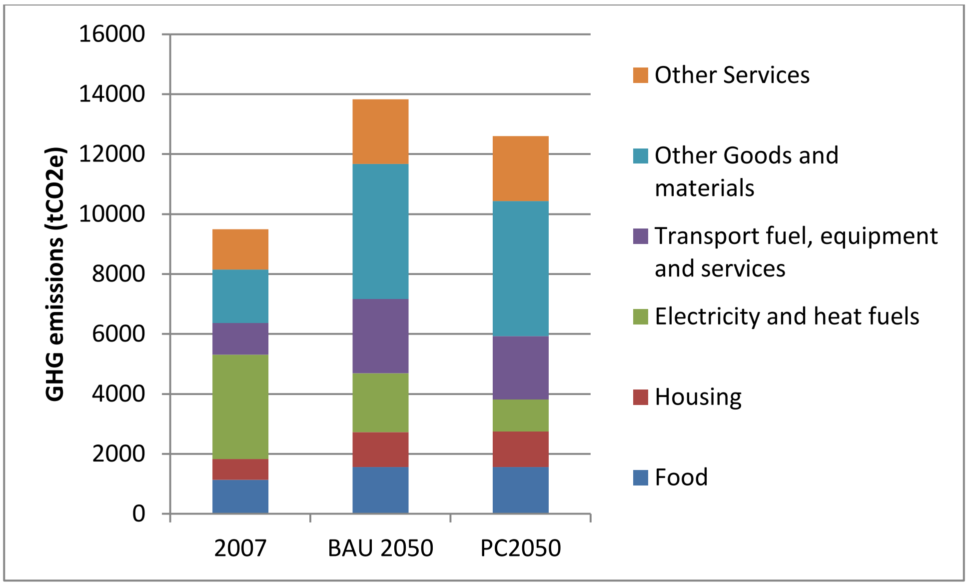

Figure 45: The contribution of product groups to the GHG footprint for 2007, BAU and 2050 for Litoměřice

The other impacts of photochemical oxidation, acidification and eutrophication show a similar rise as shown in Table 40. A noticeable difference for PC2050 is a smaller increase in photochemical oxidation, which is probably due to the improved fuel mix.

Table 40: Environmental impacts for 2007 and the scenarios for Litoměřice

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Gobal warming (kg CO2 eq)	9498	13832	12596	46%	33%
Photochemical oxidation (kg ethylene eq)	2.7	4.5	3.0	68%	13%
Acidification (kg SO2 eq)	35.3	52.8	48.3	50%	37%
Eutrophication (kg PO4--- eq)	6.2	10.4	10.0	67%	61%

Figure 46 compares the contribution of the product groups to the other environmental impacts for 2007 and the scenarios. It shows that the contribution of “electricity and heat fuels” to photochemical oxidation decreases in BAU compared to 2007, but is even less under PC2050. The contribution of “other goods and materials” increases in both BAU and PC2050, but is the major contributor in PC2050. Similar the contribution of “other goods and materials” to acidification increases in BAU and

PC2050 from 2007, whereas electricity decreases significantly and most in PC2050. Eutrophication is dominated by food as one would expect due to the high use of fertilisers in production.

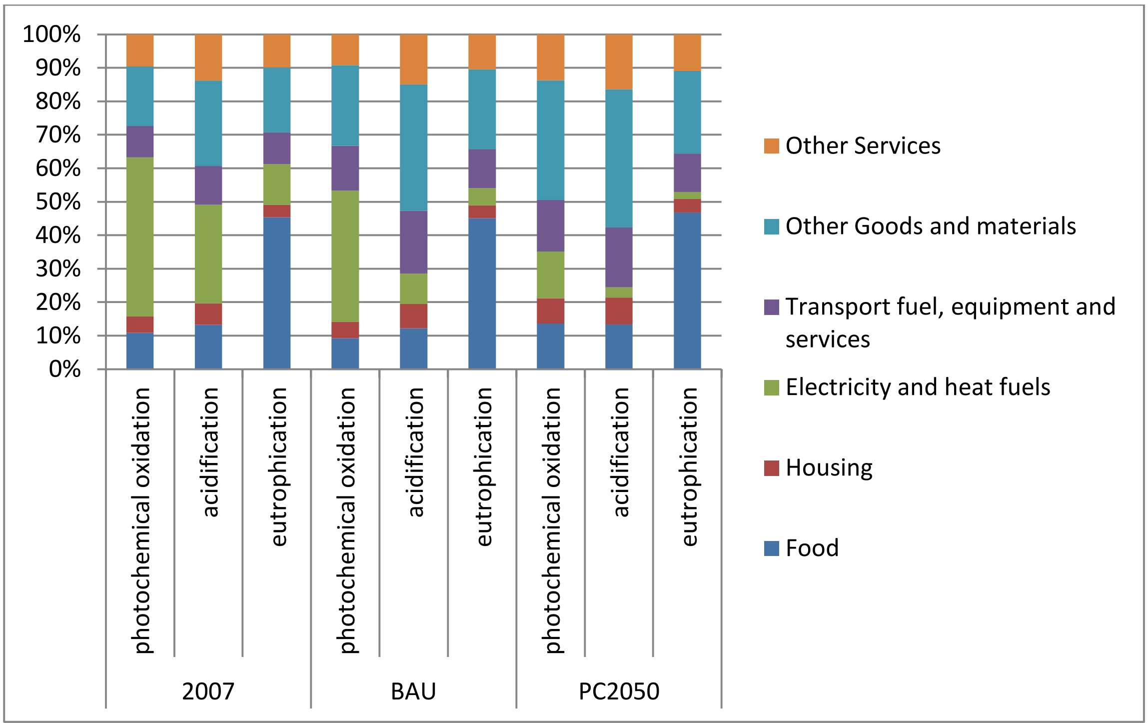

Figure 46: Comparison of other impacts for Litoměřice for 2007, BAU and PC2050

IV.VI.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Litoměřice's population decreased by -2,600 or -10.1 %. Urban land increased by 0.6 km² or 11.6 % (Annex II, Table 86). According to the BAU scenario, by 2050 population will decrease by another -500 or -2.2 %. However, urban land will still increase by 0.1 km² or 1.9 % on the account of non-urban land. According to the PC scenario, population will increase by 1,300 or 5.6 % by 2050. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Litoměřice, between 2000 and 2012, urban spread accounted for 0.6 km² with a population increase of 1,312. In the same period, urban areas with no population change accounted for 0.8 km². Urban areas with population densification accounted for 1.3 km² and for a population increase of 3,628. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 3.1 km² and for a population decrease of -7,586. In summary, the development from 2000 to 2012 was characterized by a total population decrease, some urban spread, and consequently loss of non-urban land and at the same time areas with densification (population increase) as well as areas with dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 0.1 km² with a population increase of 230. Urban land with no population change accounts for 0.9 km² while urban areas with a population increase (densification) account for 1.5 km² and a population increase of 4,044. Urban areas with a population decrease (dis-densification) account for 3.5 km² and a population decrease of -7,792. In summary, the BAU scenario indicates, that in spite of a slight population decrease, some urban spread as well as densification will take place, while other areas will be characterised by population decreases (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 1,300 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 47 and Figure 48 shows spatial patterns of historic and projected urban change for Litoměřice. Between 2000 and 2012 the central part of the city were primarily characterised by a population decrease (dis-densification). Densification (population increase) took place in the in the surroundings, while areas with urban spread were located at the northern fringe of the city. For the BAU scenario, patterns of urban development until 2050 correspond largely with the historical changes. The central part of the city is characterised by population decreases and the suburbs by densification. Urban spread is taking place at the northern fringe of the city. For the PC scenario, the entire city is characterised by population densification, except of some technical areas, which did not contain any population in 2012.

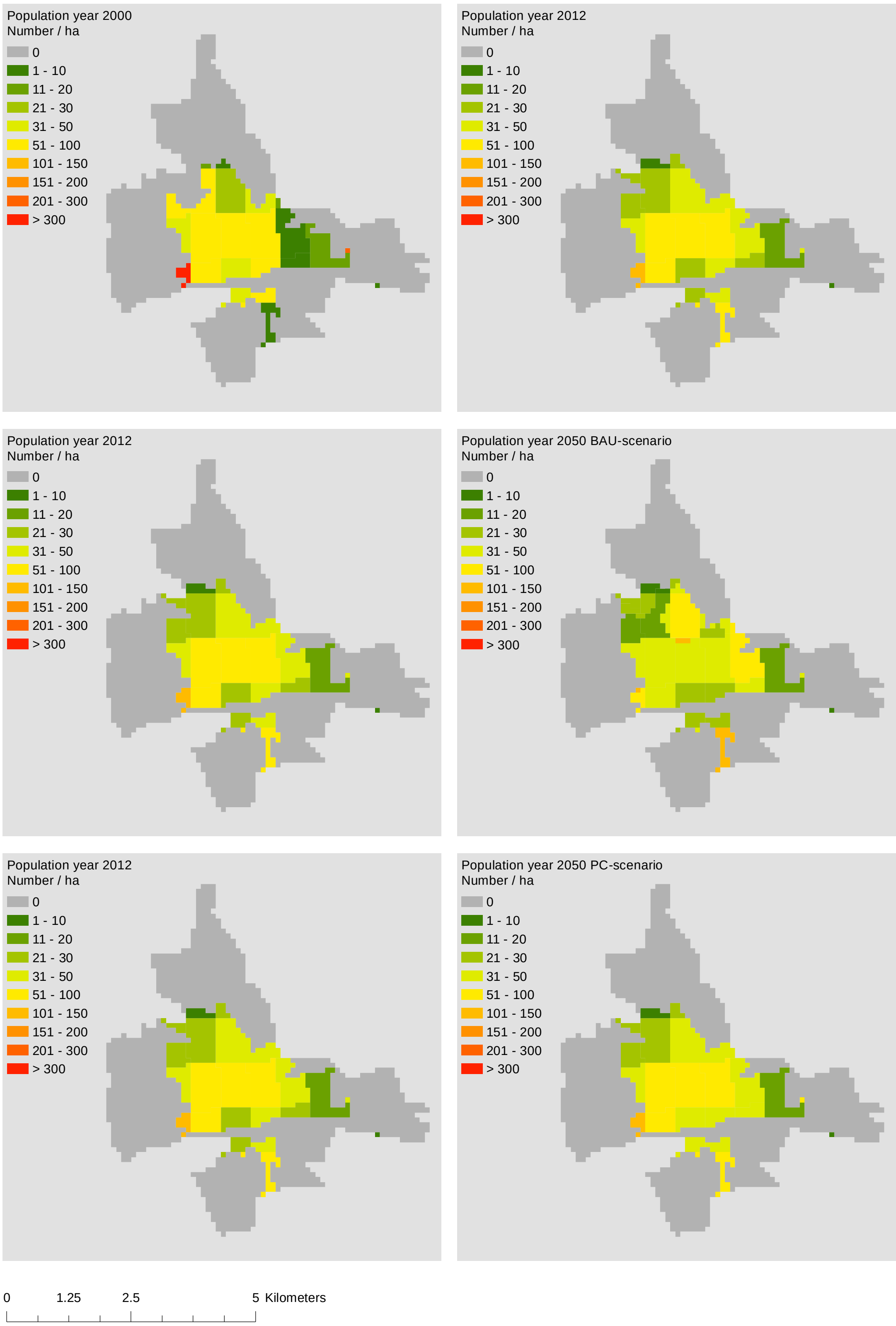

Figure 47: Population and urban change 2000-2012, BAU and PC2050 for Litoměřice

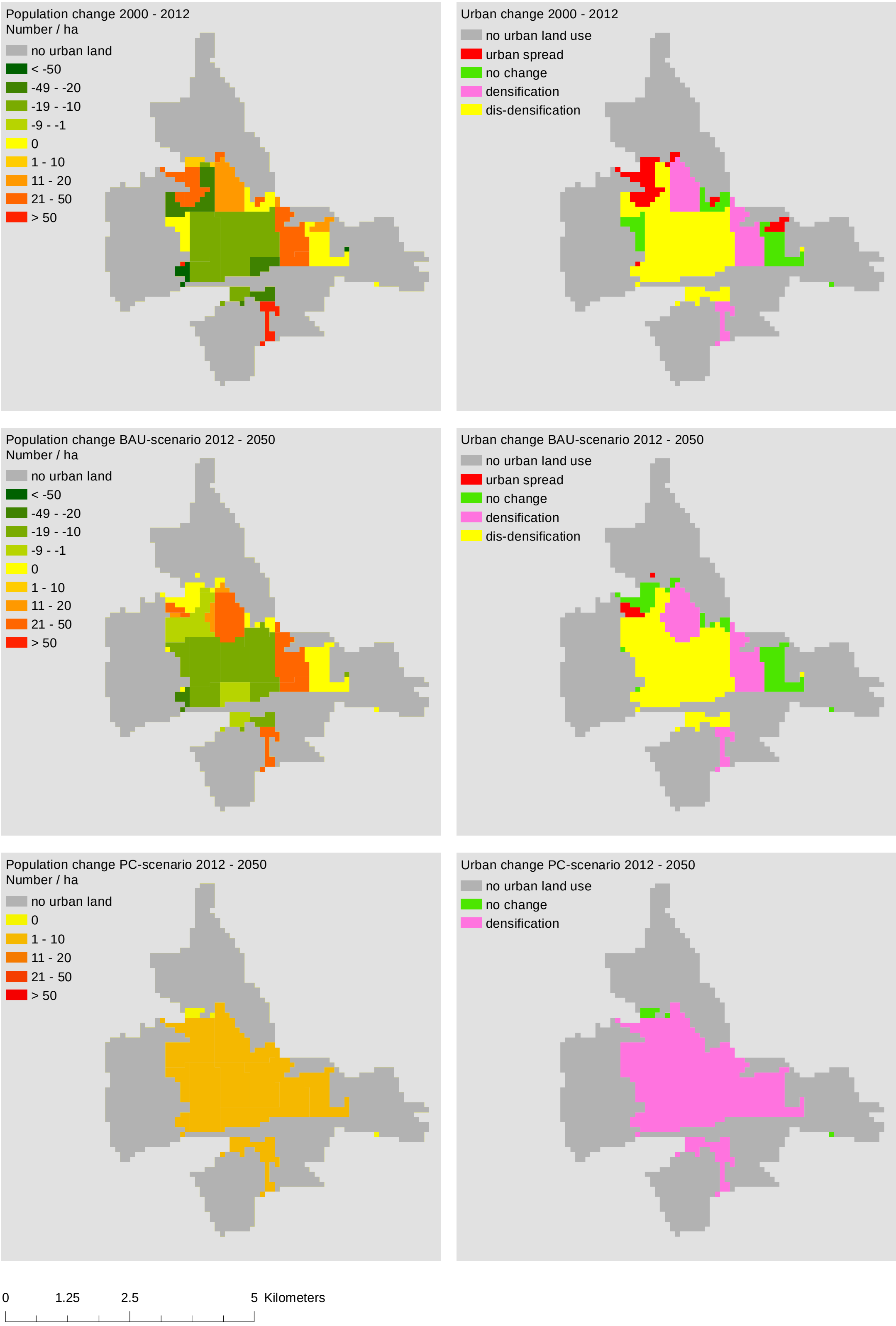

Figure 48: Population and urban change 2000-2012, BAU and PC2050 for Litoměřice (cont'd)

IV.VI.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 41. The total costs of PC2050 are 212 MEUR compared to 107 MEUR for BAU. However, the table also shows that these costs would represent only 1.53% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario, or 0.76% more than BAU.

Table 41: Investment costs for BAU and PC2050 scenarios for Litoměřice

Energy	**MEUR (2016)**
BAU	56
PC2050	94
Total costs for fossil free energy	94
Building renovations	
BAU	50
PC2050	118
Total costs (Energy and buildings)	
BAU	107
PC2050	212
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.77%
PC2050	1.53%

This translates into the following discounted costs as shown in Table 42 at various discounted rates from 2018 to 2050.

Table 42: Net costs for Litoměřice scenario investments at different discount rates (EUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	90	67	52
PC2050 Costs (NPV)	179	132	102

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Litoměřice are estimated at 9,771,987 EUR/year based on the 2010 cost of 7.4% of GDP for the Czech Republic provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 43. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050. In both BAU and PC2050 there are significant net benefits from reducing air pollution with 294 MEUR and 447 MEUR respectively. Due to the virtual elimination of fossil fuels in PC2050 the scenario achieves close to the net benefits expected from zero pollution by 2050.

Table 43: Cumulative cost savings (2018-2050) due to reduced mortality in the scenarios, and for no air pollution by 2050 (€ millions NPV), for Litoměřice

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	307	294	281
PC2050	467	447	428
No air pollution	472	451	432

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 44. Potential jobs for renewable energy are modest with 13 ongoing jobs from operation and maintenance, but contribute to nearly 1164 from manufacturing through to installation. The number of jobs created from the renovation of buildings is approximately 1143.

Table 44: Benefits of PC2050 scenario compared to BAU for Litoměřice

Additional PC2050 Jobs	MCI	O&M
Renewable energy	1164	13
Building renovation	1143	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 26.9% lower. Currently (2013) Litoměřice has 7.6% renewables in its energy mix and this is expected to increase to 42.7% in BAU and 89.1% in PC2050. Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 26.9% reduction of costs in PC2050 compared to BAU, due to reduced energy consumption and a further reduction related to the 46.4% additional renewable energy.

IV.VI.VI GAPS AND CONCLUDING COMMENTS

ENERGY

Litoměřice is progressing well under both scenarios but under PC2050 reaches very close to zero GHG emissions of only 8,561 tCO_2e, or 0.36 tCO_2e per capita. The cost of developing the renewable energy provision and energy efficiency improvements is estimated to be 0.77% and 1.53% of GDP for BAU and PC2050 respectively

SOCIO-ECONOMIC

The KPI analysis suggested that one cause for concern is the risk of poverty which seems to be increasing, but data was not available on specific percentages.

The cost-benefit analysis showed that the PC2050 scenario would cost 132 MEUR (NPV with discount rate of 3%) compared to 67 MEUR for BAU. This represents only 0.77% of the cumulative GDP (from 2018 to 2050) for BAU and 1.53% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 447 MEUR (NPV with discount rate of 1%).

URBAN SPRAWL

The population is due to decrease slightly (by only about 500 people) but urban sprawl may increase by 0.1 km^2. This does not therefore seem to be a significant concern for the strategic paper to address.

CIRCULAR ECONOMY AND CONSUMPTION

The potential for improvements in the impact of consumption are currently not well addressed in the PC2050 scenario. This is evidenced in the EE-MRIO analysis which shows an increase in the GHG emission footprint from 9500 $kgCO_2e$ to 12,600 $kgCO_2e$, or 33%. This is related to an apparent increase in consumption due to increased GDP.

IV.VII MALMÖ

IV.VII.I INTRODUCTION

Malmö in 2050 under the BAU scenario is a vibrant and dense city with a population of 500,000. In terms of energy, Malmö continues to perform generally well with new buildings and developments continuing to be low in energy and carbon use. However, due to the significant population growth and increasing electrification of society energy use has grown in total by almost 10% since 2013. The energy supply system is reasonably low in carbon with 41% of energy derived from renewable sources. There is a strong service sector that accounts for almost 80% of the GDP.

Sustainable Malmö in 2050 (PC2050 scenario) is a dense, yet green and attractive city with around 500,000 inhabitants. In Malmö it is easy to live a long, happy and climate smart life, due to supportive infrastructure and facilities. The three sustainability dimensions: economy, ecology and social, are integrated and play an equal role in the city development. Development and implementation of smart technology are major factors in building this city. Malmö has capitalised on its primary location to become Sweden's gateway to Europe, which has strengthened its diverse economy. The citizens are amongst the lowest carbon emitters in Europe, emitting only 1-2 tons of CO_2/person/year, including the carbon footprint of their consumption.

The main elements of the BAU and PC2050 scenarios were quantified in "Quantification of the Case Study Cities" (Harris et al. 2016) and a summary is provided in Table 45. This table compares the current trend with the projected scenarios.

The data availability for Malmö was generally excellent and numerous indicators and data are collected by Malmö municipality. For instance, they even have some consumption indicators such as percentage of organic milk. Although energy use data was available from 2001 to 2014, including a breakdown of renewable energy, the most detailed and comprehensive data was only available from the 2009 Malmö Energy strategy which was based on 2006 data. This was therefore converted to 2013 data to enable the projections.

Malmö has enjoyed very strong growth since a crisis in the early 1990's and population has grown steadily at approximately 5000 people per year. A move away from ship building in the 1990's towards the service sector (66% of GDP in 2013), IT, hotels and health sectors is expected to continue. By 2050 the service and commerce sectors are expected to be close to 80% of GDP for both BAU and PC2050. Malmö has a strong R&D focus and spending of 4.5% (2011) and 3.3% for the wider Skåne region, as well as a strong research sector and successful policy support for innovation in Sweden. In addition, Sweden is a leading country on sustainability, and this is expected to support an innovative response that will facilitate the emergence of a strong circular economy in both BAU and PC2050. This will be supported, particularly in the PC2050 scenario, with an increase in the industrial service sector to enable reuse, repair and remanufacturing of products, embedding a strong "locally made" culture.

Table 45: Quantification of the main elements of the scenario's for Malmö

Element	Current trend (up to 2013)	Scenario BAU 2050	Scenario PC 2050
Population	313,000	500,000	500,000
Energy	**Energy use** 7259 GWh (2013) (produced) 8230 GWh 7196 Gwh (2008). Hence, 2003-2013, +8.8%. However, it fluctuated up and	**Energy use** 8175 GWh (produced 9044 GWh) **Energy production** - Electricity from grid 26% (hydro 44%, nuclear 40.5%) - Wind and solar – 12% - Gas – 18% - Avfall – 14% - Waste heat – 2% - Biofuel – 8% - Oil – 0.1% - Diesel/petrol 19.6% Renewables therefore provide 40.7% of Malmö's energy.	**Energy use** 7440 GWh (produced 8230 GWh) **Energy production** - Electricity from grid 27.9% - Wind and solar – 40% - Gas – 5% - Avfall – 7% - Waste heat – 2% - Biofuel – 8% - Oil – 0.1% - Diesel/petrol - 10% Renewables therefore provide 62.8% of Malmö's energy
Transport	Modal share change (2003-13) (%) 2003 2013 % Change Car 52 40 -12% Bus 10 14 +4% Train 3 7 +4% Bicycle 20 22 +2% Walking 14 15 +1% Other 1 2 +1%	Modal share is projected as: Car: 32% Bus: 15% Train: 9% Bicycle: 24% Walking: 18% Other: 2%	Modal share: Car 32% Bus 15% Train 9% Bicycle 24% Walking 18% Other 2%
GDP	45,400 EUR (2011)	98,700 EUR	101,600 EUR

IV.VII.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 46 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable).

It shows Malmö is performing well for most indicators under the BAU scenario but performs noticeably better under the PC2050 scenario.

Current energy use per capita is very high but is expected to improve moderately under BAU. However, energy use is much reduced under PC2050 and GHG emissions fall significantly. The energy intensity (toe/EUR) has improved by 25% between the years 2003 and 2013, which is significant, but primarily due to the growth of the service sector which has a lower energy use per economic output than traditional industrial output.

Air quality is viewed as good under both scenarios but likely to be much improved under PC2050 with a greater share of electric vehicles. Reduction in waste generation was 11% between 2007 and 2012, whilst waste recovery improved from 27% in 2011 to 38% in 2013. This is expected to continue positively for both scenarios, but again is better under PC2050 due to an increased focus on the circular economy. The urban density is improving and so too is the population density.

In terms of sustainable economic growth there has been remarkable progress since the low of the 1990's and this has continued in recent years with a focus on the service, IT, health, commerce and education sectors. This has resulted in a 26.1% improvement in GDP per capita between 2003 and 2011. The city has a low budget deficit and low indebtedness level which have been steady in recent years.

The R&D intensity was only available for 2011 has is high and 4.5% (of GDP), even in comparison to the wider region of Skåne which at 3.3% is also fairly high.

Socially the outlook for both scenarios is also very positive, although the poverty level at 14% is fairly high. Tertiary education is high for both sexes, although men have a lower rate.

There is some concern over cultural inequality and segregation through segregated areas of housing, although this is being addressed in several ways, such as improved social spaces, meeting points and consideration of experiences and needs of people in urban planning.

In Table 47 a brief analysis is made on the POCACITO Critical Impact Analysis (PCIA) indicators ("Systemic Characteristics of the Case Study Cities", Harris et al, 2015). One key challenge in Malmö is the integration of society members of different ethnic backgrounds, which has been exacerbated by pockets of segregated housing. This is indeed a key challenge for many European (and worldwide) cities and will require a concerted and continual effort to foster integration and remove inequality. This has also translated into health inequities where average life expectancy is lower in some parts of Malmö by several years, and also amongst certain cultural or social groups, and those with a lower level of education (Commission for a Socially Sustainable Malmö, 2013). Many of these problems have been recognised for decades but despite of numerous efforts there is still an increasing trend of inequity. In 2010 Malmö launched an independent commission who proposed that a clear roadmap be developed to foster social equity. It is not known if this had any effect, although it may be too tell.

Some research has suggested that the increase in inequality and associated problems is due to the reduced generosity of the tax and welfare benefit system, and not intrinsically a function of residential segregation (Scarpa, 2015). They note that in recent years Swedish benefits have actually fallen below the OECD average. Hence causality can be reversed, and residential segregation can be viewed as the spatial manifestation of disparities in income distribution rather than location leading to income inequality or a reduction of opportunities. This is especially because the choice of residential location is driven strongly by economic circumstances.

Land use is another key issue and under BAU Malmö will face a significant urban spread of 37.4 km^2 by 2050 (compared to 9.5km^2 between 2000 and 2012).

Public transport and bike networks are other key variables identified in the PCIA analysis for further investigation. This challenge is also linked to the land use change, as the urban spread around BAU will place greater strain on the public transport network, increased investment and energy use.

Table 46: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Malmö

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	2007 2013	2.1% 4.5%	Doubled in 6 years	+	++
	Energy	Energy intensity variation rate	Toe/euro (000) 2003-2013 Toe (000)	0.06 -0.45 561-616	-25% +9.7%	+	++
		Variation rate of energy consumption by sectors	Percentage Total 2003-2012= 571.7-618.8 KToe (9,5% increase)	2003-2012 % Household 33-31 Building industry 11-11 Ag, forestry & fish 0-0 Public sector 9-9 Transport 27-28 Other services 20-21	Household -2% Building industry 0 Ag, forestry & fish 0-0 Public sector 0 Transport +1 Other services +1	0	+
	Climate and Air Quality	Variation rate of carbon emissions intensity	2000-2011 Ton CO_2 Ton $CO_2(x10^{-3})$/ euro		1.38M-1.75M: +26.8% 0.166-0.127: -23.5%	+	+
		Carbon intensity per person	Population: 262,000 (check for 2002) 313,000	5.62 t/cap 5.59 t/cap	0% change	+	++
		Variation rate of carbon emissions by sector	Ton CO_2 Total 2000-2012 1319-1606 kton (22% increase)	2000-2012 Total (up 22%) Work machines and tools: 4-5% Industry and energy 56-72% Road transport: 37-22% Transport, other: 3-2%	Work machines and tools: +48.0% Industry and energy +57.8% Road transport: -28.8% Transport, other: -44.5%	See below	See below
		Exceedance rate of air quality limit values	Nº	No notable change	-	+	+
	Transport and mobility	Variation share of sustainable transportation	Percentage (2003-2008-2013)	(2003-2008-2013) Car: 52-41-40	Car: -12% Bus: +4%	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
				Bus: 10-10-14 Train: 3-4-7 Bicycle: 20-23-22 Walking: 14-20-15 Other: 1- 2-2	Train: +4% Bicycle: +2% Walking: +1% Other: +1%		
	Waste	Variation rate of urban waste generation	Kg/person/year	2007: 370.2 2012: 329.3	- 11%	+	++
		Variation rate of urban waste recovery	Percentage	2011, 2012 and 2013 27%, 36% and 38%	Positive improvement	++	++
	Water	Water losses variation rate	m^3/person/year	Not available	Not available	N/A	N/A
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	Not available	Not available	N/A	N/A
		Urban density variation rate (population)	Nº/ km^2 (2005-2010)	3458-3527[8]	+ 1.97%	+	+
ECONOMY	Sustainable economic growth	Level of wealth variation rate	eur/person	2003-2011 35990-45400 Euro	+26.1%	++	++
		Variation rate of GDP by sectors	Percentage	Pg 22 Malmö snapshot	A positive long-term development can be noted within business services, IT and computer consultancies, hotels and restaurants, education and commerce ´A downward trend can be seen within manufacturing and agriculture/forestry/fishing	N/A	N/A
		Employment by sectors variation rate	Percentage	Pg 22 Malmö snapshot	From 09-2013 Largest were: Hotels and restaurants Law, econ, sci and tech	N/A	N/A

[8] http://www.scb.se/Statistik/MI/MI0810/2010A01Z/01_Localities2010_land_area_pop_density_2005_2010.xls

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
					Civil author. and defence >10% were Healthcare & social services Transport and warehouse		
		Business survival variation rate	Percentage		68%	N/A	N/A
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	2003=2.8% down to 1.9% in 2006 and then up to 2.8% 2011 Is equalised by tax finance	No change	++	++
		Indebtedness level variation rate	Percentage of city's GDP	2003=4-4% 2006=3.3% 2011=4.1%	No change	++	++
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	Data only for 2011 for Malmö.	4.5% (2011) For Skåne: 3.6-3.3%	++	++
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage 1996-2014 2008-2014	Male / Female -5% / -4.5% +6,5 / + 4,8	Male / Female -5% / -4.5% +6,5 / + 4,8	++	++
		Variation rate of poverty level	Percentage	14%	0%		
		Variation rate of tertiary education level by gender	Percentage (2003-2012)	Men: 32%-40% Women: 34.5-44.5%	Men: 8% Women: +10%	+	+
		Variation rate of average life expectancy	Average Nº (2003-2011)	80.2-81,7	+1.5	++	++
	Public services and Infrastructures	Variation rate of green space availability	Percentage	2000-2005 55-55%	+5%	++	++
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes		++	++

PCIA indicators	Current trend/situation	BAU	PC2050	BAU	PC 2050
Segregation of housing /inequality	Currently there exists pockets of cultural segregation within Malmö	Malmö currently has projects that aim to reduce segregation by opening up corridors to increase connect-ability. But this may not be enough to reduce social and cultural segregation and inequality. However, there social aspects were a prominent feature of the 2014 Comprehensive Plan for Malmö and so there is good potential for a positive outcome, with improved social spaces, meeting points and consideration of experiences and needs of people in urban planning.	Currently the PC2050 scenario also fails to adequately address segregation and the dangers of inequality.	+	+
Land use	This concerns the balance between urban development, green space and agriculture. With a high population growth there is a risk of urban sprawl.	There is some urban sprawl notable under the BAU scenario (see land use section below).	Within the PC2050 scenario there is an emphasis on the circular economy and local produce. Under the PC2050 there is assumed no urban sprawl. But there is a requirement to plan for urban gardens and agricultural space, as well as space and opportunities for facilities for the circular economy (for reuse, refurbishment and remanufacturing).	+	++
Public transport and bike network	The last ten years has seen a reduction in car use and an increase in public transport, by modal balance.	Under BAU total car use is expected to rise although the overall modal balance will reduce. Bicycle use rises only 1-2%.	An increased emphasis on electric mobility could improve the transport energy outlook.	0	+

Table 47: Semi quantitative assessment of the POCACITO PCIA (Sensitivity Model) indicators for Malmö

IV.VII.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

The GHG emissions and energy use of the scenarios is compared with 2013 in Figure 49. It shows that under BAU the energy use increases (due to population growth and taking into account improvements in energy efficiency) whilst the GHG emissions decrease slightly. In PC2050 energy efficiency is improved and the share of electric transport of overall transport is increased to about 60%. Figure 50 illustrates the GHG emissions per capita showing that in both scenarios per capita emissions are much reduced at 2.97 tCO_2e per capita for BAU and 1.37 tCO_2e per capita for PC2050.

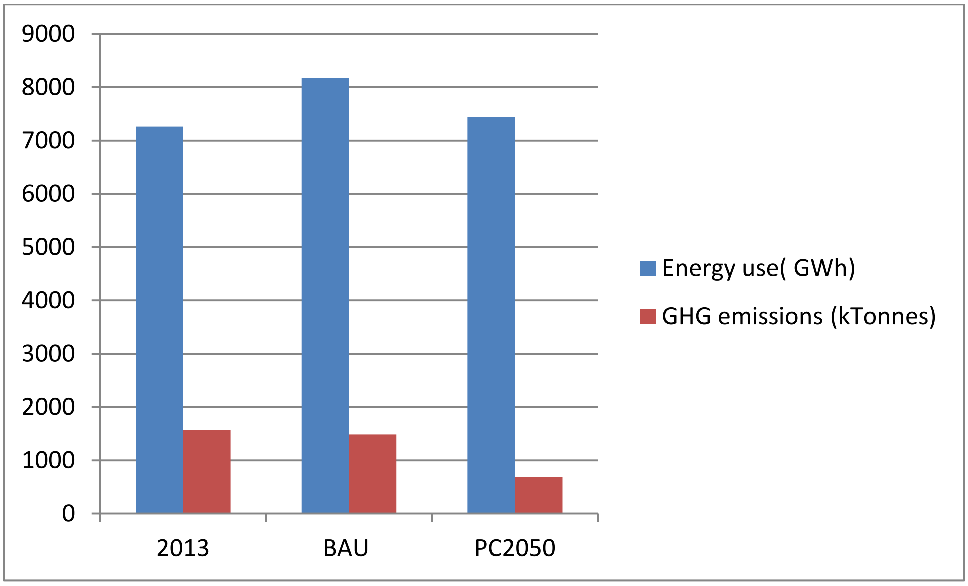

Figure 49: GHG emissions and energy use comparing 2013 with BAU and PC2050

The energy production under PC2050 (see Table 45) obtains 27.9% of electricity from the grid and an additional 40% energy from local wind and solar. Considering the low carbon national electricity supply projected for 2050[9] (albeit Sweden electricity is already very low in carbon) this brings the total renewable energy supply to 62.8%. It was not deemed possible to achieve a 100% local renewable energy supply by 2050, given the current set of actions and milestones developed in the vision workshop. One of the main contributors to GHG is fossil fuels used for transport which still account for 50% of the transport energy (see Figure 52). Therefore although this use of energy in the transport sector only accounts for 10% of the energy supply, it contributes 36.2% of the GHG emissions.

[9] Energy projections for 2050 are taken from EU Energy, Transport and GHG Emissions, Trends to 2050 (Capros P, et al. 2014).

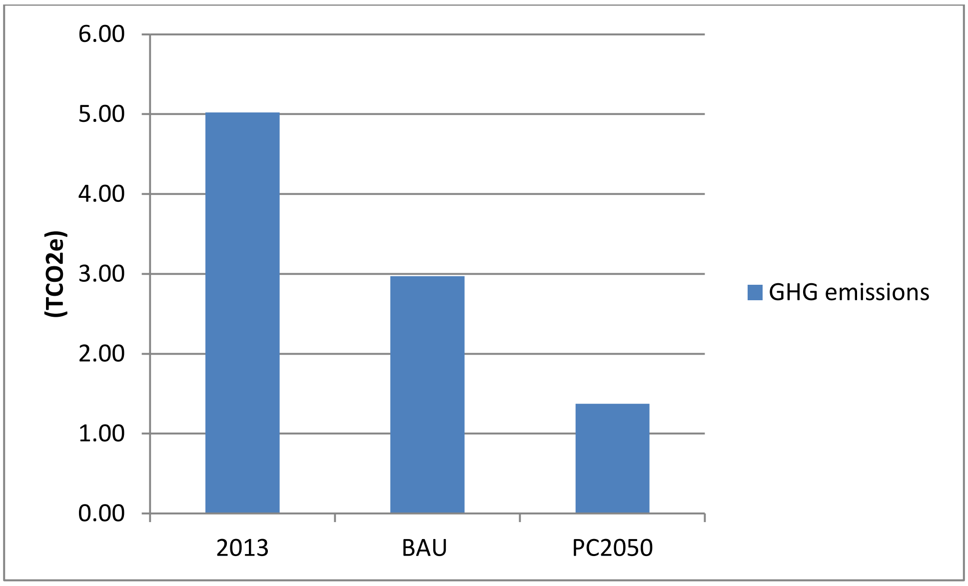

Figure 50: GHG emissions per capita for 2013 and the scenarios for Malmö

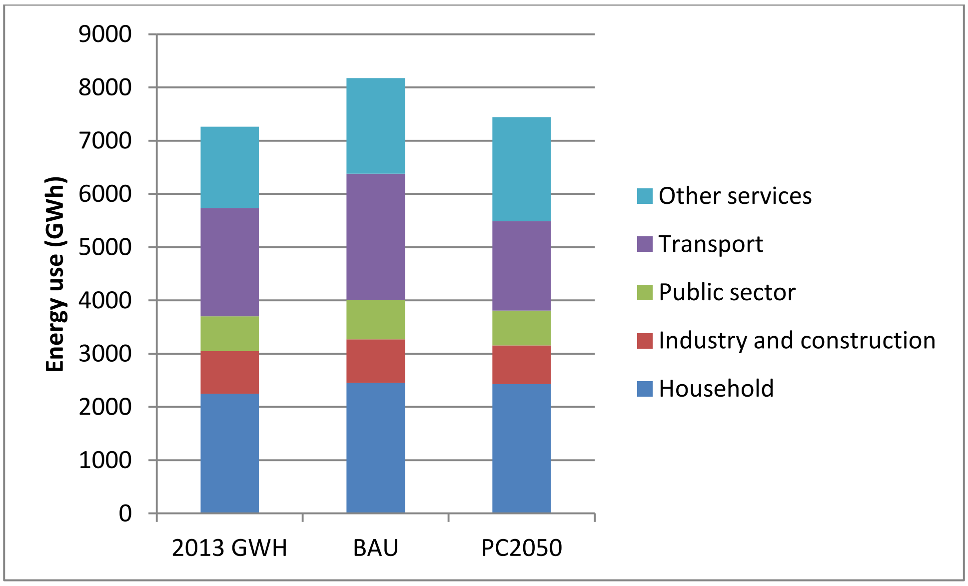

Figure 51: GHG emissions by sector in Malmö

In fact, even achieving the 40% of local renewable energy in PC2050 is an enormous challenge considering the quantities required and historical progress in local renewable energy. The amount of additional renewable energy required for each scenario is shown in Table 48. To put this into context the amount required under PC2050 is equivalent to 8 wind farms the size of Lilligrund, which at 110 MW is Sweden's largest offshore wind farm.

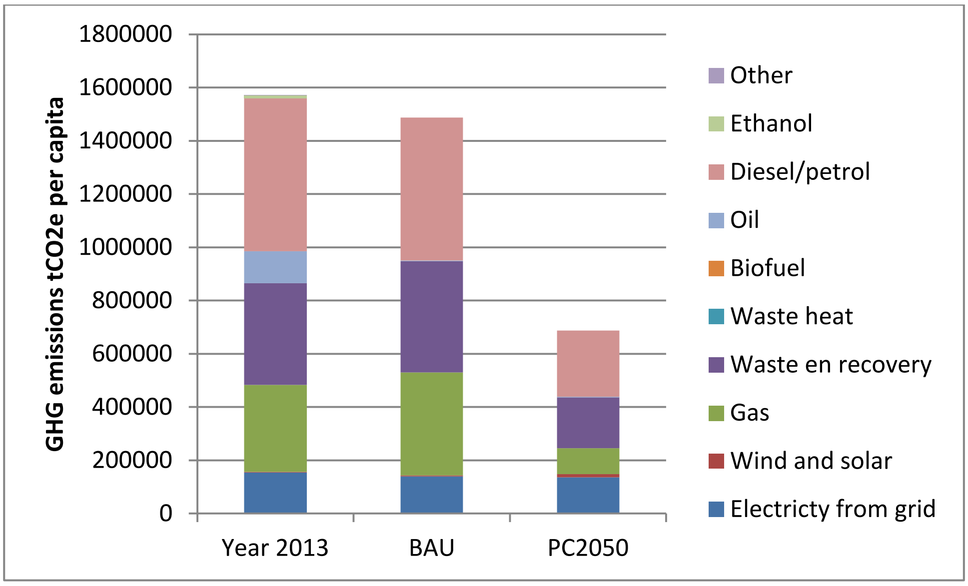

Figure 52: GHG emissions by energy source in Malmö

Table 48: Additional wind energy and capacity requirements for Malmö in the 2050 scenarios

	BAU 2050	PC 2050
Wind energy (GWh)	785	2995
Net wind capacity required (MW)	**243**	**869**

In order to replace all remaining fossil fuels under PC2050 with renewable energy an additional 830 GWh of energy is required. This is equivalent to 241 MW or about two further Lilligrunds. Hence there is also a requirement to investigate further options for major energy use reduction through energy efficiency measures.

Solar energy of course is a complementary option to supplement the wind energy. According to our calculations for Malmö 0.834 MW of solar capacity is needed for each GWh required. This means the comparable costs are: wind 2.46 EUR/kW and solar 2.06 EUR/kW.

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 53 the direct GHG emissions that occur in the city are compared with the indirect emissions. It shows that despite direct emissions falling, indirect and overall emissions increase under both scenarios. This is related to the projected increase in GDP and resulting increases in consumption. Hence despite expected improvements in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase.

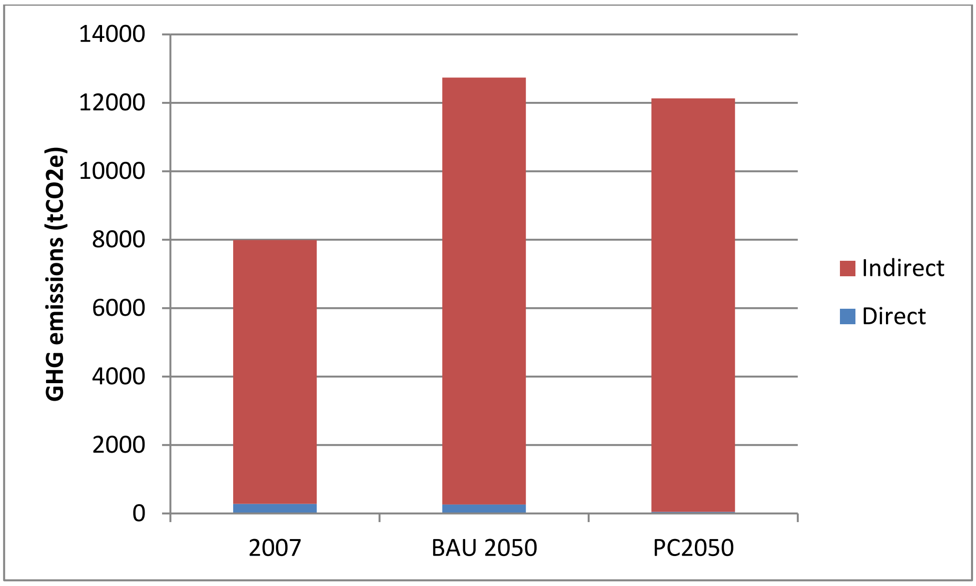

Figure 53: Direct and indirect GHG emissions for Malmö for 2007, BAU and PC2050

In Figure 54 the contribution of different sectors to the overall GHG footprint are compared for 2007 and the scenarios. It shows a large growth for both “other goods and materials” and “other services” in BAU and PC2050. Both sectors have almost doubled in both scenarios. “Transport fuel, equipment and services” also appears to have risen but this may actually be a fault with the modelling technique utilised in adjusting the energy profile, and hence should be taken with caution. In fact, transport impacts should decrease in both scenarios.

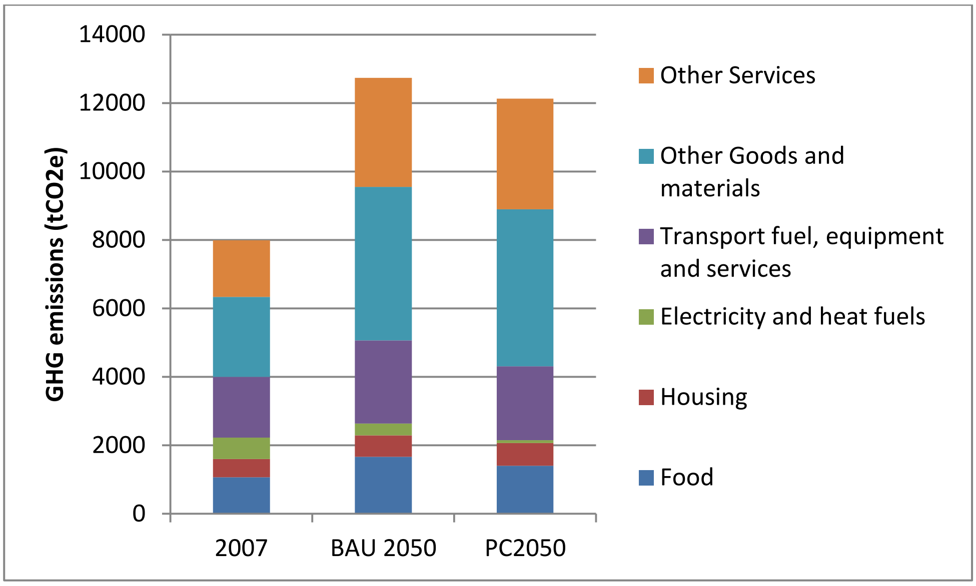

Figure 54: The contribution of product groups to the GHG footprint for 2007, BAU and 2050 in Malmö

The other impacts, photochemical oxidation, acidification and eutrophication, show a similar rise in the 2050 scenarios as shown in Table 49 . However, by proportion the rise is greatest for acidification. From Figure 54 it can be seen that this increase is primarily related to the transport sector and is thought to be the consequence of modelling a high use of biodiesel which negatively impacted the results.

Table 49: Environmental impacts for 2007 and the scenarios for Malmö

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2 eq)	7990.4	12730.2	12129.4	159%	152%
Photochemical oxidation (kg ethylene eq)	2.8	4.6	4.0	165%	146%
Acidification (kg SO2 eq)	41.3	83.1	81.3	201%	197%
Eutrophication (kg PO4--- eq)	8.4	13.3	12.3	158%	146%

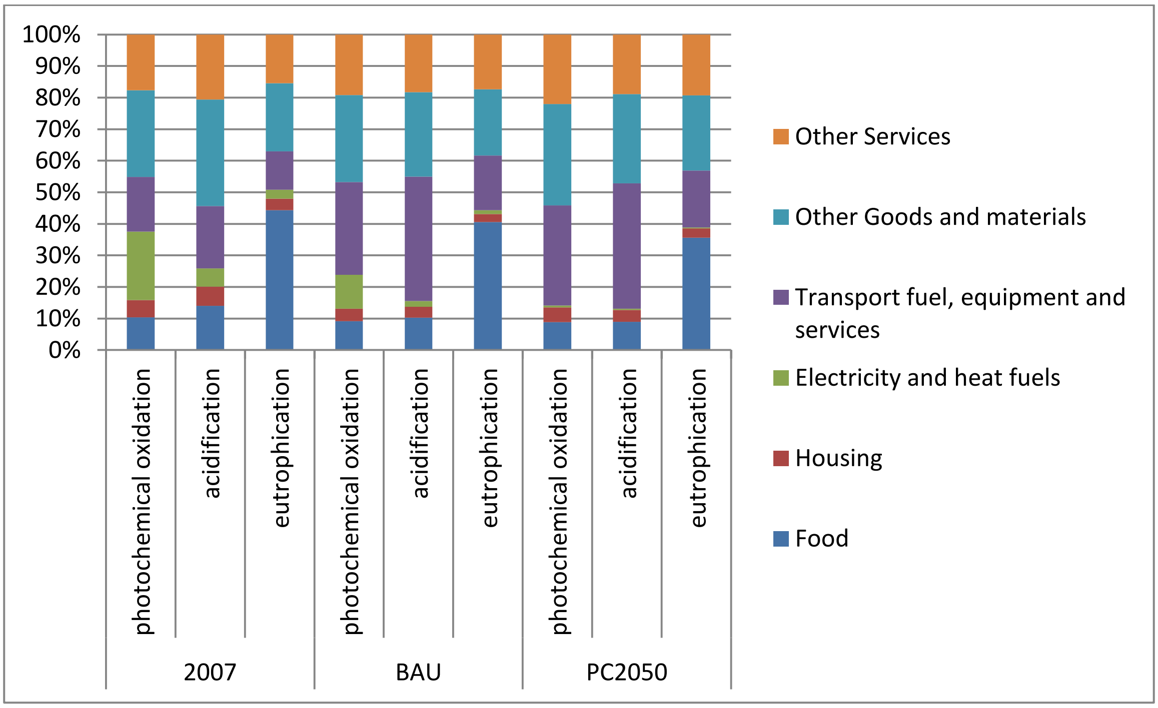

Figure 55: Comparison of other impacts for Malmö for 2007, BAU and PC2050

IV.VII.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Malmö's population increased by 24,500 or 9.2 % and urban land increased by 9.5 km² or 12.5 % (see Annex II, Table 86). According to the BAU scenario, until 2050 population will increase by another 96,100 or 33 % and urban land will increase by 37.4 km² or 43.7 % on the account of non-urban land. According to the PC scenario, population will by 2050 increase by 107,300 or 36.8 %. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Malmö, between 2000 and 2012, urban spread accounted for 9.5 km² with a population increase of 11,191. In the same period, urban areas with no population change accounted for 54.1 km². Urban areas with population densification accounted for 21.8 km² and a population increase of 48,969. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 9.7 km² and a population decrease of 35,676. In summary, the development from 2000 to 2012 was characterized by a total population increase, some urban spread, and consequently loss of non-urban land and at the same time by densification (population increase) in some urban areas and a dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 37.4 km² with a population increase of 43,893. Urban land with not population change accounts for 50.9 km² while urban areas with a population increase (densification) account for 24.7 km² and a population increase of 55,600. Urban areas with a population decrease (dis-densification) account for 9.9 km² and a population decrease of 3,381. In summary, the BAU scenario indicates, that the expected population increase until 2050 will lead to both urban spread and thus a considerable loss of non-urban land while at the same time large parts of the urban land will be characterized by population increase (densification) and a lesser part by population decrease (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 107,343 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 56 and Figure 57 show spatial patterns of historic and projected urban change for Malmö. Between 2000 and 2012 population increase was most pronounced in the central part of the city. Patterns of urban development are characterised by densification in areas close to the city centre. The city centre itself was characterised by dis-densification (population decrease) while urban spread was taking place in the southern and eastern outskirts of the city. For the BAU scenario, patterns of urban development until 2050 are characterised by large areas of urban spread in the outskirts of the city. Densification is primarily taking place south of the city centre while dis-densification is taking place in the city centre. For the PC scenario, population increase is largest in the central part of the city. Almost the entire city is characterised by population densification, except of some harbour areas and areas with infrastructure, which did not contain any population in 2012.

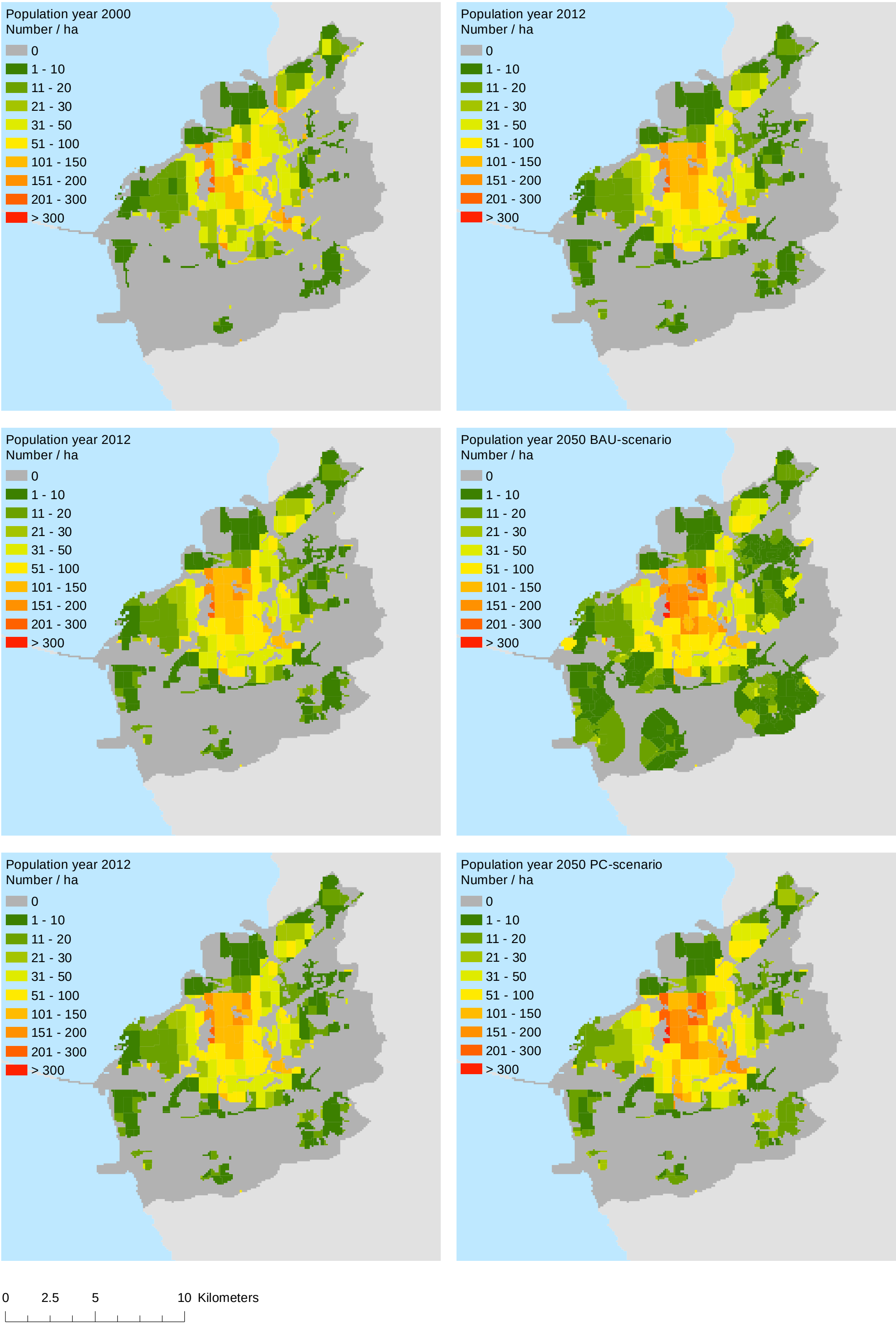

Figure 56: Population and urban change 2000-2012, BAU and PC2050 for Malmö

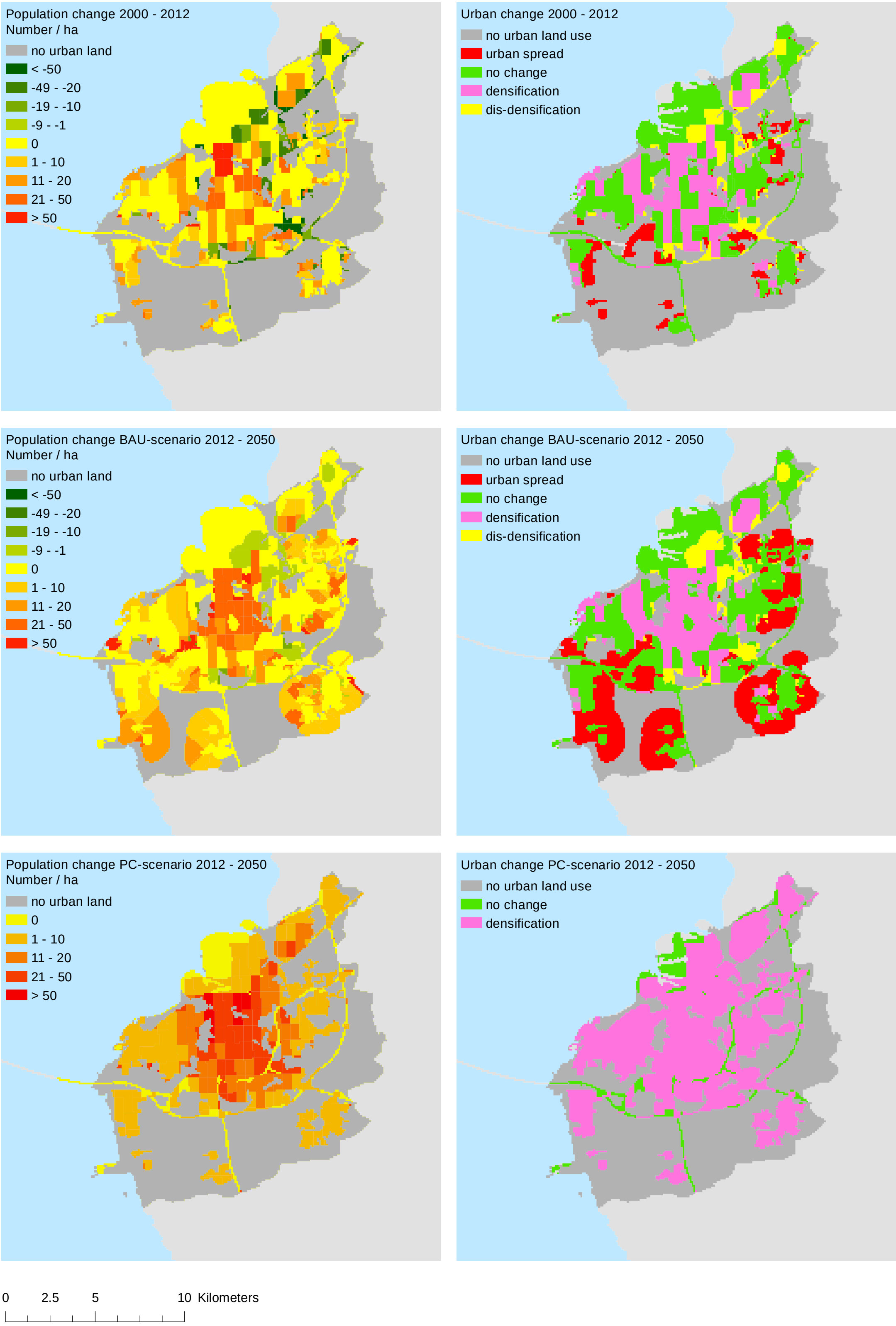

Figure 57: Population and urban change 2000-2012, BAU and PC2050 for Malmö (cont'd)

IV.VII.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 50. The total costs of PC2050 are 3,600 MEUR compared to 3,571 MEUR for BAU. However, the table also shows that these costs would represent only 0.35% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 50: Investment costs for BAU and PC2050 Malmö scenarios

Energy	**MEUR (2016)**
BAU	325
PC2050	1 228
Total costs for fossil free energy	1 781
Building renovations	
BAU	1 004
PC2050	2 343
Total costs (Energy and buildings)	
BAU	1 330
PC2050	3 571
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.13%
PC2050	0.35%

This translates into the following discounted costs as shown in Table 51 at various discounted rates from 2018 to 2050.

Table 51: Net costs for Malmö scenarios investments at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	1 124	831	642
PC 2050 costs (NPV)	3 016	2 230	1 723

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Malmö are estimated at 156 627 038 EUR/year based on the 2010 cost of 0.9% of GDP for Sweden provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 52. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050. In BAU there is a potential for increased air pollution due to the overall increased use of fossil fuels and hence there is actually a cumulative cost, as opposed to the significant net benefit of 2,158 MEUR under PC2050.

Table 52: Net benefits for Malmö scenarios (2018-2050) due to reduced mortality, and for no air pollution by 2050 (€ millions NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	-161.10	-153.93	-147.12
PC2050	2 363.70	2 258.25	2 158.13
No air pollution by 2050	4479.97	4280.53	4091.17

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 53. Potential jobs for renewable energy are modest with 121 ongoing jobs from operation and maintenance, but contribute to nearly 11,000 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 22,764.

Table 53: Benefits of PC2050 scenario compared to BAU for Malmö

Additional PC2050 Jobs	MCI	O&M
Renewable energy	10935	121
Building renovation	22764	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 9% lower. Currently (2013) Malmö has 32.5% renewables in its energy mix and this is expected to increase to 41% in BAU and 60% in PC2050. Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 9% reduction of costs in PC2050 due to reduced energy consumption and a further reduction related to the 22% additional renewable energy.

In addition, the energy consumption of Malmö is quite high in comparison to other cities at a per capita energy consumption of 26.4 GWh/year. This means there is good potential for further savings in PC2050 than have been modelled for improved energy efficiency in for example buildings and appliances.

IV.VII.VI GAPS AND RISKS

Under most indicators Malmö is performing exceptionally well as the economy has recovered in recent years and continues to prosper and grow. As is similar in many European cities there is a move towards the service sector, which has a lower energy intensity (or energy use per economic output) and facilitates the move to a post-carbon society. Recent developments in Malmö such as Västra Hamnen and Hyllie represent some cutting edge examples of sustainable development. Key gaps and considerations are discussed below.

ENERGY

Under BAU energy use continues to climb, but even under PC2050 total energy use rises slightly (due to population growth), although is less per capita. In addition, the total emissions for PC2050 are 687,000 tonnes of CO2e or 1.37 tonnes per capita, therefore falling short of post carbon status.

In order to completely remove all fossil fuels from the energy profile enough additional renewable energy capacity is needed to supply 2995 GWh (this is assuming further energy efficiency measures are not taken). If this were all supplied by wind energy then 869 MW of capacity would be required which the equivalent of eight Lilligrunds. Therefore measures to reduce energy use through energy efficiency measures should be high on the agenda to reduce the investment and effort required to supply adequate energy.

Transport and the cessation of using fossil fuels is probably one of the biggest challenges. Under PC2050 currently, transport accounts for 36% of GHG emissions, due to 50% of the transport still being powered by fossil fuels.

URBAN SPRAWL

Under BAU urban sprawl covers an additional 37.4 km^2 which is of concern and although we have assumed no urban sprawl occurs under PC2050, this aspect needs careful attention in strategic planning. This also has ramifications for private and public transport, which could increase more than the scenarios if urban sprawl remains unchecked.

SOCIO ECONOMIC

Currently the PC2050 scenario also fails to adequately address segregation and the dangers of inequality. The poverty level of 14% is also high. Inequality is a growing challenge in many cities and hence needs an adequate strategy, actions and indicators to monitor progress.

The cost benefit analysis showed that the PC2050 scenario would cost 2,230 MEUR (NPV with discount rate of 3%) compared to 831 MEUR for BAU. This represents only 0.13% of the cumulative GDP (from 2018 to 2050) for BAU and 0.35% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 2258 MEUR (NPV with discount rate of 1%).

CIRCULAR ECONOMY AND CONSUMPTION

Within the PC2050 scenario there is an emphasis on the circular economy and local produce. Hence there is a requirement to plan for urban gardens and agricultural space, as well as space and opportunities for facilities for the circular economy (for reuse, refurbishment and remanufacturing).

However, the EE-MRIO footprint analysis suggests that despite local GHG emissions and impacts decreasing, there is a risk that the total footprint impacts of the city will increase under both scenarios. This is largely caused by a large increase in GDP which will potentially cause increased spending and consumption. Hence the analysis suggests that GHG emission per capita footprint will rise by 52% under PC2050 despite a local reduction of 73%.

This clearly emphasises the need to address lifestyles and consumption and promote a more circular economy.

IV.VIII MILAN

IV.VIII.I INTRODUCTION

In the Milan BAU scenario both the population and the overall energy use continue to grow to 2050. The population has grown to over 1.5 million and is supplied by 31% renewable energy. The district heating network has grown to supply more than 10% of the city's heating needs and is connected to the waste incineration plants. The industrial sector declined and the service sector now supplies almost 80% of GDP.

Milan PC2050 is dense, spacious, green and rich in biodiversity, suitable for pedestrians, and uses carbon-free transport. The energy sources are renewable, with energy efficient technologies employed. In Milan, people are sensitive to environmental issues and use accessible services with a low carbon footprint. The city has experienced a general change in direction from previous patterns of carbon intensive consumption and emissions. Milan has a green economy, with continuously enhancing economic, environmental, and social well-being. This success has been achieved by setting short term goals – once one is achieved, the next goal is set, to limit costs and maintain momentum.

The City of Milan is part of the Covenant of Mayors and as such produced a Strategic Energy Action Plan. This document provided some of the best data available on energy and GHG emissions for Milan, including both energy production and energy use data. It was however, based on data from 2005 and hence needed to be treated accordingly. Recent data from a 2013 was only recently obtained and the analysis here was updated. This shows a slight drop in energy use from 24,831 GWh in 2005 to 23,914 GWh in 2013. It is not known whether this is due to the financial crisis or the result of a successful energy plan. In fact other data collected in WP3 shows that energy use rose from 2005 to 2010 to 25,655 GWh.

IV.VIII.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 54 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable).

It shows that overall the trend is positive and performance is expected to be good under both scenarios for almost all indicators. However, under PC2050 the situation will improve further particularly in relation to the energy and carbon indicators. The only negative trends were for water losses which saw a 3% increase from 2003 to 2012 to reach 14% and for unemployment and the poverty level. The indicators and their outlook under the scenarios are discussed in more detail below.

ENVIRONMENTAL

For biodiversity, the level of protected areas in Milan has remained constant over the reporting period, although this is very short at 4 years. The level of 15.6% is relatively high, but can be misleading as this is the figure for the entire Lombardy region and the main parts of the protected areas is relatively far from Milan. Therefore the level of protected areas in the city of Milan is not as high as the figure indicates. Nevertheless, with additional integration of the green spaces in the city in combination with reopening of waterways as in the PC2050 scenario Milan will improve the situation.

Although total energy use has increased during 2003-2012 the associated carbon emissions have decreased. In addition, energy intensity and carbon intensity (per MEUR) have both have improved considerably. This is expected to continue, but will be much more positive under PC2050, albeit post-carbon status may not be reached under the current scenario.

There appears to be no long term plan to improve air quality, and hence no major improvement is expected in the BAU scenario. In PC2050 there are more extensive measures and together with a reduction in fossil fuel transport the air quality should improve significantly and no exceedances of air pollution thresholds should occur.

Current trends show an increase in public transportation and an associated reduction of car traffic. In the BAU scenario this trend can be expected to continue to a certain degree. However, under PC2050 more measures are expected and the use of public transportation will increase strongly.

In terms of waste generation, the current trend shows is it decreasing. This can be expected to continue under both BAU and PC2050 note that no further measures on this matter are foreseen under the PC2050 scenario. There were also no additional measures noted under the PC2050 to reduce the water losses which have increased in recent years.

ECONOMIC

The sustainability of the economic situation for Milan appears to be undergoing a positive trend and this is expected to continue under both scenarios. As in most cities the service sector is increasing and this can be expected to continue under both scenarios. The research and development investment ratio is however, very small and may deserve some further attention in the city strategy to diversify and strengthen the long term economic outlook.

SOCIAL

There is some concern with the social indicators which show a negative trend for both the unemployment level and the poverty level. The poverty level is expected to be of concern in both the BAU and PC2050 scenarios, as there have been no measures noted under PC2050 to address this.

On the positive side there appears to be a good level of equality with close quantities for both sexes in terms of employment and tertiary education level. However, the actual level of tertiary education appears to be quite low at 12.7% and 13.5% for men and women respectively. The life expectancy is also high and continuing in a positive direction for both scenarios.

Table 54: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Milan

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	2008 2012	15.6% 15.6%	Constant	0	+
	Energy	Energy intensity variation rate	Toe/Meuro 2003-2010 Toe (000)	67.16 -61.21 2114-2202	-8,9% +4.1%	+	++
		Variation rate of energy consumption by sectors	Percentage Total 2005-2010= 2114-2202 KToe (4.1 % increase)	2003-2012 % Residential 36.1-33.3 Services 36.6-38.9 Ag, forestry & fish 0-0 Transport 15.2-17.5 Industry 12-10.3	Residential -4% Services +11% Ag, forestry & fish -2% Transport +20% Industry -11%	N/a	N/a
	Climate and Air Quality	Variation rate of carbon emissions intensity	2003-2010 Ton CO_2 KTon CO_2/M euro		6701-6310: -5.9%% 0.21-0.17: -20%	+	++
		Carbon intensity per person	Population: 1272,000 2013: 1,324,169	5.26 t/cap 4.76 t/cap	-9,5%	+	++
		Variation rate of carbon emissions by sector	Ton CO_2 Total 2005-2010 6702-6310 kton (6% decrease)	2005-2010 Total (down 6%) Services 38-39% Residential 33-31% Industry: 15-18% Transport: 14-12% Agriculture: 0-0	2005-2010 Services -2% Residential -11% Industry: +13% Transport: -23% Agriculture: -7%	N/a	N/a
		Exceedance rate of air quality limit values	Nº of days 2008-2012 PM10 Nº of days 2002-2012 NO2 O3	PM10 127-117 NO2 10-39 O3 19-4	PM – 8% NO2 +390% O3 – 79%	+	++
	Transport and mobility	Variation share of sustainable	Percentage (2005-2013)	(2003-2013)	Car: -8%	+	++

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
		transportation		Car: 38-30 Public transportation: 51-57 Motorbikes 6-7 Bicycle: 5-6	Public transportation +6% Bicycle: +1% Motorbikes +1%		
	Waste	Variation rate of urban waste generation	Kg/person/year	2000: 542.2 2012: 500.9	-7.6%	+	+
		Variation rate of urban waste recovery	Percentage	2000: 28.6% 2012: 38.18	+9.58%	+	+
	Water	Water losses variation rate	m^3/person/year	2003: 11% 2012: 14%	+3%	-	-
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	2010: 0.2% 2014: 1%	+0.8%	0	++
		Urban density variation rate (population)	Buildings/ km^2 (2001-2011)	2001: 263.74 2011: 356.84	+ 35.3%		+
ECONOMY	Sustainable economic growth	Level of wealth variation rate	eur/person	2000: 33 200 Euro 2011: 46 600 Euro	+40.4%	++	++
		Variation rate of GDP by sectors	Percentage 2000-2011	Agriculture: 0.3%-0.2% Industry: 26.2%-21.8% Services: 73.5%-78%	Agriculture: -0.1% Industry: -4.4% Services: +4.5%	N/a*	N/a*
		Employment by sectors variation rate	Percentage 2000-2011	Agriculture: 0.2%-0.2% Industry: 25.9%-22.8% Services: 73.9%-77%	Agriculture: 0 Industry: -3.1% Services: +3.1%	N/a*	N/a*
		Business survival variation rate	Percentage	No data		N/a	N/a
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	N/a		N/a	N/a
		Indebtedness level variation rate	Percentage of city's GDP	2004=3.4% 2009=3.4% 2014=4.04%	+0.64%	++	++
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	2003: 1.17% 2011: 1.32%	+0.15%	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage 2004-2013	Male / Female 2004: 3.6% / 4.6% 2013: 7.3% / 7.7%	Male / Female +3.7 / +3.1%	-	+
		Variation rate of poverty level	Percentage	2004: 15.6% 2012: 19.1%	+3.5%	-	-
		Variation rate of tertiary education level by gender	Percentage (2004-2013)	Men: 9.5%-12.7% Women: 8.6%-13.5%	Men: +3.2% Women: +4.9%	++	++
		Variation rate of average life expectancy	Average Nº (2003-2012)	80.6-82.8	+2.2	++	++
	Public services and Infrastructures	Variation rate of green space availability	Percentage	2000-2009 9.8%-11.7%	1.9%	0	+
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes		++	++

**It should be noted that no score or prediction is provided for these KPI's because it cannot be said whether movement towards one sector of the economy (e.g. an increasing service sector) is positive or negative.*

IV.VIII.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

The energy sources and quantities for the baseline year 2005 and the BAU and PC2050 scenarios are shown in Table 55.

The PC2050 sees a much higher transition to a further electrification of society and the transport sector. Under this scenario all public transport is electric (or similar low emission) and 50% of private transport is fossil fuelled.

Table 55: Energy production by source for 2008, BAU and PC2050

	2005		BAU	PC2050
Source	**GWh**	Source	GWh	GWh
Natural gas	9885.5	Natural gas	**4519**	875
Diesel	7245.5	Diesel	**3294**	181
Petrol	3314.6	Petrol	**735**	181
Oil, biodiesel LPG	290.8	LPG	**177**	0
Grid electricity	7164.08	Grid electricity	**8969**	7000
Heat		Waste*	**2000**	2000
from gas	*72.4*	Solar	**1500**	4000
from waste	*195.0*	Wind	**500**	2000
		Geothermal	**500**	600
		Biofuel	**228**	362
Total (GWh)	**28167.86**		**22422**	**17199**

**(For GHG calculations it is assumed that 20% of waste is non-bio based)*

This assumes an ambitious but modest development of local renewable energy, which is the result of an interpretation of the actions and milestones developed in the stakeholder's workshops. Hence there is room for improvement, which is highlighted in Figure 58, comparing the GHG emissions for 2005 with the scenarios. For PC2050 it can be seen that the major portion of GHG emissions arises from the electricity (national supply) which assumes an emissions factor developed by Capros (2014) for 2050.

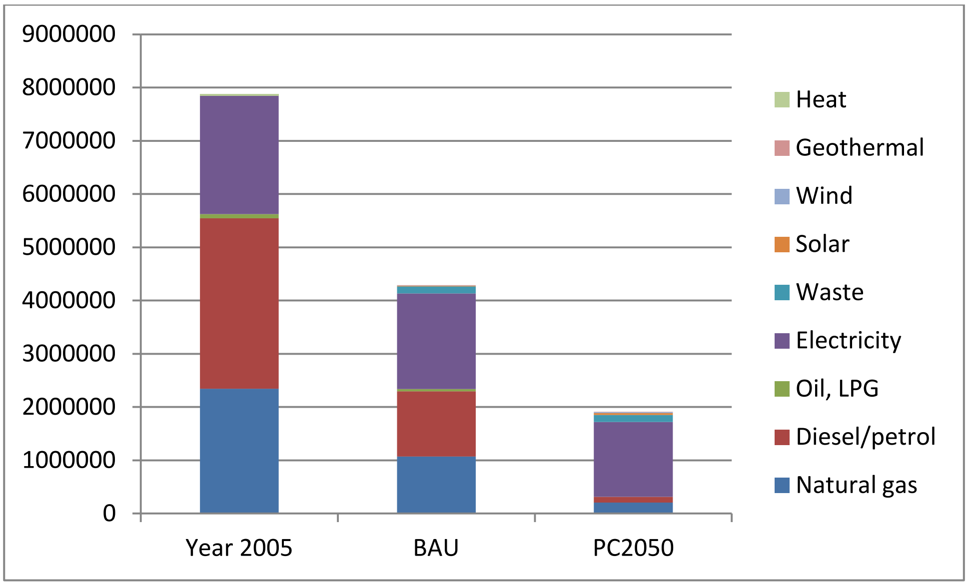

Figure 58: GHG emissions for Milan Municipality for 2005, BAU and PC2050

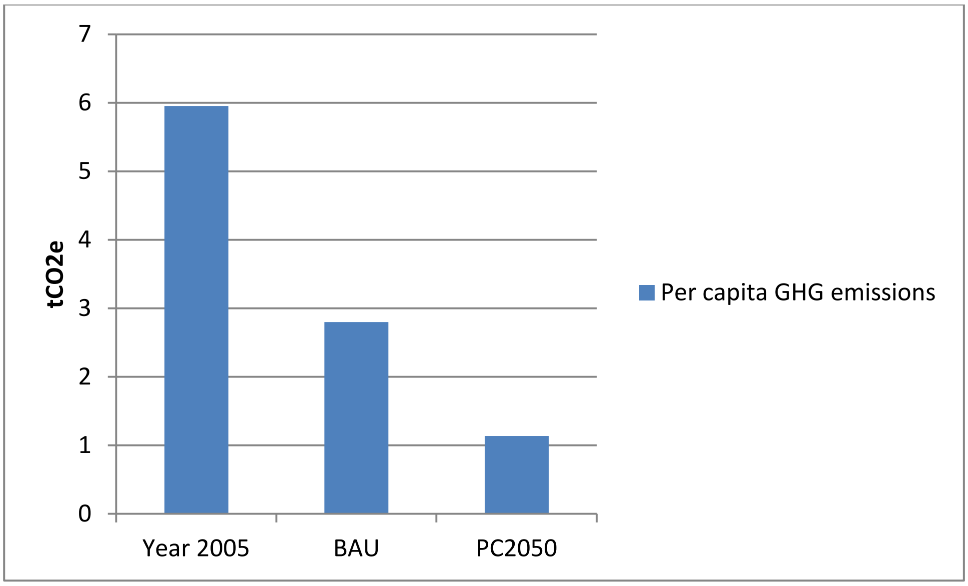

Figure 59: GHG emissions per capita for Turin Municipality for 2005, BAU and PC2050

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 60, the direct GHG emissions that occur in the city are compared with the indirect emissions. It shows that direct emissions are decreasing in BAU compared to 2007 but even more so in PC2050. However, total emissions in PC2050 appear to be slightly more than those of BAU probably due to increased consumption, related to a higher GDP.

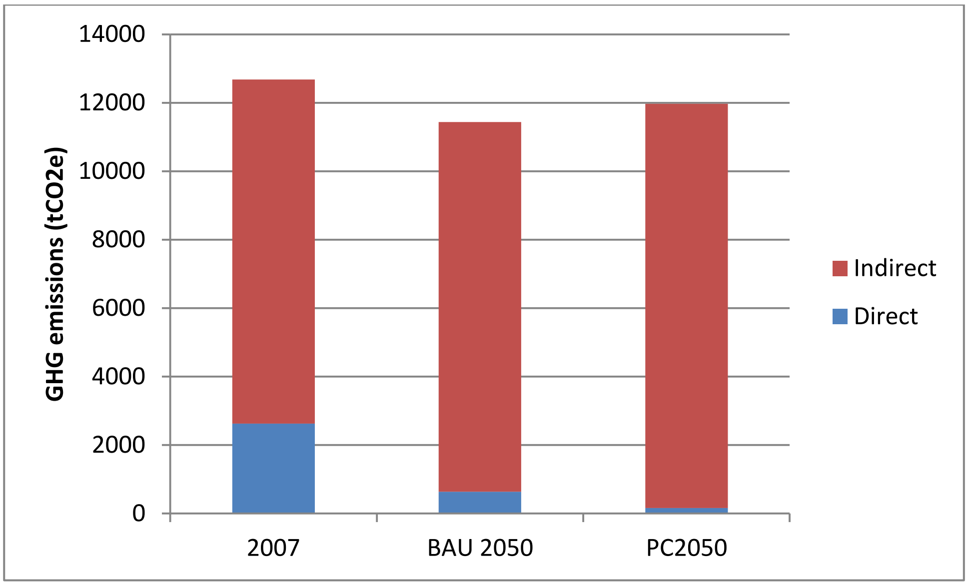

Figure 60: Direct and indirect GHG emissions for Milan for 2007, BAU and PC2050

Figure 61 compares the contribution of the product groups to the GHG emissions for each scenario. It shows that in both BAU and PC2050 "transport fuel, equipment and services" and "electricity and heat fuels" decrease considerably compared to 2007. However, there are increases in the contribution of food particularly in PC2050. In addition the share of "other goods and materials" and "other services" increases in both scenarios compared to PC2050. Overall, this suggests that despite reductions in the impact of transport and energy, increases in consumption typically linked to increasing affluence have increased meaning that the overall reduction in emissions is minimal.

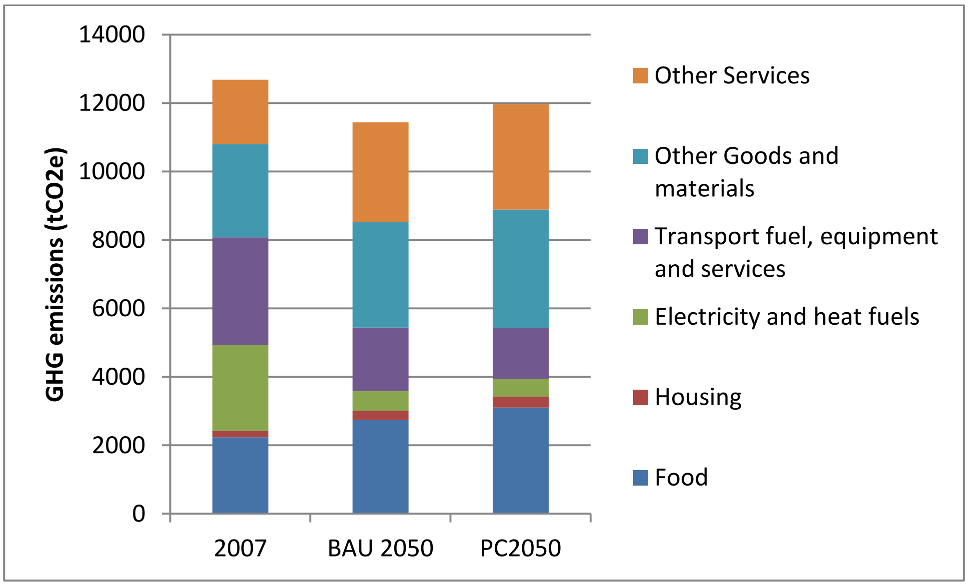

Figure 61: The contribution of product groups to the GHG footprint for 2007, BAU and 2050 in Milan

The impact of the scenarios on other the impacts of photochemical oxidation, acidification and eutrophication are shown in Table 56. Eutrophication in particular shows the largest rise in both scenarios, which is linked to the increase in food consumption.

Table 56: Environmental impacts for 2007 and the scenarios for Milan

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
global warming (kg CO2 eq)	12675.5	11437.2	11972.4	-10%	-6%
photochemical oxidation (kg ethylene eq)	2.5	2.5	2.6	0%	2%
acidification (kg SO2 eq)	44.4	42.2	45.6	-5%	3%
eutrophication (kg PO4--- eq)	10.6	11.8	13.0	11%	22%

Figure 62 examines these additional impacts further by comparing the contribution of the product groups for 2007 and the scenarios. It shows that the contribution of food has increased in all impact categories, whereas transport and electricity has decreased in the scenarios compared to 2007. Eutrophication is dominated by food as one would expect due to the high use of fertilisers in production.

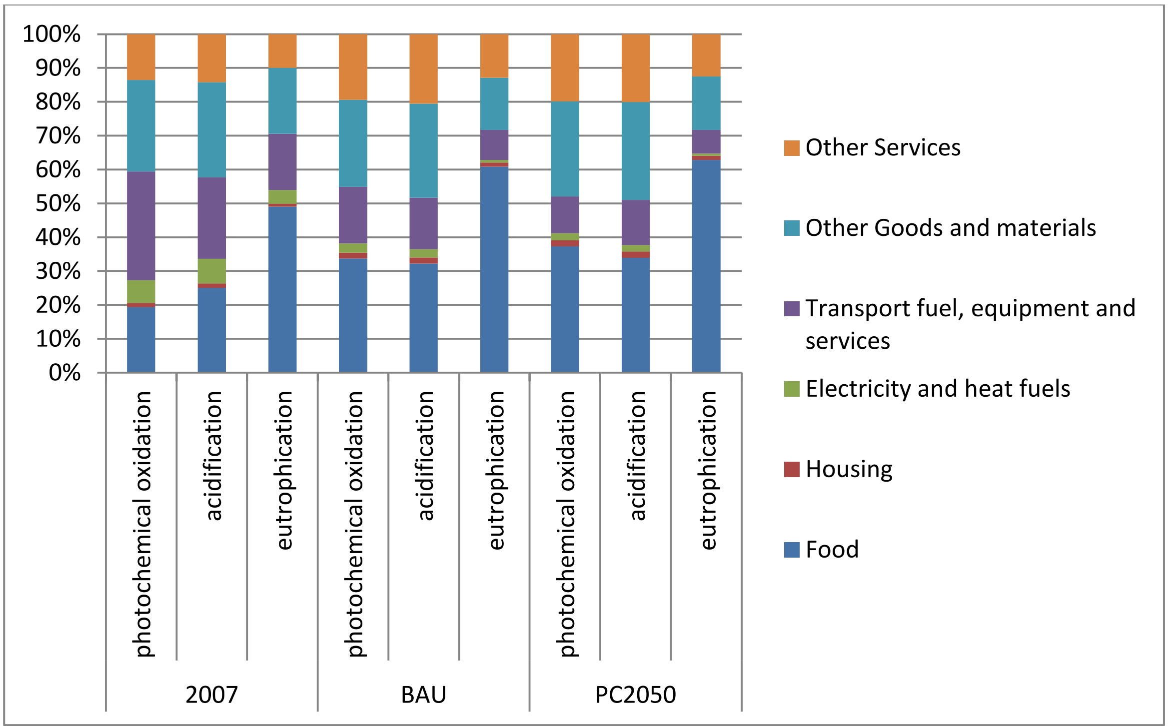

Figure 62: Comparison of other impacts for Milan for 2007, BAU and PC2050

IV.VIII.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Milan's population increased by 315,100 or 8.8 % and urban land increased by 61.0 km² or 9.3 % (see Annex II, Table 86). According to the BAU scenario, by 2050 the population will increase by another 209,400 or 5.4 % and urban land will increase by 40.4 km² or 5.6 % on the account of non-urban land. According to the PC scenario, population will until 2050 increase by 665,300 or 17.1 %. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Milan, between 2000 and 2012, urban spread accounted for 61.0 km² with a population increase of 190,267. In the same period, urban areas with no population change accounted for 107.2 km². Urban areas with population densification accounted for 396.0 km² and a population increase of 1,231,740. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 151.2 km² and a population decrease of 1,106,862. In summary, the development from 2000 to 2012 was characterized by a total population increase, a considerable urban spread, and consequently loss of non-urban land and at the same time by densification (population increase) in some urban areas and a dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 40.4 km² with a population increase of 126,094. Urban land with not population change accounts for 117.4 km² while urban areas with a population increase (densification) account for 432.7 km² and a population increase of 609,981. Urban areas with a population decrease (dis-densification) account for 165.3 km² and a population decrease of 526,632. In summary, the BAU scenario indicates, that the expected population increase until 2050 will lead to both urban spread and thus a loss of non-urban land while at the same time large parts of the urban land will be characterized by population increase (densification) and other parts by population decrease (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 665,255 will result in a population increase (densification) on land that is populated in 2012.

Spatial patterns of urban change

Figure 63 and Figure 64 show spatial patterns of historic and projected urban change for Milan. Between 2000 and 2012 the areas around the city centre and along the main transportation routes were characterised by population decreases (dis-densification) or no change. Population increase (densification) was most pronounced in the centre and in the suburbs. Urban spread took place at the fringe of the city. For the BAU scenario, patterns of urban development until 2050 are characterised population decreases (dis-densification) around the city centre and along the main transportation routes. Densification (population increase) is taking place in the city centre and in suburbs and urban spread in the outskirts of the city. For the PC scenario, population increase is largest in the central part of the city. The entire city is characterised by population densification, except of some technical and airport areas, which did not contain any population in 2012.

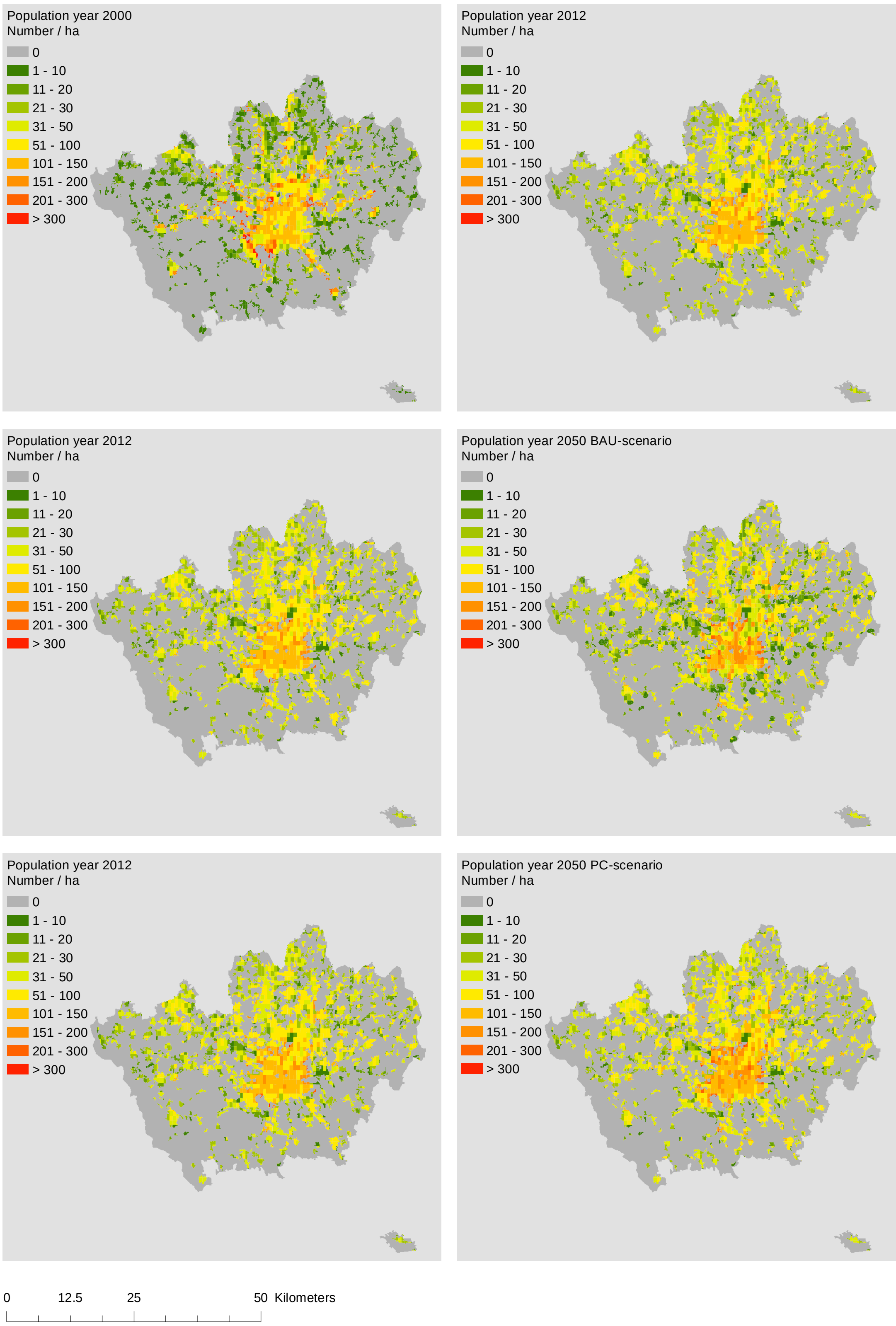

Figure 63: Population and urban change 2000-2012, BAU and PC2050 for Milan

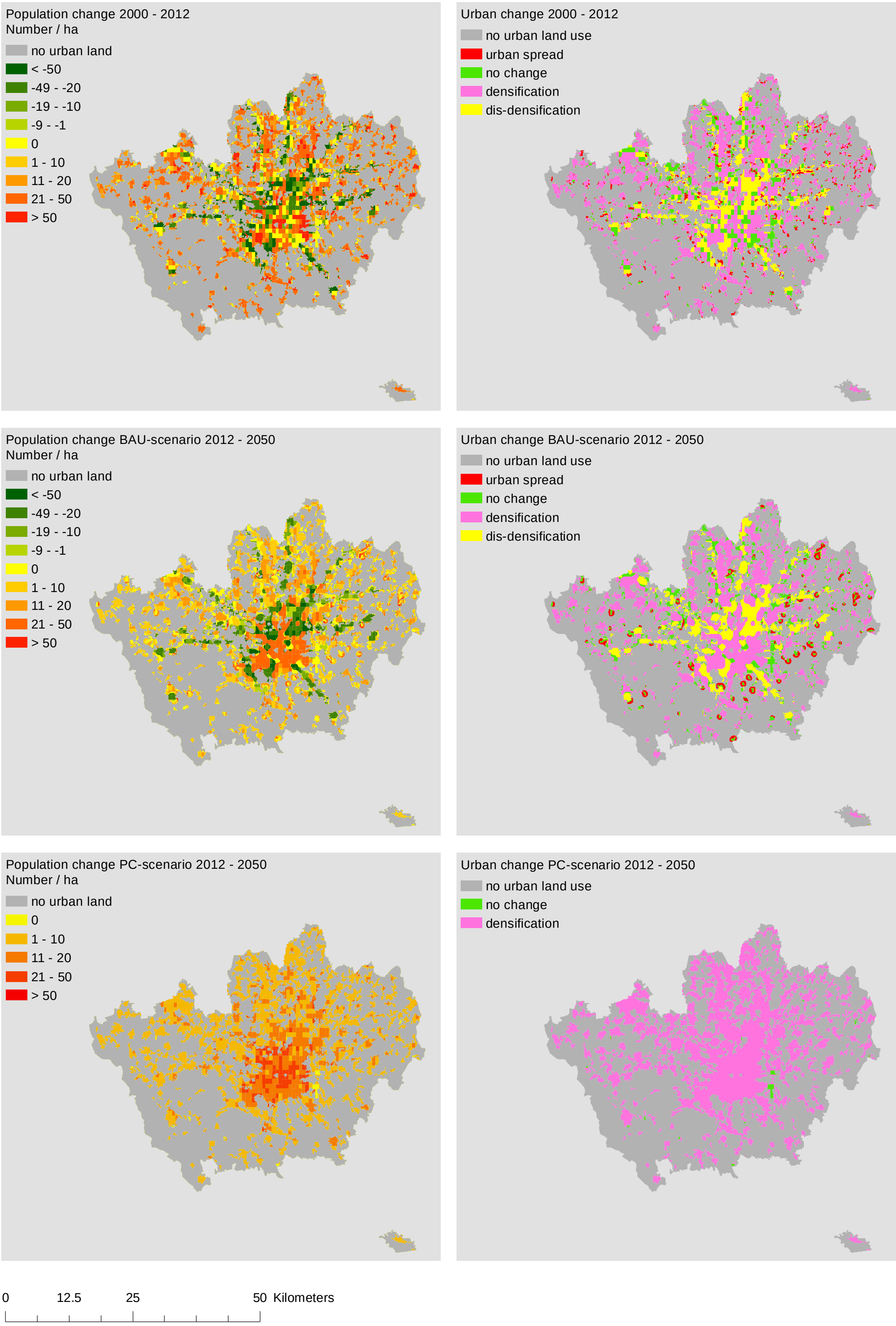

Figure 64: Population and urban change 2000-2012, BAU and PC2050 for Milan (cont'd)

IV.VIII.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 57. The total costs of PC2050 are 22,891 MEUR compared to 4,647 MEUR for BAU. The difference in costs between the scenarios is primarily due to the PC2050 scenario stipulating a high level of energy efficiency in buildings. Therefore in the modelling we assumed that a "deep" level of renovation was required for the majority of existing buildings. However, the table also shows that these costs would represent only 0.73% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 57: Investment costs for BAU and PC2050 Milan scenarios

Energy	MEUR (2016)
BAU	326
PC2050	1 228
Total costs for fossil free energy	3 983
Building renovations	
BAU	3 572
PC2050	19 645
Total costs (Energy and buildings)	
BAU	4 647
PC2050	22 891
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.15%
PC2050	0.73%

This translates into the following discounted costs as shown in Table 58 at various discounted rates from 2018 to 2050.

Table 58: Net costs for Milan scenarios investments at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	3 925	2 903	2 243
PC2050 Costs (NPV)	19 336	14 299	11 048

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCE AIR POLLUTION

The current costs of air pollution in Milan are estimated at 3 324 MEUR/year based on the 2010 cost of 4.7% of GDP for Italy provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 59. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050. The results show that there are significant net benefits under both BAU and PC2050, but that the benefits are almost double under PC2050 at 54,193 MEUR. This is a very significant amount and more than double the cumulative costs of PC2050.

Table 59: Net benefits for Milan scenarios (2018-2050) due to reduced mortality, and for no air pollution by 2050 (€ millions NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	30 868	29 552	28 301
PC2050	56 630	54 193	51 877
No air pollution by 2050	64 511	61 760	59 145

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 60Table 53. Potential jobs for renewable energy are modest with 540 ongoing jobs from operation and maintenance, but contribute to 38100 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 273,000.

Table 60: Benefits of Milan PC2050 scenario compared to BAU for Milan

Additional PC2050 Jobs	MCI	O&M
Renewable energy	38,100	540
Building renovation	273,000	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 23.3% lower. Currently (2013) Milan has 6.7% renewables in its energy mix and this is expected to increase to 33.1% in BAU (12% local and the rest in grid electricity) and 65.5% in PC2050 (40% local). Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 23.3% reduction of costs in PC2050 compared to BAU due to reduced energy consumption and a further reduction related to the 62% additional renewable energy.

In addition, the energy consumption of Milan is quite high in comparison to other cities at a per capita energy consumption of 26.4 GWh/year. This means there is good potential for further savings in PC2050 in addition to those modelled for improved energy efficiency in for example buildings and appliances.

IV.VIII.VI GAPS AND RISKS

The most prominent gaps for Milan under the current PC2050 scenario are as follows:

ENERGY

The projected per capita GHG emissions for PC2050 are low by current standards but the current gaps in actions result in total emissions of 1.9 million tCO_2e per year. The main cause of this is the inadequate supply of local renewable energy and a reliance on national grid supplied electricity (a large portion of which is still projected to be based on fossil fuels in 2050).

Nonetheless the quantities of renewable energy under the current PC 2050 are fairly challenging at 8962 GWh (or just under 7000 GWh not including waste). To further remove the reliance of grid electricity, an additional 7000 GWh would need to be supplied with renewable energy.

Hence, the role of increased energy efficiency should not be ignored to further reduce the overall energy use further. There exist further potential to reduce energy use in the residential and services sectors.

SOCIO-ECONOMIC

There is some concern with the poverty level which has increased to 21%, a very high share of Milan residents. This indicates a high level of inequality which has not been addressed in either scenario.

The cost benefit analysis showed that the PC2050 scenario would cost 14,299 MEUR (NPV with discount rate of 3%) compared to 2,903 MEUR for BAU. This represents only 0.15% of the cumulative GDP (from 2018 to 2050) for BAU and 0.73% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 54,193 MEUR (NPV with discount rate of 1%).

URBAN SPRAWL

Under BAU urban sprawl will increase by 40.4 km^2 due to a population increase of 315,000. Currently the potential for urban sprawl and increased densification is not adequately addressed within the PC2050 scenario. With a projected increase of 665,300 people by 2050 under PC2050, there is a need for the city's strategy to develop a clear series of milestones and strategies to ensure urban sprawl is contained. This obviously also has ramifications for energy use, infrastructure investment and transport.

CIRCULAR ECONOMY AND CONSUMPTION

The EE-MRIO footprint analysis suggests that despite local GHG emissions per capita decreasing by 81% under PC2050, the total footprint impacts of the city will only decrease by 6% to 11.9 tCO2e per capita. This clearly emphasises the need to address lifestyles and consumption and promote a more circular economy.

IV.IX ROSTOCK

IV.IX.I INTRODUCTION

In the BAU scenario Rostock grows steadily until 2030, where it then grew more slowly to reach a population of 215,000 in 2050. Overall energy use is only slightly lower than in 2010, partly due to the population growth, partly due to an increase in electricity use. The largest reduction of energy use took place in the transport sector due to an increase in the use of electric cars and to the improvement of public transport.

Rostock PC2050 is a compact city of short distances hosting a thriving green economy. Its 220,000 inhabitants have integrated new arrivals and together reached a good quality of life. In Rostock it is easy to live a healthy and calm life. Regional products are accessible and self-sufficiency is supported. A culture of care for old and young and alternative working time models have been established. Generations are mixing and living space is affordable and sustainable.

The city's Masterplan (Masterplan 100% Klimaschutz für die Hansestadt Rostock, Gicon, 2013) was used for the calculations, and the scenarios "Trend" used for BAU and "Ambitious" used for PC2050. However, the energy use was adjusted using the POCACITO population projections as these were viewed as more realistic. Rostock's Masterplan was calculated on an assumed decline in population. But according to Oxford Economics projections and consultation with the case study team, the population is now expected to increase, due to recent local and national increases. In addition we assume further renewable energy is developed to provide 60% of the transport energy.

The population is higher in the PC2050 scenario as we also used the IIASA SSP[10] national projections as a basis (IIASA, 2015). Under this scenario the national population decreases by 0.4% but urbanisation increases by 4.8%. However, it is also consistent with an approach of increased population density to reduce urban sprawl and regional travel.

IV.IX.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 61 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable).

It shows that for most indictors there is currently a positive trend which results in a positive improvement and outcome under BAU. However, for most indicators the improvement is even better under PC2050 and is projected as very positive.

In particular energy use and GHG emissions are improving under both scenarios but most markedly under PC2050 (this is further discussed in the following section).

Sustainable transport modes (such as walking, cycling and public transport) are also projected to continuing a positive trend. However, under PC2050 there is a marked improvement due to an increased reduction in the use of fossil fuels.

There is a large availability of green space which has increased in area from 2003 to 2012 and this looks likely to continue under both scenarios (further discussion is provided below in the eco-system services.

[10] We utilised the Shared Socio-economic Pathways research of IIASA as a basis for estimating differences in population and GDP for the BAU and PC2050 scenarios. Please see: Harris et al. (2015) for further explanation.

Some of the social indicators are not performing so well, such as for unemployment level and poverty level. This is of some concern and could be a focus future strategies, e.g. including the POCACITO Roadmap. Similarly, as is well documented in OECD countries, there is an aging population with levels of over 65 years likely to be over 35% in 2050. This creates its own challenges in terms of adequate workforce, economic performance and adequate care facilities.

Further analysis for additional indicators identified in the Sensitivity Model/PCIA workshops are provided in Table 62. This shows that there is potential to improve the building density under the PC2050 scenario and ensure an expansion of green spaces in order to also provide corridors for biodiversity.

Table 61: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Current trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Percentage	13 km2 (7.1%) of protected areas in 2008.	Unknown trend. But increasing green space (See below)	0	0
	Energy	Energy intensity variation rate	toe/EUR toe	0.0000551 – 0.0000452 (2005-2012) 277 100 – 282 040 (2005-2012)	-18% +1.8%	+	++
		Variation rate of energy consumption by sectors	Percentage	Industry/agriculture/services: 57% Transport: 14% Residential: 29% (for wider area only)	No data on trend	N/A (see below)	N/A
	Climate and Air Quality	Variation rate of carbon emissions intensity	ton CO_2/EUR ton CO_2	0.000177 – 0.000133 (2002-2012) 890 000 – 830 000 (2002-2012)	-25% (2002-2012) -7%	+	++
		Variation rate of carbon emissions by sector	ton CO_2	Industry, agriculture and services 44%, transport 19%, Residential: 37%	Unknown trend	N/A	N/A
		Exceedance rate of air quality limit values	Nº	O_3: about 9-6 (2010-2012) NO_2: about 1-0 (2010-2012) SO_2: about 1-0 (2010-2012) $PM_{2.5}$: 0 – 0 (2010-2012) PM_{10}: 33– 14 (2010-2012)	Improvements	+	++
	Transport and mobility	Variation share of sustainable transportation	Percentage	59% - 65% (1998-2008)	+6 points Major increase in bicycling (9-20%)	+	++
	Waste	Variation rate of urban waste generation	kg/person/year	Average decrease of 9% from 2006 to 2012	Decrease in all materials except metal	+	+
		Variation rate of urban waste recovery	Percentage	53% - 54% (2009-2013)	+1 point	+	+
	Water	Water losses variation rate	m^3/person/year	14.1 – 7.9 (2003-2012)	-44%	++	++

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Current trend	BAU 2050	PC 2050
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	No data available	No data available		
		Urban density variation rate	Nº/km^2	626 - 652 (2001-2011)	+4.1%	+	+
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person	23 066 – 30 746 € GDP/person	+34%	+	+
		Variation rate of GDP by sectors	Percentage	Agriculture/Industry/Services (2003-2012): 0.1%/15.9%/84% - 0.05%/18.5%/81.45%	Increase in industry	N/A	N/A
		Employment by sectors variation rate	Percentage	Agriculture/industry/services (2002-2012): about 1%/about 20%/79.6% - about 1%/about 20%/82.2%	Small increase in services	N/A	N/A
		Business survival variation rate	Percentage	No data	No data	N/A	N/A
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	About -1.7% - +0.2% (2002-2011)	General increase	++	++
		Indebtedness level variation rate	Percentage of city's GDP	About 4.9% - 6.3%(2003-2012)	Significant variations	++	++
SOCIAL	Research & Innovation dynamics	R&D intensity variation rate	Percentage	1.32% - 2.07% of value added (2003-2011)	Positive trend	+	+
	Social Inclusion	Variation rate of unemployment level by gender	Percentage	Male: average 16% (2003-2013) Female: average 15% (2003-2012)	Significant annual variations	0	0
		Variation rate of poverty level	Percentage	18.4%-20.3% (2005-2013)	+1.9 points	-	0
		Variation rate of tertiary education level by gender	Percentage	Male: 17.5% (2011) Female: 18.2%(2011)	No data on trend (too few data points)	ND	ND
		Variation rate of average life expectancy	Average Nº	77.1-79.9 (2002-2012)	+2.8 years	+	+

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Current trend	BAU 2050	PC 2050
	Public services and Infrastructures	Variation rate of green space availability	Percentage	41.5%-43.4% (2003-2012)	+1.9 points	++	++
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes, for reductions of CO2 emissions	-	N/A	N/A

Table 62: Additional POCACITO critical impact assessment (PCIA) indicator assessment

PCIA indicators	Current trend/situation	BAU	PC2050	BAU	PC 2050
Demographic trend	Currently there is an aging population in Rostock, with people older the 65 from 22.9% in 2011 to 25.4% in 2025.	The general aging trend is likely will continue. The share of over 60's in Germany was 26.7% in 2011 and is predicted to be 37.6% in 2050[11]. Hence a similar profile can be expected in Rostock, although Rostock may increase its attraction (research, industry, service sector job opportunities) for young professionals moving into the city.	See BAU.	-	-
Building density	Throughout Germany there has been a slight increase in inhabitants per m2. A widespread district heating network is established (60% of all households are supplied with heating and hot water) (see POCACITO-Factsheet).	See ecosystem service analysis. The push for an increased network for district heating network is supported by increased building density.	See ecosystem service analysis. The district heating network will be expanded to supply 80% of all households with heating and hot water.	0	0

[11] Source: Statistisches Bundesamt: Lange Reihen: Bevölkerung nach Altersgruppen, 13. koordinierte Bevölkerungsvorausberechnung: Bevölkerung Deutschlands bis 2060 http://www.bpb.de/nachschlagen/zahlen-und-fakten/soziale-situation-in-deutschland/61541/altersstruktur

PCIA indicators	Current trend/situation	BAU	PC2050	BAU	PC 2050
Sustainable housing	Most of the buildings from the German Democratic Republic (before 1990) have already undergone energy-related upgrades. Therefore the next stage of modernisations will take some time. There is a potential for efficiency improvement and for a transition from fossil to renewable energies (Masterplan).	Slight increase of energy use for hot water (e.g. wellness/spa) will be needed by 2020, and this trend is likely to continue. Energy for electricity (new consumer electronic appliances and elevators) will increase by 1% per year. The energy for heating will decline by 17% due to efficiency. (Masterplan).	On top of the BAU scenario additional efficiency efforts (new and efficient devices, etc.) will be accompanied with a focus on changing consumer behaviour to reduce the overall energy consumption slightly by 0.8% in total. Environmentally friendly behaviour of residents will be inspired by different measures (education, campaigning, etc.). (Masterplan)	+	++
Green space and corridors	There is a high percentage of green space that has increased from 2003 to 2012 from 41.5% to 43.4%.	Following recent trends a projected rise in population will result in an increase in urban land of 5.7 km^2, which could impinge on green space (see eco-system services analysis). Despite a high percentage of green space, the emphasis on green corridors that allow and increase ease of passage for wildlife could increase and should be a future consideration.	Despite a high percentage of green space, the emphasis on green corridors that allow and increase ease of passage for wildlife could increase and should be a future consideration.	+	+
Budget deficit	The total budget deficit per inhabitant in Rostock is high, but consolidated since the year 2010 by ca. 1.900 EUR per capita (Statistisches Jahrbuch 2015),	This variable influences the possibility of having financial capacity to invest in the future and into transition activities	This is difficult to project for 2050 with the available data, but a positive outlook can be expected under the PC2050 scenario.	0	+

IV.IX.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

As described above, for simplicity and consistency the energy use projections of the scenarios follow the Masterplan projections, but are adjusted for a slight increase in population projected in the POCACITO scenarios.

Due to limited data, the analysis has focussed on heating, electricity and transport, but does not include waste treatment. A comparison of the scenarios is provided in Table 63, which highlights that under BAU electricity consumption is expected to rise considerably and even under PC2050 is not expected to fall appreciably (this does not include electricity for transport, which is included under transport (see Table 64).

Table 64 shows the energy profile for the two scenarios, showing that PC2050 would have 22.2% lower energy use than BAU. In both scenarios the main energy use occurs due to heating. In our calculations we have assumed the additional heating energy needed other than renewable is provided by gas (energy sources are not discussed in the Masterplan. This may be the reason that the associated GHG emissions are slightly lower in our calculations than for the Masterplan).

Table 63: Comparison of energy use of 2010, BAU and PC2050 scenarios for Rostock

	Year / Scenario		
Energy use	**2010**	**BAU**	**PC2050**
Heating	2010	1904	1540
Electricity consumption	773	1094	741
Transport	993	604	524
Total	3776	3603	2805

Table 64: The energy use profile of Rostock for both scenarios

	BAU2050		PC2050	
	GWh	%	GWh	%
Renew heat	668	18.5%	668	23.8%
Gas	1236	34.3%	872	31.1%
Heat total	**1904**	**52.9%**	**1540**	**54.9%**
Renew	545	15.1%	545	19.4%
Grid	549	15.3%	196	7.0%
Electricity total	**1094**	**30.4%**	**741**	**26.4%**
Renewable	60	1.7%	315	11.2%
Fossil	544	15.1%	210	7.5%
Transport total	**604**	**16.8%**	**524**	**18.7%**
Total	**3603**	**100.0%**	**2805**	**100.0%**

The electricity use in the PC2050 is reduced due to a major improvement in energy efficiency and policies that promote energy efficient appliances. However, some of the electricity is now shown under transport (renewable energy) where we assume that 60% of the transport is powered by electricity.

The transport modal share is expected to be:

- Walking: 4%
- Bike: 12%
- Public transport: 49%
- Private transport: 35%

However, this suggests that in fact the total transport energy could be somewhat lower if this modal balance is reached, compared to the one above based on the Masterplan data.

The associated carbon emissions profiles for the scenarios are shown in Figure 65 with 693,000 tCO_2e for BAU and 346,700 CO_2e for PC2050. This corresponds to per capita emissions of 3.22 tCO_2e and 1.58 tCO_2e respectively.

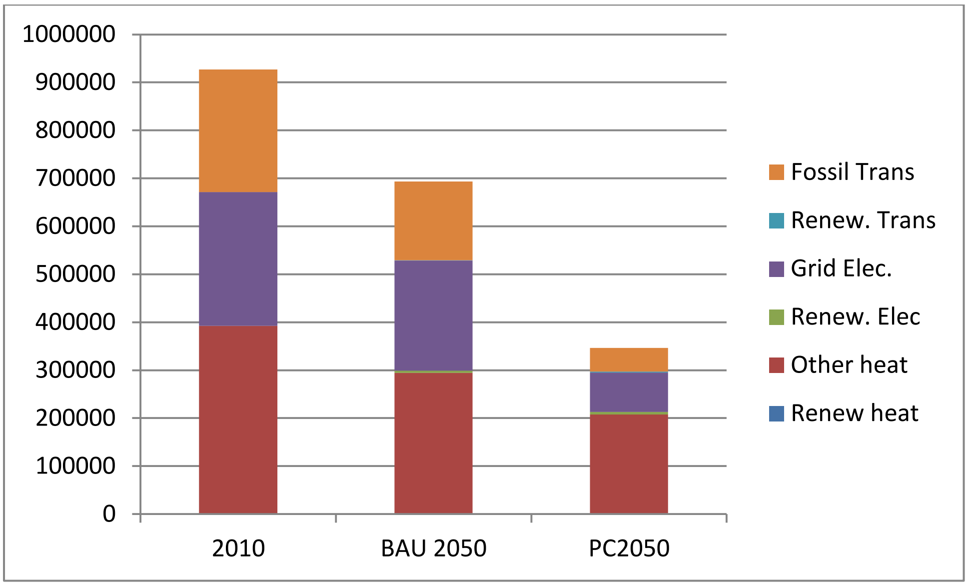

Figure 65: The projected GHG emissions in 2050 scenarios for Rostock

The figure highlights the importance of the choice of heating fuel in buildings and fossil fuels in transport, where there exists potential for further reductions.

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. In Figure 66, the direct GHG emissions that occur in the city are compared with the indirect emissions. It shows that whilst direct emissions decrease in BAU and even more so in PC2050, the large increase in indirect emissions mean that total emissions increase in both scenarios. This is related to the projected increase in GDP and the expected associated increases in consumption. Hence, although by 2050 we would expect an improvement in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase.

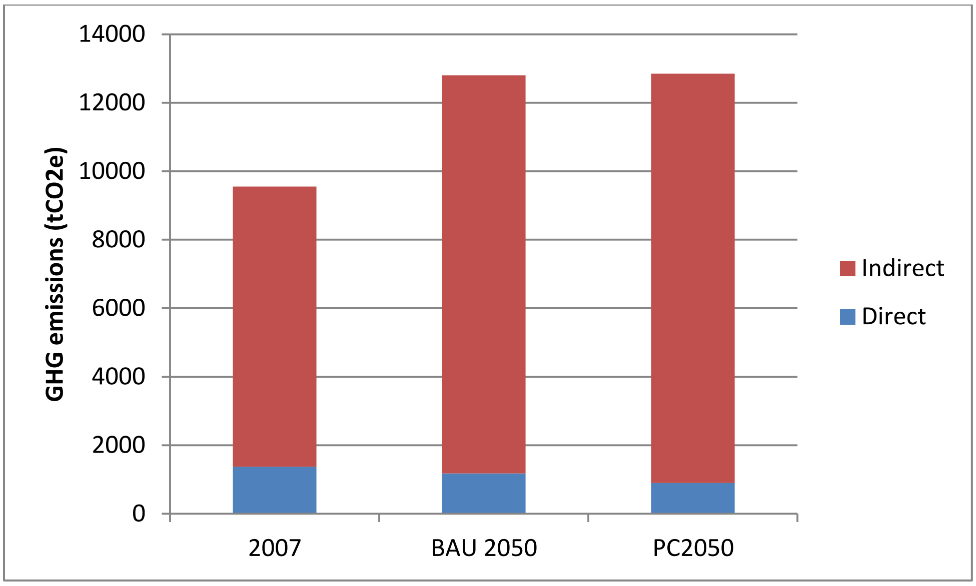

Figure 66: Direct and indirect GHG emissions for Rostock for 2007, BAU and PC2050

Figure 67 compares the contribution of the product groups to the GHG emissions for each scenario. It shows that in both BAU and PC2050 "other goods and materials" increase considerably, whereas "electricity and heat fuels" decreases in both scenarios, and especially in PC2050. There are also increases for "other services", "transport fuel, equipment and services", "food" and "housing" in both scenarios.

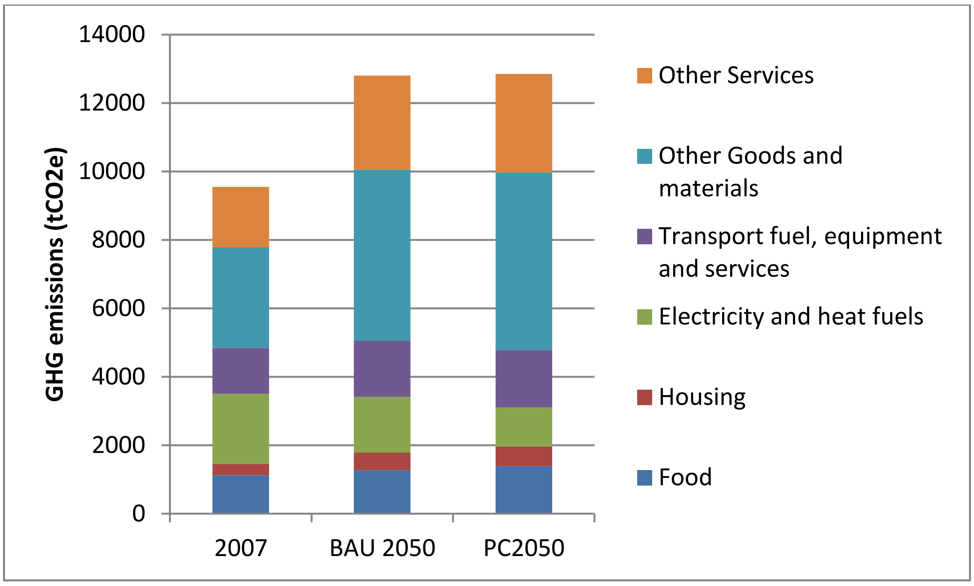

Figure 67: The contribution of product groups to the GHG footprint for 2007, BAU and 2050 for Rostock

The other impacts of photochemical oxidation, acidification and eutrophication show a similar rise as shown in Table 65. A noticeable difference for PC2050 is the larger increases in acidification and eutrophication, which seems to be linked to transport in the case of acidification and food consumption for eutrophication.

Table 65: Environmental impacts for 2007 and the scenarios for Rostock

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2eq)	9548.3	12802.1	12842.8	134%	135%
Photochemical oxidation (kg ethylene eq)	2.3	2.9	3.0	125%	129%
Acidification (kg SO2 eq)	36.2	45.3	56.1	125%	155%
Eutrophication (kg PO4--- eq)	9.2	11.2	14.5	123%	158%

Figure 68 examines these additional impacts further by comparing the contribution of the product groups for 2007 and for the scenarios. It highlights that the contribution of transport to the acidification impact is more significant in PC2050. This could be due to an increase in electric vehicles and their production. The profile for photochemical oxidation is fairly similar for 2007 and both scenarios and eutrophication is dominated by food as one would expect due to the high use of fertilisers in production.

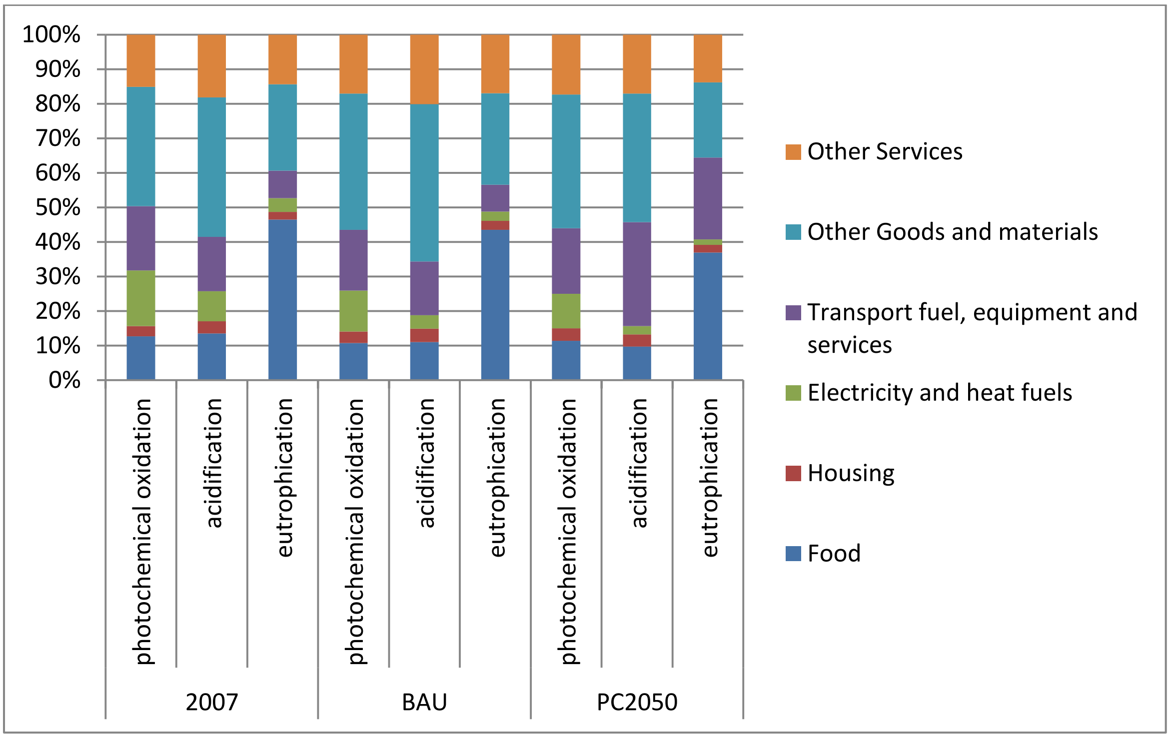

Figure 68: Comparison of other impacts for Rostock for 2007, BAU and PC2050

IV.IX.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Rostock's population increased by 11,300 or 6.2 % and urban land increased by 5.5 km² or 11.6 % (see Table 86, Annex II). According to the BAU scenario, until 2050 population will increase by another 11,800 or 6.1 % and urban land will increase by 5.7 km² or 10.8 % on the account of non-urban land. According to the PC scenario, the population will increase by 16,600 or 8.6 % by 2050. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Rostock, between 2000 and 2012, urban spread accounted for 5.5 km² with a population increase of 9,487. In the same period, urban areas with no population change accounted for 25.2 km². Urban areas with population densification accounted for 12.2 km² and a population increase of 37,699. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 10.0 km² and a population decrease of 36,169. In summary, the development from 2000 to 2012 was characterized by a total population increase, a considerable urban spread, and consequently loss of non-urban land and at the same time by densification (population increase) in some urban areas and a dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 5.7 km² with a population increase of 9,924. Urban land with no population change accounts for 30.5 km² while urban areas with a population increase (densification) account for 12.3 km² and a population increase of 39,315. Urban areas with a population decrease (dis-densification) account for 10.1 km² and a population decrease of -37,487. In summary, the BAU scenario indicates, that the expected population increase until 2050 will lead to both urban spread and thus a loss of non-urban land while at the same time large parts of the urban land will be characterized by population increase (densification) and other parts by population decrease (dis-densification).

Spatial patterns of urban change

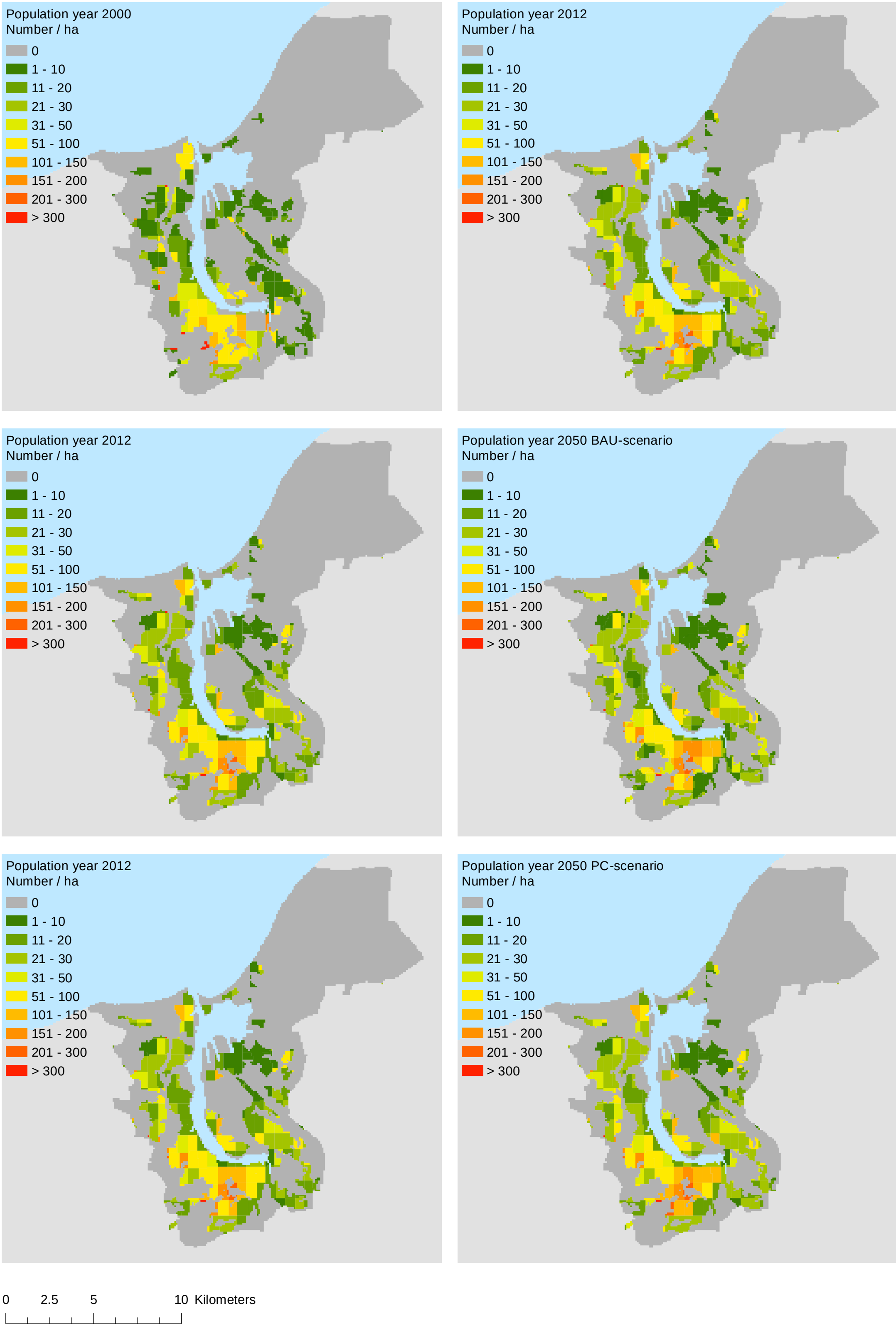

Figure 69 and Figure 70 show spatial patterns of historic and projected urban change for Rostock. Between 2000 and 2012 parts of the city centre were characterised by population decreases (dis-densification). Large areas, particularly along the harbour areas, were characterised by no population change. Population increase (densification) was most pronounced in the suburbs. Urban spread took place at the fringe of the city. For the BAU scenario, patterns of urban development until 2050 are characterised by further population decreases (dis-densification), particularly in the central parts of the city. Densification (population increase) is taking place in the suburbs and urban spread in the outskirts of the city. For the PC scenario, population increase is largest in the central part of the city. Most of the city is characterised by population densification, except for some harbour and technical sites, which did not contain any population in 2012.

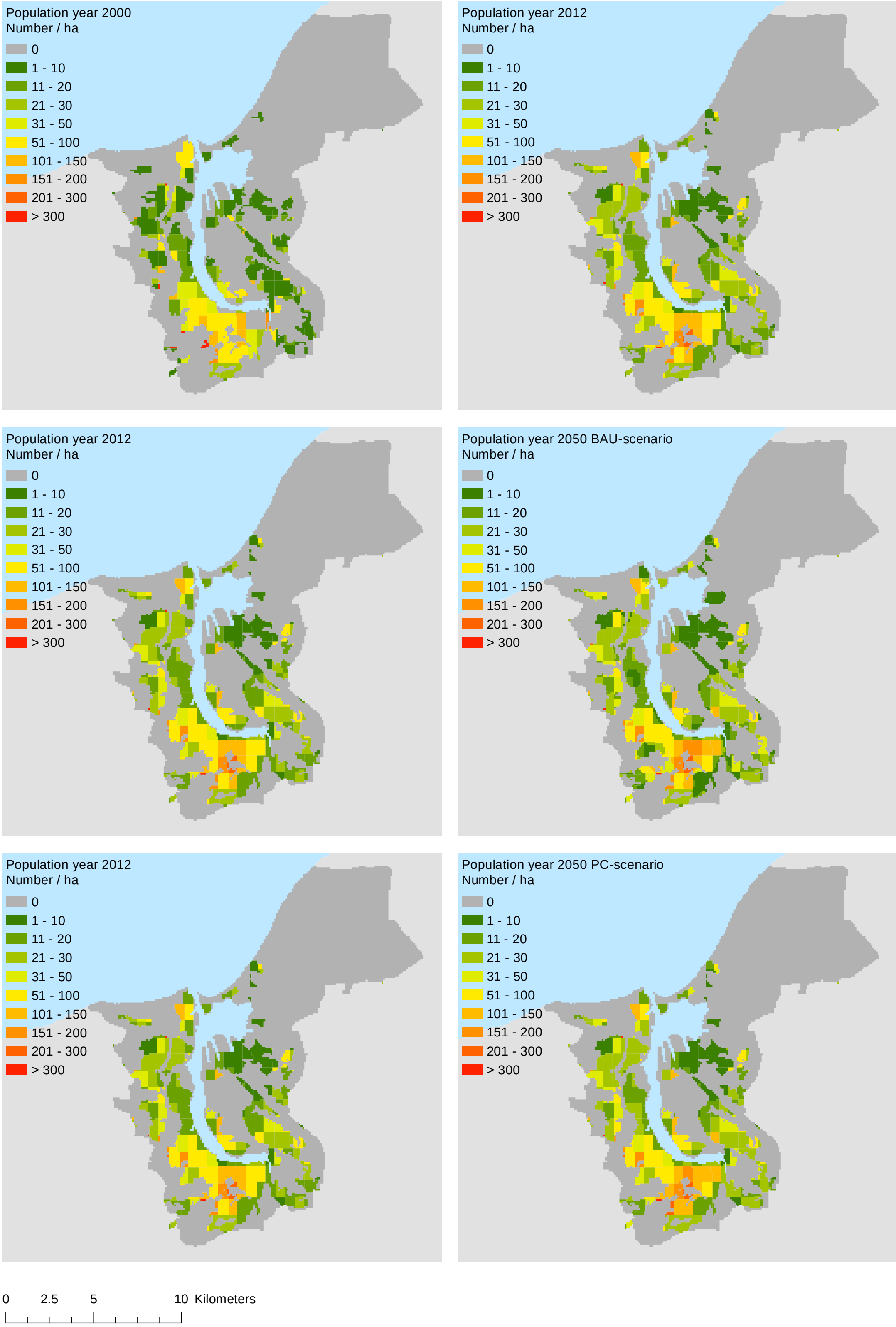

Figure 69: Population and urban change 2000-2012, BAU and PC2050 for Rostock

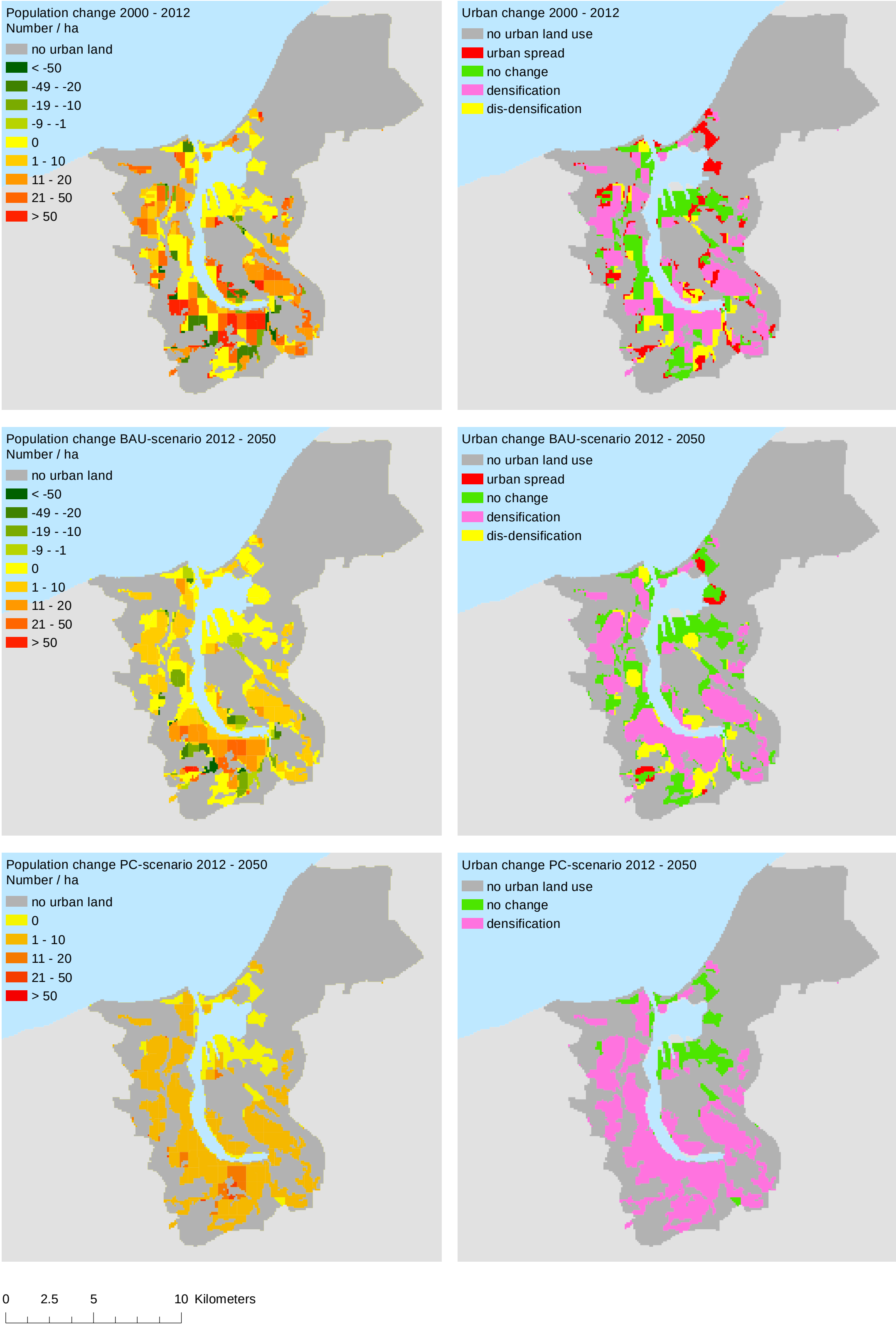

Figure 70: Population and urban change 2000-2012, BAU and PC2050 for Rostock (cont'd)

IV.IX.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 66. The total costs of PC2050 are 1,737 MEUR compared to 591 MEUR for BAU. However, the table also shows that these costs would represent only 0.63% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 66: Investment costs for BAU and PC2050 Rostock scenarios

Energy	MEUR (2016)
BAU	255
PC2050	358
Total costs for fossil free energy	844
Building renovations	
BAU	591
PC2050	1 379
Total costs (Energy and buildings)	
BAU	846
PC2050	1 737
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.34%
PC2050	0.63%

This translates into the following discounted costs as shown in Table 67 at various discounted rates from 2018 to 2050.

Table 67: Net costs for Rostock scenarios investments at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	715	528	408
PC2050 Costs (NPV)	1 467	1 085	838

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCE AIR POLLUTION

The current costs of premature deaths from air pollution in Rostock are estimated at 298 MEUR/year based on the 2010 cost of 4.5% of GDP for Germany provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 68. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050. The net benefits of the PC2050 scenario are 2,179 MEUR compared to 808 MEUR under BAU, but this falls some way short of the potential available if air pollution was reduced to zero by 2050. However, it means that the potential benefits of PC2050 from reduced premature deaths alone are more than the cost of PC2050 at 1,737 MEUR.

Table 68: Net benefits for Rostock scenarios (2018-2050) due to reduced mortality, and for no air pollution by 2050 (MEUR NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	844	808	775
PC2050	2 276	2 179	2 087
No air pollution by 2050	4 957	4 750	4 552

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 69. Potential jobs for renewable energy are modest with 61 ongoing jobs from operation and maintenance, but contribute to nearly 3,424 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 13,398.

Table 69: Benefits of Rostock PC2050 scenario compared to BAU for Rostock

Additional PC2050 Jobs	MCI	O&M
Renewable energy	3424	61
Building renovation	13398	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 22.2% lower. Currently (2010) Rostock has 5.3% renewables in its energy mix and this is expected to increase to 45% in BAU and 59% in PC2050 (with 35% and 54% respectively of this being supplied locally). Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 22.2%% reduction of costs in PC2050 due to reduced energy consumption and a further reduction related to the 14% additional renewable energy.

IV.IX.VI GAPS AND ANALYSIS

Under the BAU scenario Rostock performs quite well, but improves considerably under the PC2050 scenario. It approaches post-carbon status with 1.58 tCO_2e under the PC2050 scenario, which corresponds to a total reduction of 62.6% on 2010 emissions (despite a projected increase in population). However, there is considerable room for improvement under the current PC2050 scenario in order to reach the goal actual post-carbon status remains elusive and there is still potential for improvement.

The major components where improvement can be made are heating and the electricity supply.

- Gas for heating use is the major contributor of GHG emissions. Firstly, the energy demand for heating could be improved by increased action on energy efficiency measures such as increased passive housing and improvements in insulation. Secondly, there is a need to move away from gas (and other fossil fuels) as a heating source to more sustainable sources such as biomass, geothermal or renewable electricity. Hence the policy of heating supplied via district heating networks despite being more efficient, are not significantly lower in GHG emissions unless sustainable sources are utilised.
- Despite the grid supplied electricity only being 7% of the total energy it makes a significant contribution to the GHG emissions. This is because Germany's grid electricity in 2050 is projected to still use some fossil fuels.

With 40% of the transport energy still supplied by fossil fuels there is scope for improvement by further promoting sustainable transport, banning fossil fuelled transport within the city and/or increased action and support for electric vehicles.

In the PC2050 scenario roof space has been fully utilised for solar energy (providing about 100 GWH or around 4%), and therefore other sources, are likely to be required, unless green space is impinged on to provide solar farms. Other options are to identify external sources (external solar farms) or offshore wind.

The cost-benefit analysis showed that the PC2050 scenario would cost 1,085 MEUR (NPV with discount rate of 3%) compared to 528 MEUR for BAU. This represents only 0.34% of the cumulative GDP (from 2018 to 2050) for BAU and 0.63% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 2,179 MEUR (NPV with discount rate of 1%).

THE CHALLENGE OF SUSTAINABLE CONSUMPTION AND LIFESTYLES

An increased challenge for post-carbon cities is highlighted by the results of the EE-MRIO footprint analysis. The analysis emphasises that despite efforts to reduce GHG emissions within the city boundaries, the total footprint of the city is likely to increase. Whilst the territorial GHG emissions are reduced by 60% under PC2050 to 1.6 tCO_2e per capita, the footprint emissions are projected to increase by 35% to 12.8 tCO_2e per capita (from 9.5 tCO_2e per capita in 2007). This is due to increased spending and consumption that result from an increased GDP per capita.

Hence policies and projects that foster and support the circular economy through reuse, repaired refurbishment and remanufacturing are required. However, real progress here is only likely to be made with national policy support that facilitates the restructuring of the supply chain, so that products are produced, repaired and remanufactured locally. This also has the potential to increase local jobs.

OTHER CONSIDERATIONS

Under BAU there is a further encroachment of urban land which will increase by 5.7 km^2 or 10.8% of non-urban land. This is opposed to the PC2050 where we have assumed that there will be densification and no further increase in the urban area.

In BAU the major urban development and spread occurs on the outskirts of the city with a reduction in population density. No negative effects on the other KPI's or variables identified in the Sensitivity Model process are foreseen along a post carbon path.

Similarly under PC2050 the green areas and eco-system services retain their current status. In addition, there would be some improvement in the health of flora and fauna due to reduced pollution uptake by plants and animals through reduced air pollution and urban run-off. However, there is potential to improve biodiversity through improving and maintaining green corridors that connect protected areas and allow movement of fauna among them. Improving this connection between wildlife and city, would potentially result in associated benefits on health and well-being within the city, in a similar way that green space have been shown to.

IV.X TURIN

IV.X.I INTRODUCTION

Under the BAU scenario Turin in 2050 has recovered from a three decade long decline to a path of positive economic growth. Despite an increase in population to 1.1 million from 902,000 (2013) the energy use of the city has declined. Car use is still high and represents a larger modal share than public transport. However, electric vehicle use is increasing. Many buildings have undergone energy efficiency renovations and solar cells are common, resulting in lower energy use in the residential sector despite a population increase.

In PC2050 Turin has expanded to 1,215,000 people whilst total energy use has been reduced 30%. However, progress in local renewable energy has been slow and this only account for 25% of the energy. Fossil fuel transport still accounts for 50% of the transport energy and combustible fuels still provide 45% of Turin's total energy.

Turin is part of the Covenant of Mayors for Climate & Energy initiative and as such has produced the Turin Action Plan of Energy. This was the primary source of energy data and provided detailed data on energy and GHG emissions for 1990 and 2005, with targets for 2020. Since a number of initiatives have been put in place as part of this plan, the targets for 2020 were used as a starting point for the energy and GHG projections. In addition, the action plan shows that the energy use and GHG emissions have already been reduced from 1990 to 2005, although part of this may be due to declining industry.

IV.X.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 70 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable). It shows a moderately positive trend for most indicators, although three of the indicators are negative under BAU. Firstly, transport is negative under BAU due to the sustained high use (45.1% in 2010) of the car with a small increase from 2000 to 2010. Unemployment is also a concern under BAU, although it has also not been specifically addressed within the PC2050 scenario. The poverty level is also very high at 21% in 2012 having risen from an already high level of 18.4% in 2004. Since this has also not been addressed under the PC2050 scenario, this is also projected as negative under PC2050. For other indicators the projection is for primarily moderate progress under BAU and PC2050, with few indicators achieving "likely very positive" progress even under PC2050. The other indicators are discussed briefly discussed below.

ENVIRONMENT

The level of ecosystem protected areas in Turin has been held constant at 4.55% during the last years. The level can be considered as relatively low and since no measures have been noted under either BAU or PC2050, this is assumed to remain unchanged. The recent improvement in air quality can be expected to continue in both the BAU scenario and in the PC scenario due to new measures such as a congestion charge and updated public transport.

Current trends show a small increase in car use, mainly on behalf of public transportation. In the BAU scenario this trend can be expected to change due to a number of different measures such as congestion charge and updated public transport. Similar measures will be made in the PC scenario with a similar result.

There are also positive implications for waste with waste generation declining and waste recovery increasing markedly. However, no additional measures are noted under PC2050. For both BAU and PC2050 scenarios several measures have been suggested to increase the energy efficiency of buildings. Hence, a substantial increase in passive and carbon neutral buildings can be expected.

ECONOMIC

Despite recent challenges for the industry sector the overall trend for sustainable economic growth is positive. This is expected to continue under both BAU and PC2050, with a potential move to green technology under PC2050. Despite a slight increase in the R&D intensity rate the level of 1.88% is still fairly low, and since we have been unable to find any measures to improve the performance of this indicator in the future, the projections are for only moderate progress for both scenarios.

SOCIAL

There are some concerns within the social indicators as noted above in terms of unemployment and poverty, which have not been specifically addressed in the PC2050. On the positive side, levels of tertiary education are rising, and so are life expectancy and green space availability under PC2050.

Table 70: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Turin

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	2008 2012	4.55% 4.55%	Constant	0	0
	Energy	Energy intensity variation rate	Toe/MEUR 2001-2011 Toe (000)	86.5-63.05 4861-4294	-27% -11.7%	+	++
		Variation rate of energy consumption by sectors	Percentage Total 2005-2010= 4861-4294 KToe (11.7% decrease)	2003-2012 % Residential 34.8-39.4 Services 9.6-12.4 Agriculture 0.9-1.3 Transport 26.0-24.8 Industry 28.7-22.1	Residential +0.1% Services +14% Agriculture 18% Transport -15% Industry -32%	N/A	N/A
	Climate and Air Quality	Variation rate of carbon emissions intensity	2002-2011 KTon CO_2 KTon CO_2/M euro	(Province level) 14945-11852 0.26-0.17	-20.7%% -35%	+	+
		Carbon intensity per person	Population (Province) : 2002: 2,171,000 2013: 2,294,000	6.88 t/cap 5.16 t/cap	-25,0%	+	+
		Variation rate of carbon emissions by sector	Ton CO_2 Total 2005-2010 14945-11852 KTon (20.7% decrease)	2002-2011 Total (down 20.7%) Residential & Services 41-47% Industry: 31-24% Transport: 27-28% Agriculture: 1-1%	2002-2011 Residential &Services +6% Industry: -7% Transport: +1% Agriculture: 0%	+	+
		Exceedance rate of air quality limit values	Nº of days 2004-2013 PM10 NO2 O3	PM10 213-126 NO2 68-31 O3 74-39	PM – 41% NO2 -44.5% O3 – 47.3%	++	++

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
	Transport and mobility	Variation share of sustainable transportation	Percentage (2000-2010)	(2000-2010) Car: 44.1-45.07 Public transportation: 25.76-23.32 Bikes & motorbikes 3.2-3.28 Foot: 26.66-27.83 Other: 0.27-0.49	Car: +0.97% Public transportation -2.44% Bikes & motorbikes +0.08% Foot +1.17% Other +0.22%	-	+
	Waste	Variation rate of urban waste generation	Kg/person/year	2000: 536.7 2012: 505.5	-5.8%	+	+
		Variation rate of urban waste recovery	Percentage	2002: 24% 2012: 43%	+19%	++	++
	Water	Water losses variation rate	m^3/person/year	2003: 32% 2012: 22%	-10%	+	+
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	2010: 0.2% 2014: 1%	+500%	+	+
		Urban density variation rate (population)	Buildings/ km^2 (2001-2011)	2001: 352.6 2011: 490.49	+ 39%	+	+
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person	2000: 26 500 Euro 2011: 28 900 Euro	+9%	+	+
		Variation rate of GDP by sectors	Percentage 2000-2011	Agriculture: 0.8%-0.6% Industry: 29.9%-25.4% Services: 69.3%-74%	Agriculture: -0.2% Industry: -4.5% Services: +4.7%	N/A	N/A
		Employment by sectors variation rate	Percentage 2000-2011	Agriculture: 1.5%-1.5% Industry: 33.4%-26.8% Services: 65.1%-71.7%	Agriculture: 0 Industry: -6.6% Services: +6.6%	N/A	N/A
		Business survival variation rate	Percentage	2008-2010	8.9%-9.7%	+	+
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	No data	No data	ND	ND
		Indebtedness level variation rate	Percentage of city's GDP	2004=3.4% 2009=3.4% 2014=4.04%	+19%	0	0

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	2003: 1.57% 2011: 1.88%	+0.31%	+	+
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage 2004-2013	Male / Female 2004: 5.1% / 7.4% 2013: 11.1% / 11.7%	Male / Female +6 / +4.3%	-	0
		Variation rate of poverty level	Percentage	2004: 18.4% 2012: 21%	+2.6%	-	-
		Variation rate of tertiary education level by gender	Percentage (2004-2013)	Men: 7.9%-12.7% Women: 11.0%-12.4%	Men: +4.8% Women: +1.4%	+	+
		Variation rate of average life expectancy	Average Nº (2003-2012)	Male / Female 2003: 77.2 / 82.9 2012: 80.0 / 84.6	Male: +5.7 Female: +4.6	++	++
	Public services and Infrastructures	Variation rate of green space availability	Percentage	2000-2009 13.7%-16.4%	+2.7%	+	++
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes		N/A	N/A

IV.X.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

Figure 71 compares the energy consumption of 2005 with the BAU and PC2050 scenarios. It shows that in the PC2050 scenario the energy consumption of almost 13,000 GWh per year is only slightly less than for BAU. However, under PC2050 the population has increased more than for BAU, resulting in an energy consumption per capita of 10.7 MWh for PC2050 compared to 12.9 MWh for BAU. For both scenarios this is a significant decrease from the 2005 level of 20.9 MWh per capita.

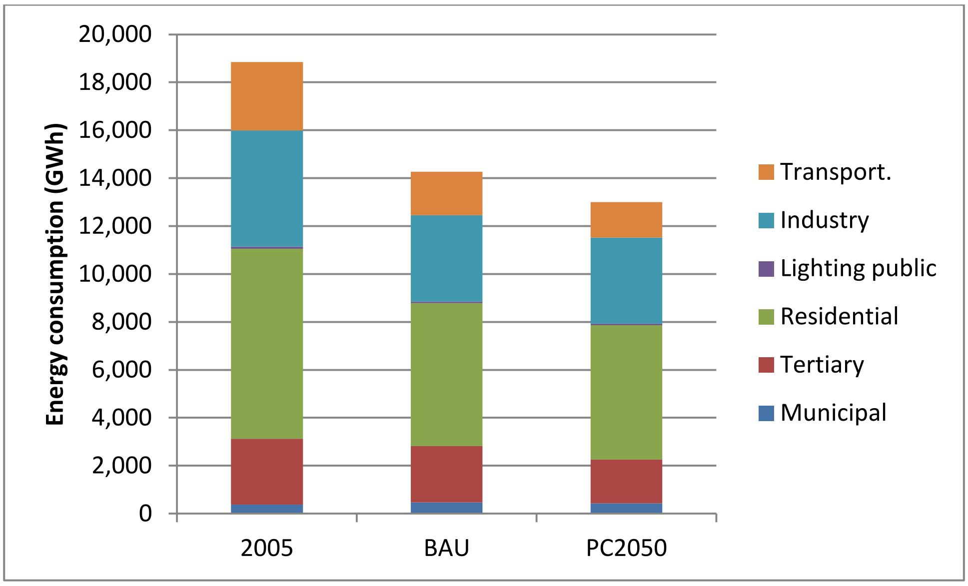

Figure 71: Final energy consumption comparison for scenarios and 2005 in Turin

Under BAU there is only 5% of local renewable energy. This may be a low estimation considering the existence of the Turin Action Plan for Energy. However, since no up to date data was available on any progress since 2005, then the trend from 1990 to 2005 was the basis of the calculation and the goal for 2020 could not be assumed to be achieved automatically. Due to weak actions and milestones that were derived in the stakeholder workshops, PC2050 was only modelled on the basis of a 25% share of renewable energy on overall energy use.

Figure 72 and Figure 73 compare the base year with the projected total GHG emissions and GHG emissions per capita, respectively. These figures show that despite Turin being projected to not achieve absolute carbon neutrality under either scenario, under PC2050 the GHG emissions have dropped to 2.3 tCO_2e/year per capita compared to the 2005 figure of 5.6 tCO_2e/year per capita.

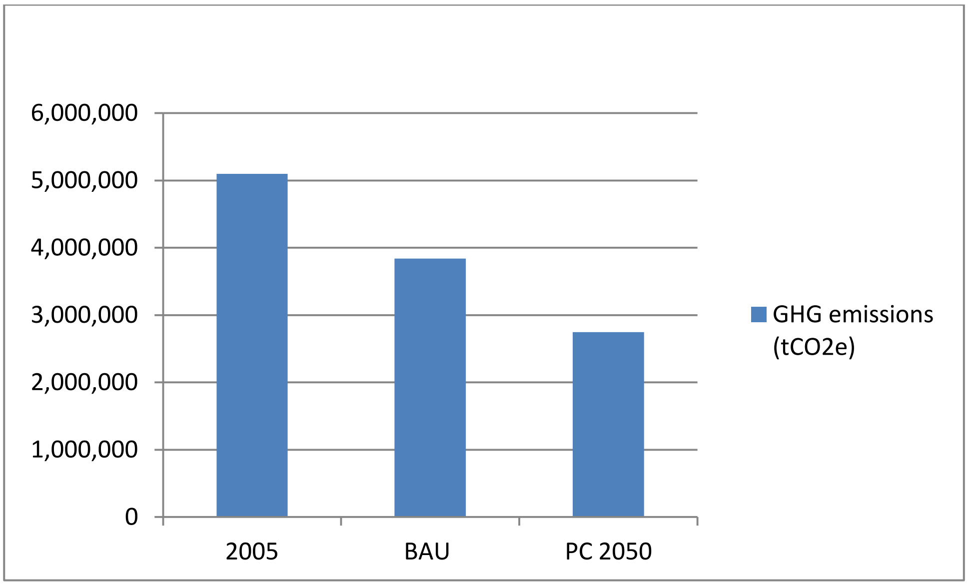

Figure 72: GHG emissions for Turin Municipality for 2005, BAU and PC2050

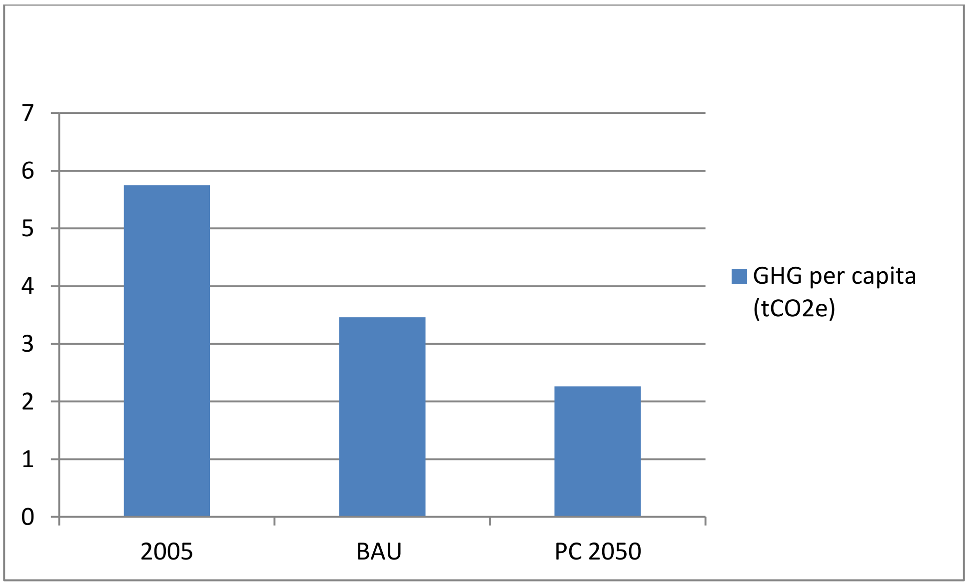

Figure 73: GHG emissions per capita for Turin Municipality for 2005, BAU and PC2050

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. Figure 74 compares both the overall GHG footprint for the scenarios with 2007, as well as the direct and indirect GHG emissions. It shows that direct emissions decrease in both scenarios, and more so for PC2050. However, the indirect emissions actually increase slightly in the PC2050 scenarios due to increased consumption, meaning the overall footprints of BAU and PC2050 are very similar. Hence although by 2050 we would expect an improvement in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase.

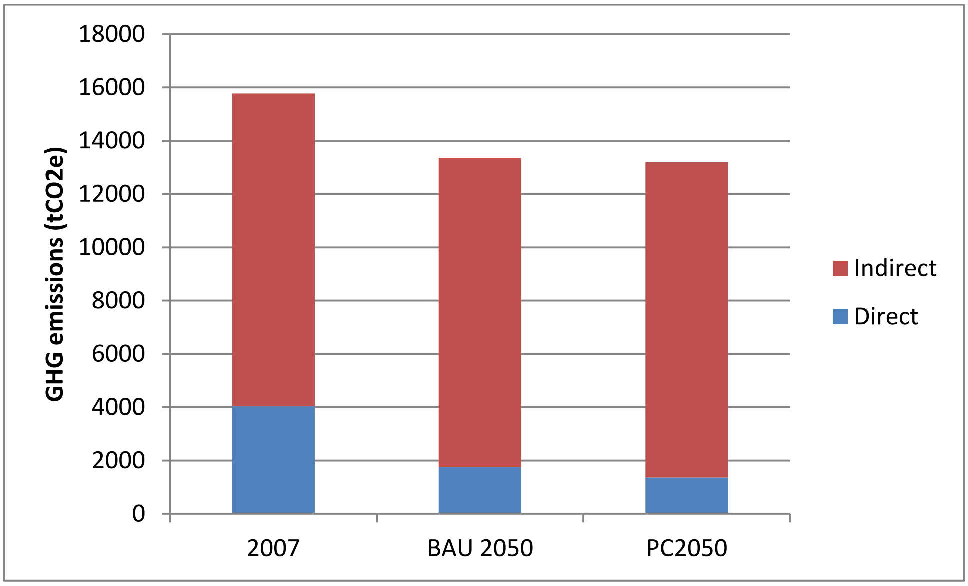

Figure 74: Direct and indirect GHG emissions for Turin for 2007, BAU and PC2050

Figure 75 compares the contribution of the product groups to the GHG emissions for each scenario. It shows that the contribution of "transport fuel, equipment and services" and "electricity and heat fuels" decrease in both scenarios, with transport decreasing considerably in PC2050. In the PC 2050 scenario the contribution of electricity is larger than in BAU which is not an accurate reflection of the scenarios, and is most likely due to a fault within the modelling and underlying database.

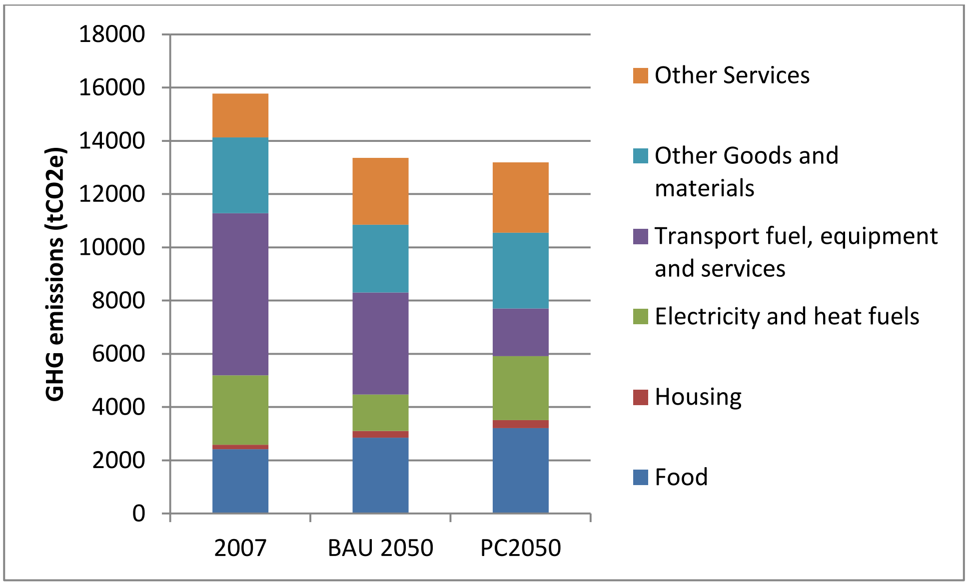

Figure 75: The contribution of product groups to the GHG footprint for 2007, BAU and 2050

The other impacts of photochemical oxidation, acidification and eutrophication show a similar decrease as shown in Table 71. A noticeable difference is the increase in eutrophication which is due to the increasing food spending.

Table 71: Environmental impacts for 2007 and the scenarios for Turin

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2 eq)	15775.1	13361.5	13185.5	-15%	-16%
Photochemical oxidation (kg ethylene eq)	3.6	3.1	2.8	-15%	-23%
Acidification (kg SO2 eq)	55.1	49.1	50.4	-11%	-8%
Eutrophication (kg PO4--- eq)	12.2	12.5	13.4	3%	10%

Figure 76 examines these additional impacts further by comparing the contribution of the product groups for 2007 and the scenarios. It shows that for photochemical oxidation the contribution of transport has decreased in both scenarios, particularly in PC2050. The contributions for acidification are quite similar in 2007 and the scenarios, although in PC2050 transport is less significant and “other goods and materials” is more significant. Eutrophication is dominated by food as one would expect due to the high use of fertilisers in production.

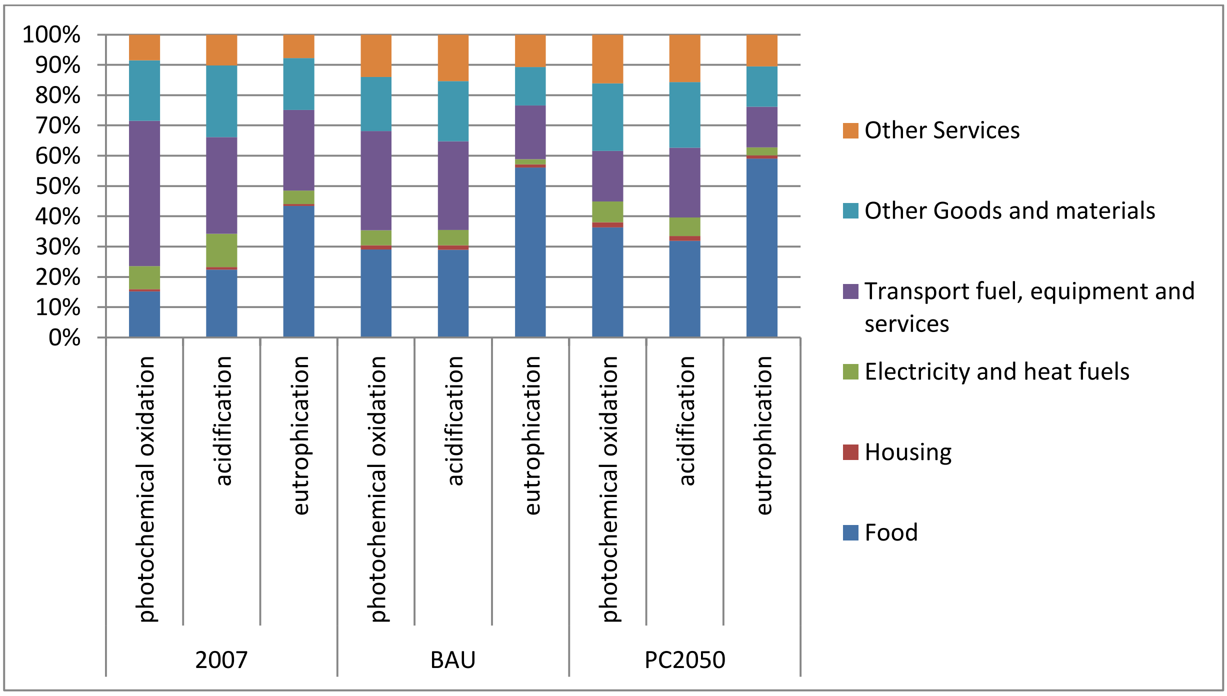

Figure 76: Comparison of other impacts for Turin for 2007, BAU and PC2050

IV.X.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Turin's population increased by 186,100 or 9.7 % and urban land increased by 65.6 km² or 16.7 % (see Annex II, Table 86) (it should be noted that these are calculated for the Province and not the municipality and that the provincial area of 6829 Km^2 is the fourth largest in Italy, spanning from the French border on the Alpine divide to the flatlands of the Po valley; however the vast majority of the population lives in Turin's metropolitan area). According to the BAU scenario, by 2050 the provincial population will decrease by 29,000 or 1.4 %. However, urban land will still increase by 32.6 km² or 7.1 % on the account of non-urban land. According to the PC scenario, population will by 2050 increase by 203,300 or 9.6 %. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Turin, between 2000 and 2012, urban spread accounted for 65.6 km² with a population increase of 152,127. In the same period, urban areas with no population change accounted for 66.8 km². Urban areas with population densification accounted for 247.7 km² and a population increase of 689,315. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 78.6 km² and a population decrease of 655,370. In summary, the development from 2000 to 2012 was characterized by a total population increase, some urban spread, and consequently loss of non-urban land and at the same time by densification (population increase) in a considerable part of the city and some dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 32.6 km² with a population increase of 75,820. Urban land with no population change accounts for 78.9 km² while urban areas with a population increase (densification) account for 289.5 km² and a population increase of 284,569. Urban areas with a population decrease (dis-densification) account for 90.3 km² and a population decrease of -389,493. In summary, the BAU scenario indicates that in spite of a slight population decrease, some urban spread as well as densification is will take place, while some areas will be characterised by population decreases (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 203,300 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 77 and Figure 78 shows spatial patterns of historic and projected urban change for Turin. Between 2000 and 2012 the central part of the city and its immediate surroundings were characterised by no population change or a population decrease (dis-densification). Densification (population increase) primarily took place in the suburbs and some parts of the city centre, while areas with urban spread were located at the fringe of the city. For the BAU scenario, patterns of urban development until 2050 correspond largely with the historical changes. The central part of the city is characterised by no change or population decreases, some parts of the city centre and the suburbs by densification and urban spread is taking place at the fringe of the city. For the PC scenario, population increase is largest in the central part of the city. The entire city is characterised by population densification, except of some areas with infrastructure, which did not contain any population in 2012.

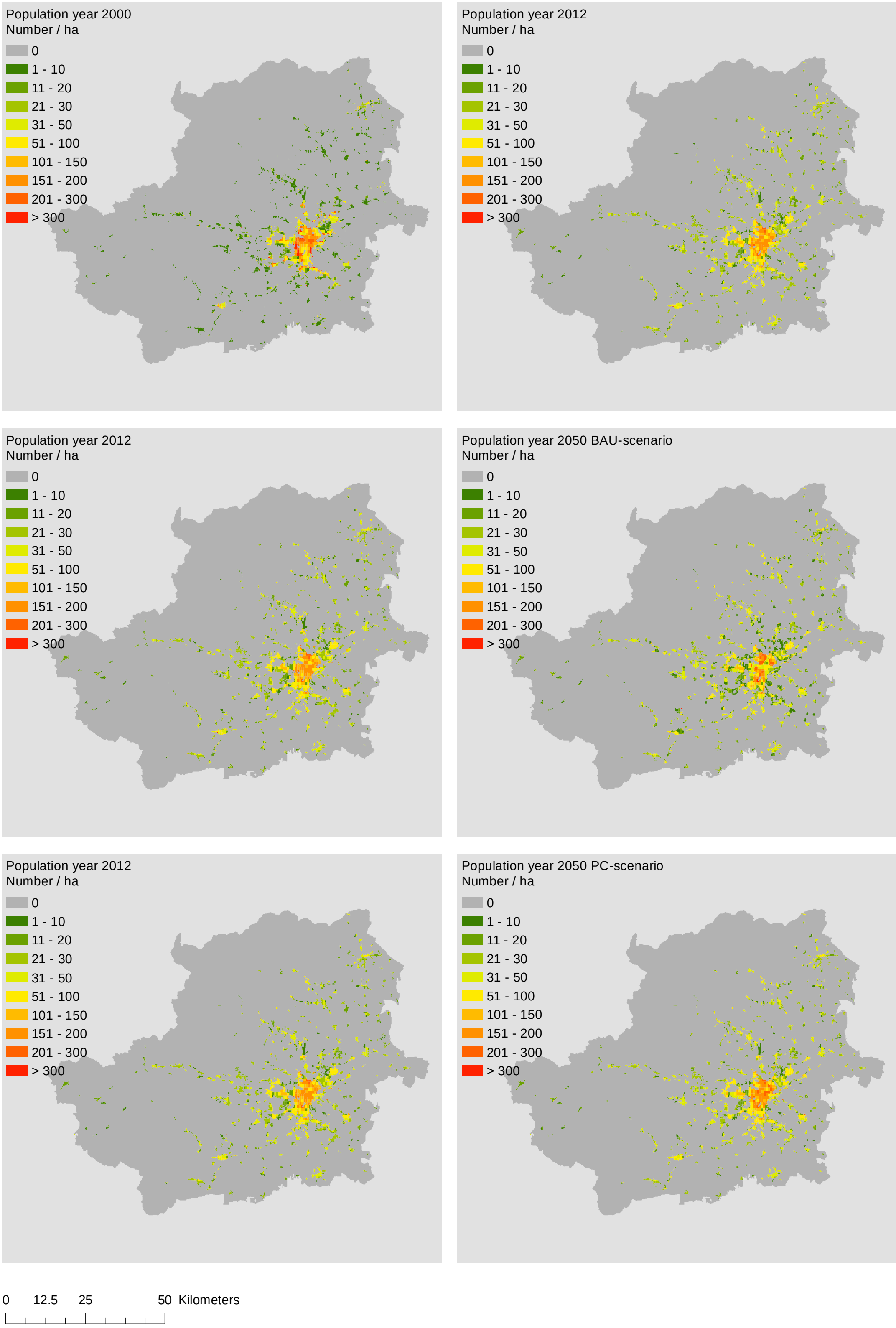

Figure 77: Population and urban change 2000-2012 and modelled for 2050, Turin

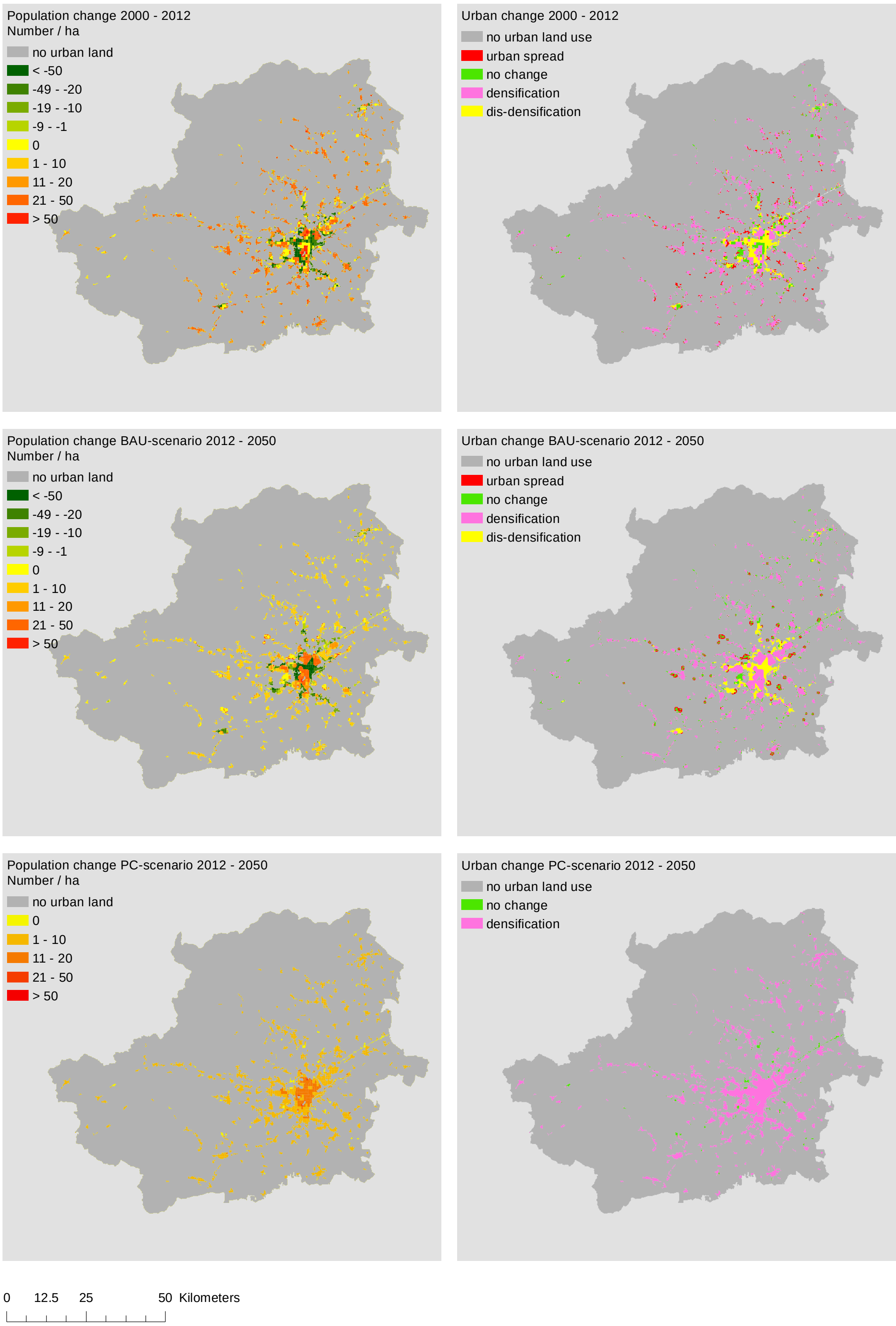

Figure 78: Population and urban change 2000-2012 and modelled for 2050, Turin (cont'd)

IV.X.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 50. The total costs of PC2050 are 7,795 MEUR compared to 2,830 MEUR for BAU. However, the table also shows that these costs would represent only 0.68% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario, or 0.32% more than BAU.

Table 72: Investment costs for BAU and PC2050 Turin scenarios

Energy	MEUR (2016)
BAU	397
PC2050	2 117
Total costs for fossil free energy	4 514
Building renovations	
BAU	2 433
PC2050	5 678
Total costs (Energy and buildings)	
BAU	2 830
PC2050	7 795
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.26%
PC2050	0.68%

This translates into the following discounted costs as shown in Table 73 at various discounted rates from 2018 to 2050.

Table 73: Net costs for Turin scenarios investments at different discount rates

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	2 390	1 768	1 768
PC2050 Costs (NPV)	6 584	4 869	3 762

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of air pollution in Turin are estimated at 1,277 MEUR/year based on the 2010 cost of 4.7% of GDP for Italy provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 74. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from

2018 to no air pollution in 2050. It shows that there are significant net benefits of 13,968 MEUR, compared to 8,313 MEUR in BAU. However, this falls quite short of the potential net benefits of 21,860 MEUR that would be obtained if fossil fuels were removed from the energy mix.

Table 74: Net benefits for Turin scenarios (2018-2050) due to reduced mortality, and for no air pollution by 2050 (MEUR NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	8 680	8 313	7 964
PC2050	14 591	13 968	13 376
No air pollution by 2050	22 826	21 860	20 942

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 53. Potential jobs for renewable energy are modest with 324 ongoing jobs from operation and maintenance, but contribute to nearly 20,237 from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 55,157.

Table 75: Benefits of PC2050 scenario compared to BAU for Turin

Additional PC2050 Jobs	MCI	O&M
Renewable energy	20237	324
Building renovation	55157	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 9% lower. Currently (2013) Turin has 6.6% renewables in its energy mix and this is expected to increase to 35.1% in BAU and 57.5% in PC2050 (with local renewables contributing 13% and 35% respectively and the rest being present in the electricity mix). Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 9% reduction of costs in PC2050 compared to BAU due to reduced energy consumption and a further reduction related to the 22% additional renewable energy.

IV.X.VI GAPS AND RISKS

The most prominent gaps for Milan under the current PC2050 scenario are as follows:

ENERGY

Currently the PC2050 still has high (although reduced) GHG emissions of 2.7 $MTCO_2e$ or 2.26 tCO_2e per capita. This is due to the interpretation of the limited actions and milestones that addressed these aspects in the first set of stakeholder workshops.

Hence the current energy mix of30% grid electricity, 45% combustible fossil and 25% renewable energy sources can be greatly improved through increased actions. This essentially means that there is a gap of almost 10,000 GWh in renewable energy if the combustible fuels and grid electricity are to be replaced by renewable energy (in addition to the 3251 GWh assumed under PC2050 currently).

SOCIO-ECONOMIC

The KPI analysis showed that there is some concern with the poverty level which has increased to 21%, which is very high. This indicates a high level of inequality which has not been addressed in either scenario.

The cost benefit analysis showed that the PC2050 scenario would cost 4,869 MEUR (NPV with discount rate of 3%) compared to 1,768 MEUR for BAU. This represents only 0.26% of the cumulative GDP (from 2018 to 2050) for BAU and 0.68% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 13,968 MEUR (NPV with discount rate of 1%).

URBAN SPRAWL

Under BAU urban sprawl will increase by 32.6 km^2 despite a reduction in population of 29,000 (for the Province area). Currently the potential for urban sprawl and increased densification is not adequately addressed within the PC2050 scenario. With a projected increase of 203,300 people by 2050 under PC2050, there is a need for the strategic paper to develop a clear series of milestones and strategies to ensure urban sprawl is contained. This obviously also has ramifications for energy use, infrastructure investment and transport.

CIRCULAR ECONOMY AND CONSUMPTION

The EE-MRIO footprint analysis suggests that despite local GHG emissions per capita decreasing by 60% under PC2050 to 2.3 tCO_2e per capita, the total footprint impacts of the city will only decrease by 16% to 13.1 tCO_2e per capita. This clearly emphasises the need to address lifestyles and consumption and promote a more circular economy.

OTHER COMMENTS

The level of biodiversity protected areas in Turin is relatively low and this together with increased green spaces and green corridors (for wildlife) could be improved in the strategic document.

IV.XI ZAGREB

IV.XI.I INTRODUCTION

In BAU 2050 Zagreb, the population has continues to grow strongly reaching 875,000 people. Public transport is improved and represents the major form of transport, although the car is still a strong second option. Energy use per person is lower than in 2010 and despite the increase in population overall energy use of the city has been reduced by almost 11%.

Zagreb under PC2050 is a city of increased density with a population of 919,000. Energy use has decreased by 24% to 8,600 GWh and the GHG emissions have decreased significantly by almost 60%, despite the population increase. However, at 1.24 tCO2e per capita the GHG emissions have not reached post-carbon status.

Despite Zagreb being part of the initiative of Covenant of Mayors for Climate and Energy the available energy data was fairly limited. However, the data was available for both 2005 and 2013 and therefore a basic trend for energy use and GHG emissions could be established on which to base the scenario projections. In addition to these data challenges, there was no available data for several of the indicators used for the qualitative assessment in the next section.

IV.XI.II KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

Table 76 summarises the current trends of the KPI and provides a projection of the likely outcome and performance under each of the scenarios (where possible and applicable). A summary of the KPI's current trends and the expected outcomes under the scenarios is given below

ENVIRONMENTAL

There has been a decrease in the number of eco-system protected areas, but the reason for this is not clear. The trend is assumed to continue in the BAU scenario. In the PC scenario the topic was not discussed.

No current trend for energy or carbon intensity can be seen due to low data availability. In the PC scenario effort will be put into energy efficiency and thus one can expect a reduction in energy intensity. In the BAU scenario the renewable part of the energy mix is expected to increase which will contribute to a reduction in the carbon emission intensity.

the PC scenario several measures will be taken, such as construction of hydro power plants on the river Sava and a high level of energy production on a household level which will decrease the carbon intensity significantly. However, in general there were inadequate actions and milestones for renewable energy which was simply stipulated as 50% renewable energy in 2030 and supported by four hydropower stations.

A small increase in the share of transportation can be observed in the energy consumption by sector. In the future, the industry is expected to lower its share. The trends in air quality can also not be observed and so it is difficult to project the trend for BAU. However, we would generally expect air quality to be greatly improved by 2050 with improved transport emissions. This is not only due to hybrid and electric vehicles but also to improvements also in emission technology for fossil fuels. There were poor measures and goals of transport in the PC2050 scenario, apart from the development of walking and cycling trails. There was no mention of supporting the emergence of electric transportation. Hence under the current PC2050 scenario the transport energy and emission are similar to the BAU.

However, the current trend shows a slight increase in cycling which is expected to continue in the BAU scenario. In the PC scenario a new biking network will be put in place resulting in an increase in the share of cycling with a corresponding reduction in car traffic.

For waste generation, the current trend shows a decrease, but the data is limited and the trend is therefore uncertain. In the BAU scenario a minor decrease in waste generation can be expected. In the PC scenario, focus will be put on the circular economy which could improve waste recovery and generation. Although the circular economy is recognised as a strategic goal under PC2050 the supporting actions and milestones were limited to only one milestone. The milestone was to conduct a survey of available local resources and new technologies for the circular economy. On this basis it is uncertain that much progress can be made due to the weak set of measures.

The water losses have been unchanged during the last ten years. The current levels are high and the issue has not been dealt with in either the BAU scenario or in the PC2050 scenario. Therefore water losses are expected to be a future problem, especially in combination with effects from climate change.

There is no data available on energy efficient buildings but due to investments in energy efficiency, improvements can be expected in both the BAU scenario and in the PC2050 scenario.

ECONOMIC

The trend for sustainable economic growth is positive with the level of wealth showing an increase of 61% from 2003 to 2010. This trend is expected to continue and will be slightly higher in the PC2050 scenario. As is happening in most European cities, the service sector share of GDP and employment is growing and this will continue under both scenarios, with an associated fall in the contribution by industry. There was no data available for the other economic KPI's.

SOCIAL

In terms of equality, the indicators are positive with a very low unemployment rate and a high rate of tertiary education for both sexes. The male rate of tertiary education is however 9% lower at 45.6% compared to the 54.4% for females. No significant changes are expected for either the PC or the BAU scenario.

The poverty level is quite high at 20.5% (2013) and has increased over the last 5 years, which is of some concern. However, in both scenarios and particularly for PC2050 a decrease can be expected as a result of the economic development. The life expectancy has improved considerably from 2003 to 2012, but is still low at 78.8 years by European standards.

In terms of green space there is a strong cause for concern as the amount of forest has decreased significantly from 168.8 km^2 to 92.9, a reduction of 45%, over 6 years from 2006 to 2012. This suggests either considerable urban sprawl and/or deforestation for another cause.

Table 76: Semi quantitative assessment of the POCACITO KPI's under BAU and PC2050 for Zagreb

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
ENVIRONMENT	Biodiversity	Variation rate of ecosystem protected areas	Percentage	15.1%-13.4% (2001-2011)	Decrease.	-	0
	Energy	Energy intensity variation rate	toe/euro toe	101.4-79.7 toe/euro (2006-2008) No data	Too short time span for trend No data	+	++
		Variation rate of energy consumption by sectors	Percentage	Residential and commercial/Industry/Transportation: 53.4%/17.5%/29% - 53.9%/15.1%/31% (2003-2012)	Small increase in share of transport?		
	Climate and Air Quality	Variation rate of carbon emissions intensity	ton CO_2/euro ton CO_2	0.00024-0.000189 (2006-2008) 2732-2769 (2006-2008)	Short time period Short time period	+	++
		Carbon intensity per person	ton CO_2 eq.	Data not available	-	+	++
		Variation rate of carbon emissions by sector	ton CO_2	Buildings [t CO2] 1.007.443,1 Transportation [t CO2] 1.731.927,4 Illumination [t CO2] 29.157,6 Industry [t CO2] 3.555.076,5	No data on trend		
		Exceedance rate of air quality limit values	Nº	No data?	No data?	0	+
	Transport and mobility	Variation share of sustainable transportation	Percentage	Walking, cycling and public transport: 62.9%-63% (2001-2011)	Little difference, share of bicycling increased slightly?	+	+
	Waste	Variation rate of urban waste generation	kg/person/year	465-378 (2008-2011)	Too short time period?	+	++
		Variation rate of urban waste recovery	Percentage	3.3%-5.6% (2008-2011)	Increasing, but low levels?	+	++
	Water	Water losses variation rate	m^3/person/ye	67.22-67.64 (2003-2012)	Small change?	0	0

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
			ar				
	Buildings and Land Use	Energy-efficient buildings variation rate	Percentage	No data available	No data available	+	+
		Urban density variation rate	Nº/km^2	1214-1228 (2001-2011)	+1%	0	+
ECONOMY	Sustainable economic growth	Level of wealth variation rate	EUR/person	€11527-€18645 GDP/person (2003-2010)	+61%	++	++
		Variation rate of GDP by sectors	Percentage	Agriculture, forestry/Industry/Commercial/Tourism/Business sector (2003-2009): 5.7/18/11.8/3.6/17% - 5.9/16.7/9.5/3.9/21.3% (2003-2009)	Industry->Business?	N/A	N/A
		Employment by sectors variation rate	Percentage	Agriculture/industry/services (2009-2012): 0.4%/23.8%/75.7% - 0.43%/20.22%/79.3% (2009-2012)	Industry->Services?	N/A	N/A
		Business survival variation rate	Percentage	No data	No data	ND	ND
	Public Finances	Budget deficit variation rate	Percentage of city's GDP	No data	No data	ND	ND
		Indebtedness level variation rate	Percentage of city's GDP	No data	No data	ND	ND
	Research & Innovation dynamics	R&D intensity variation rate	Percentage	No data	No data	ND	ND
SOCIAL	Social Inclusion	Variation rate of unemployment level by gender	Percentage	Male: 3.64%-4.79%(2006-2012) Female: 5.56%-4.71 (2006-2012)	Annual variations	ND	ND
		Variation rate of poverty level	Percentage	19.0%-20.5% (2005-2013)	Increase	+	+
		Variation rate of tertiary education level by gender	Percentage	Male: 49%-45.6% (2001-2011) Female: 51%-54.4%(2001-2011)	Different trends	+	+
		Variation rate of average life expectancy	Average Nº	75.6-78.8 (2003-2012) 6 years difference between male/female	+2.2 years	+	+
	Public services and Infrastructures	Variation rate of green space availability	Percentage	(2006-2012) Forest (km^2): 168.8 – 92.9 Parks (km^2): 0.573 – 0.592	Large reduction in forest area	--	0

	SUB-DIMENSION	INDICATOR	UNIT/INFO	Quantity	Trend	BAU 2050	PC 2050
				Grass surfaces: 9.3 -10.3			
	Governance effectiveness	Existence of monitoring system for emissions reductions	Yes/No Description	Yes	-	N/A	N/A

IV.XI.III QUANTITATIVE ANALYSIS

ENERGY AND GHG

A comparison of the energy consumption by energy source for the baseline year 2008, and the BAU and PC2050 scenarios is shown in Figure 79 [12]. It shows the dominance of natural gas in both 2008 and BAU, but this is replaced in PC2050 by wind, solar and hydro-power. The reduction in total energy use is 9.9% in BAU and 22.8% in PC2050, despite a projected increase of 10.3% and 15.9% respectively. However, there is potential for a much greater reduction in energy use in PC2050 than is illustrated here. This is because it has been modelled using the energy efficiency measures that were derived in the PC 2050 vision and milestone workshop, which were quite was limited.

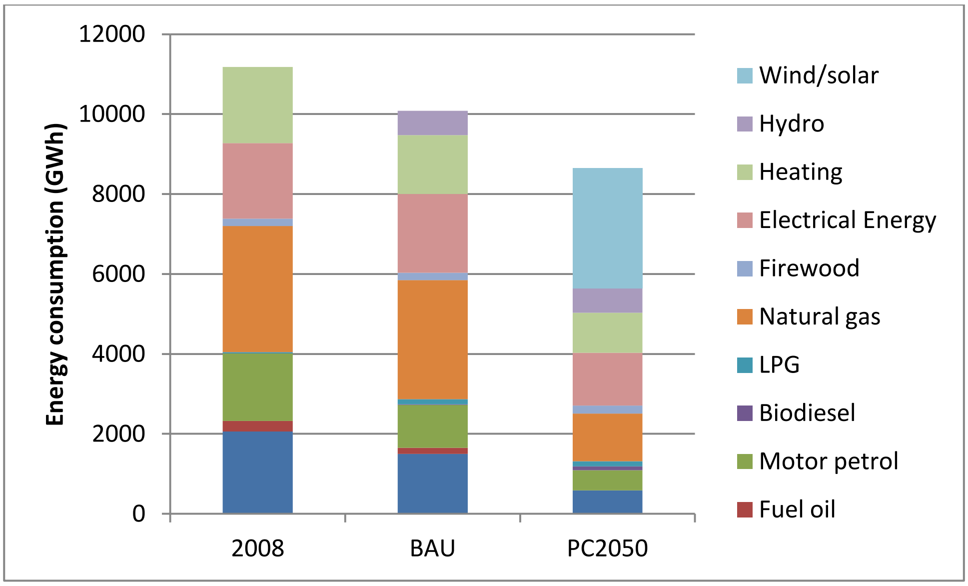

Figure 79: Energy consumption by energy source for 2008, BAU and PC2050 in Zagreb

For example there were no robust actions noted for renovation of the current building stock to improve energy efficiency. Figure 80 highlights the significance of the building sector in energy consumption in all scenarios.

[12] The initial figures for 2008 are taken from the Zagreb Sustainable Energy Action Plan from the Covenant of Mayors programme.

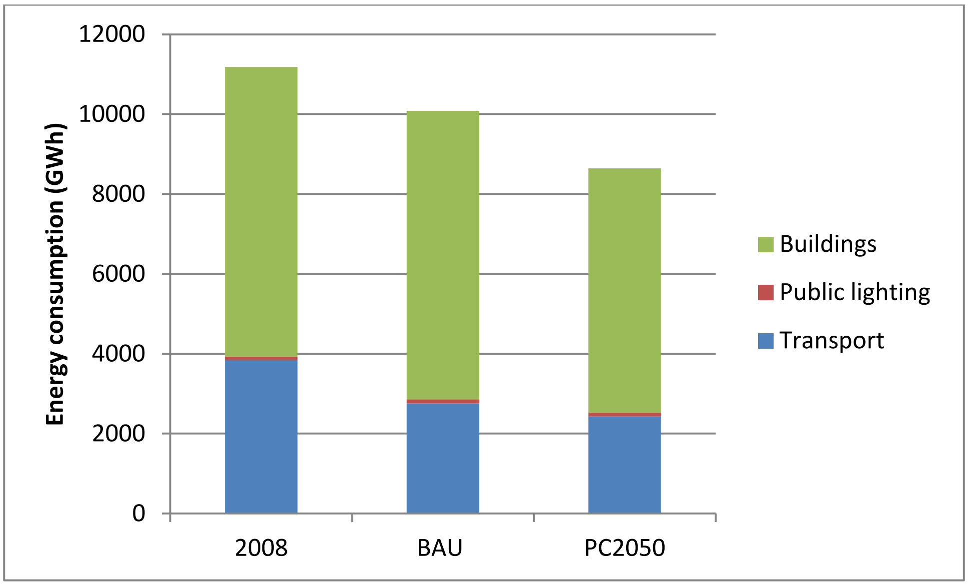

Figure 80: Energy consumption by sector for 2008, BAU and PC2050 in Zagreb

In Figure 81 the GHG emissions for the scenarios are compared with 2008, showing the significance of electrical energy and natural gas in each. Due to poor data availability it is not known what the original energy source of the “heating” and so the original emission factor has been used to calculate the emissions in both 2050 scenarios.

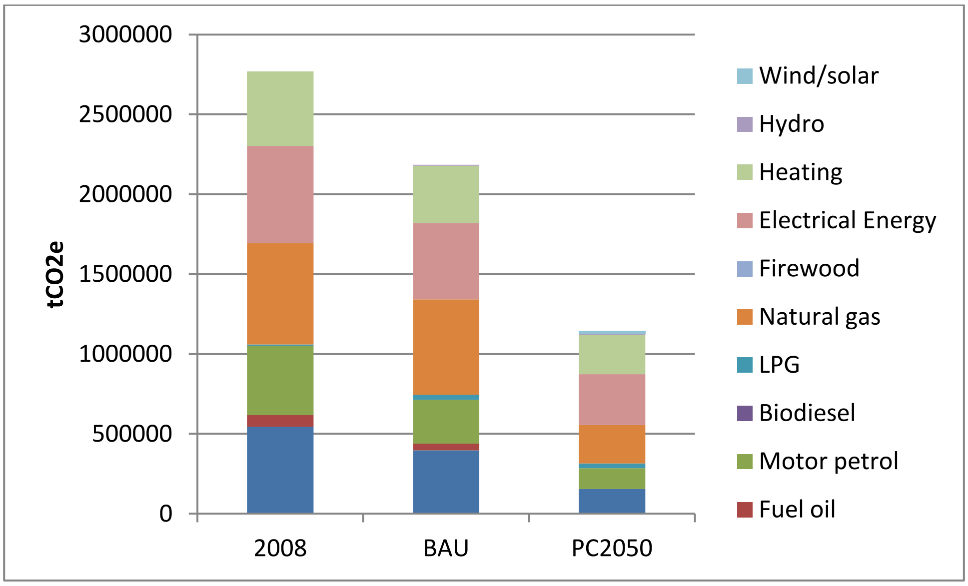

Figure 81: GHG emissions by energy source for 2008, BAU and PC2050 in Zagreb

The importance of the building sector is again highlighted in Figure 82, which also shows that in PC2050 there has been a significant reduction of 65.7% for GHG emission in the transport sector.

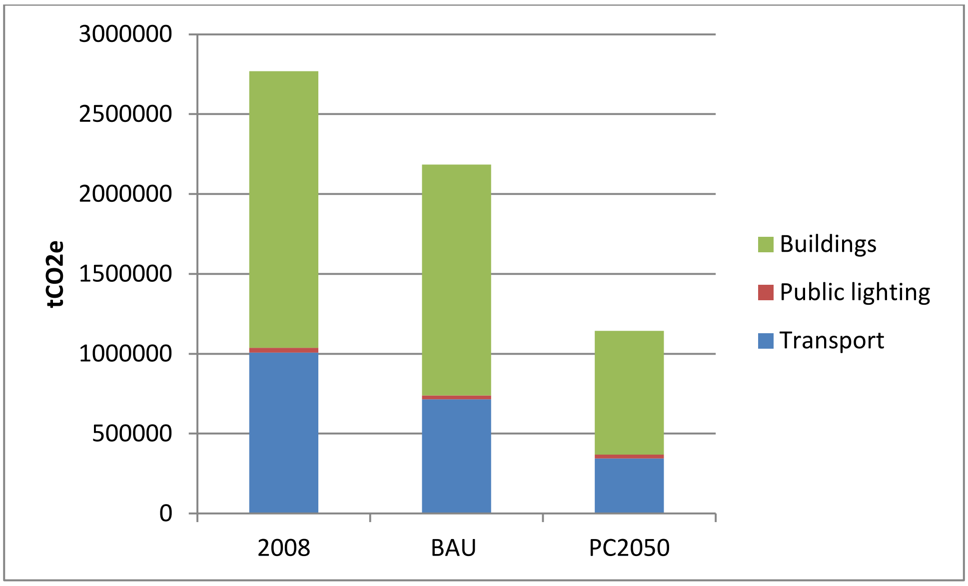

Figure 82: GHG emissions by sector for 2008, BAU and PC2050 in Zagreb

Finally, Figure 83 compares the GHG emissions per capita showing a significant reduction in PC2050 compared to 2008, but that at 1.24 tCO2e per capita, post carbon status has not been achieved.

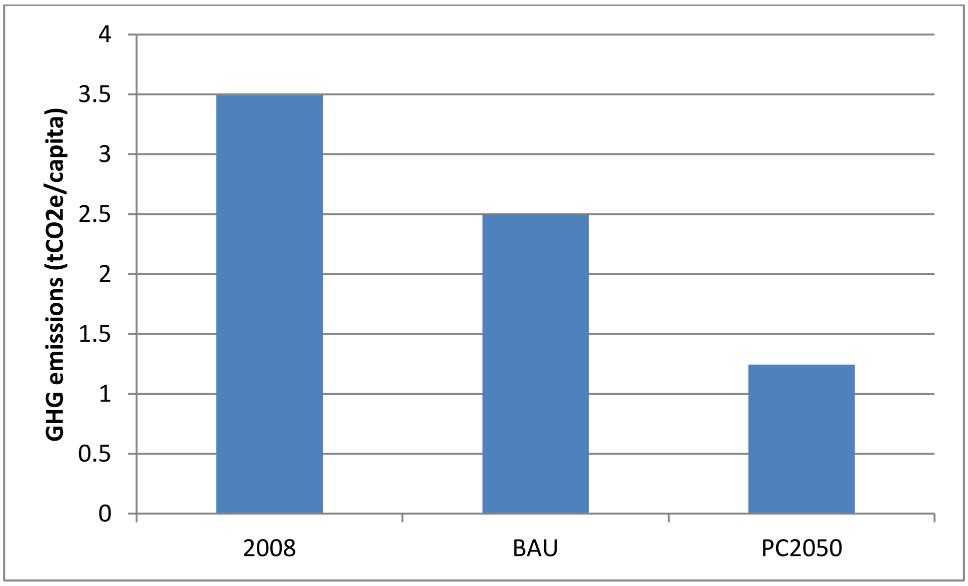

Figure 83: GHG emissions per capita for 2008, BAU and PC2050 in Zagreb

MRIO – FOOTPRINT IMPACTS

The results of the footprint analysis comparing the base year 2007 with the scenarios are shown below. Figure 84 compares both the overall GHG footprint for the scenarios with 2007, as well as the direct and indirect GHG emissions. It shows that both direct and indirect emissions are expected to increase in both scenarios. This can primarily be contributed to an expected increase in affluence and GDP for Zagreb with an associated increase of consumption in energy and products and services.

The direct emissions in PC2050 are less than for BAU, but indirect are however higher (due to increased GDP and therefore consumption in PC2050), meaning the overall emissions of both scenarios are very similar. Hence although by 2050 we would expect an improvement in the efficiency of the underlying production systems for the products and services, these are outweighed by increased consumption and overall emissions increase.

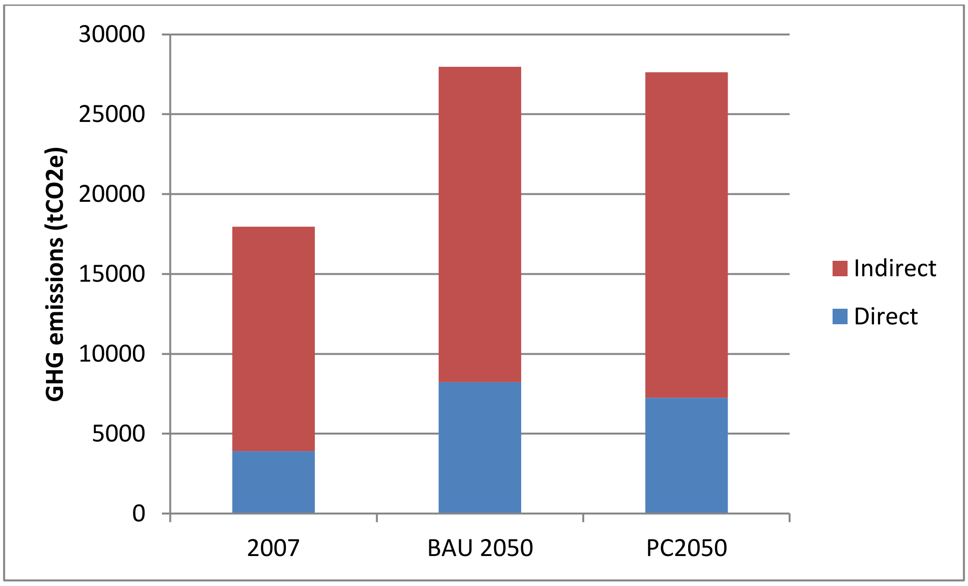

Figure 84: Direct and indirect GHG emissions for Zagreb for 2007, BAU and PC2050

Figure 85 compares the contribution of the product groups to the GHG emissions for each scenario. It shows that in both BAU and PC2050 there is a marked increase in nearly all product groups. Under PC2050 "electricity and heat fuels" is less than in BAU but this is compensated by an increase in "other goods and materials". Emissions associated with "food" have not changed significantly in PC2050 compared with 2007 and there is only a slight increase in the emissions or "housing".

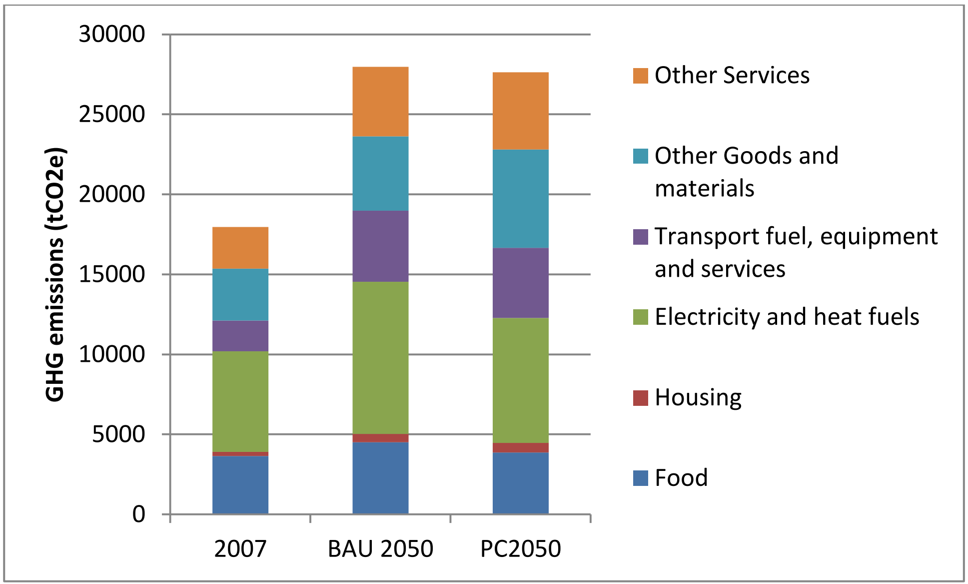

Figure 85: The contribution of product groups to the GHG footprint for 2007, BAU and 2050

The other impacts of photochemical oxidation, acidification and eutrophication also show varying increases as shown in Table 77. Eutrophication and acidification are particularly high under PC2050.

Table 77: Environmental impacts for 2007 and the scenarios for Zagreb

				% INCREASE FROM 2007	
	2007	BAU	PC2050	BAU	PC2050
Global warming (kg CO2 eq)	17966	27975	27627	156%	154%
Photochemical oxidation (kg ethylene eq)	5.5	6.2	6.0	113%	110%
Acidification (kg SO2 eq)	89.3	107.1	156.2	120%	175%
Eutrophication (kg PO4--- eq)	14.4	21.8	33.0	152%	230%

Figure 86 examines these additional impacts further by comparing the contribution of the product groups for 2007 and the scenarios. It shows that the increase in eutrophication is caused by the increasing eutrophication of “transport fuel, equipment and services”. However, this seems to be an unusual result and is most likely an anomaly due to difficulties in the modelling process and apparent high sensitivity of some products to changes in percentage profiles.

The figure also shows that the contribution of electricity to photochemical oxidation decreases in BAU and even more so in PC2050. The contribution of transport to acidification also increases in both scenarios and may also be an anomaly due to difficulties in the modelling process.

However, the overall finding from the MRIO analysis are that there is a risk of increased impact due to increasing GDP (which is projected to more than double by 2050) and the associated spending.

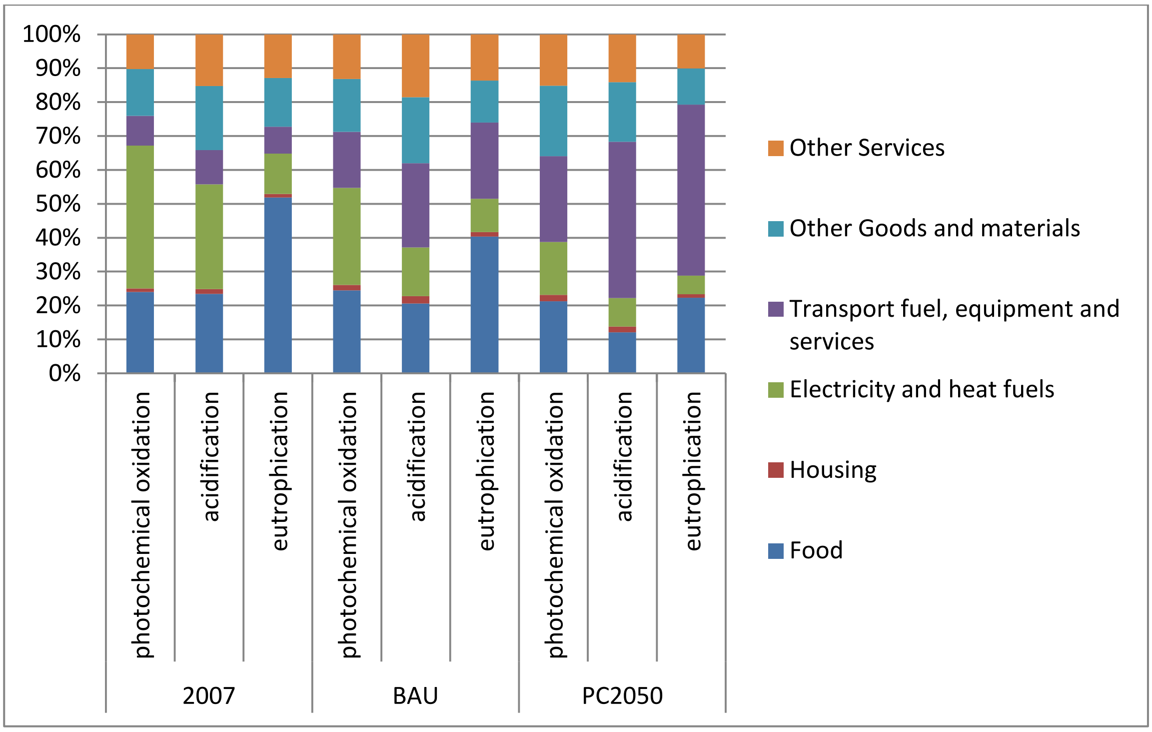

Figure 86: Comparison of other impacts for Zagreb for 2007, BAU and PC2050

IV.XI.IV ECO-SYSTEM SERVICES

LAND USE COVER CHANGES

Population and land use changes

Between 2000 and 2012 Zagreb's population increased by 53,400 or 7.2 % and urban land increased by 7.3 km² or 4.7 % (Table 86, Annex II). According to the BAU scenario, by 2050 the population will increase by another 83,700 or 10.5 % and urban land will increase by 11.5 km² or 7.1 % on the account of non-urban land. According to the PC scenario, population will increase by 153,000 or 19.2 % by 2050. Since the PC scenario assumes that no urban spread will take place, no land use changes are projected.

Urban change

In Zagreb, between 2000 and 2012, urban spread accounted for 7.3 km² with a population increase of 12,820. In the same period, urban areas with no population change accounted for 79.9 km². Urban areas with population densification accounted for 58.9 km² and a population increase of 109,807. Meanwhile, urban areas with a decrease in population (dis-densification) accounted for 16.0 km² and a population decrease of 69,242. In summary, the development from 2000 to 2012 was characterized by a total population increase, some urban spread, and consequently loss of non-urban land and at the same time by densification (population increase) in a considerable part of the city and some dis-densification (population decrease) in other areas.

The BAU scenario results in an urban spread of 11.5 km² with a population increase of 19,989. Urban land with no population change accounts for 83.6 km² while urban areas with a population increase (densification) account for 61.7 km² and a population increase of 115,354. Urban areas with a population decrease (dis-densification) account for 16.8 km² and a population decrease of 51,637. In summary, the BAU scenario indicates, that the expected population increase by 2050 will primarily lead to densification and some urban spread, while at the same time parts of the urban land will be characterized by population decrease (dis-densification). Since our assumption for the PC scenario is that no urban spread will take place, the scenario indicates that the expected population increase of 153,000 will result in a population increase (densification) on all urban land with a population in 2012.

Spatial patterns of urban change

Figure 87 and Figure 88 show spatial patterns of historic and projected urban change for Zagreb. Between 2000 and 2012 the central part of the city and its immediate surroundings were characterised by no population change or a population decrease (dis-densification). Densification (population increase) primarily took place in the suburbs, while areas with urban spread were located at the fringe of the city. For the BAU scenario, patterns of urban development until 2050 correspond largely with the historical changes. The central part of the city is characterised by no change or population decreases, the suburbs by densification and urban spread is taking place at the fringe of the city. For the PC scenario, population increase is largest in the central part of the city. The entire city is characterised by population densification, except of some areas with infrastructure, which did not contain any population in 2012.

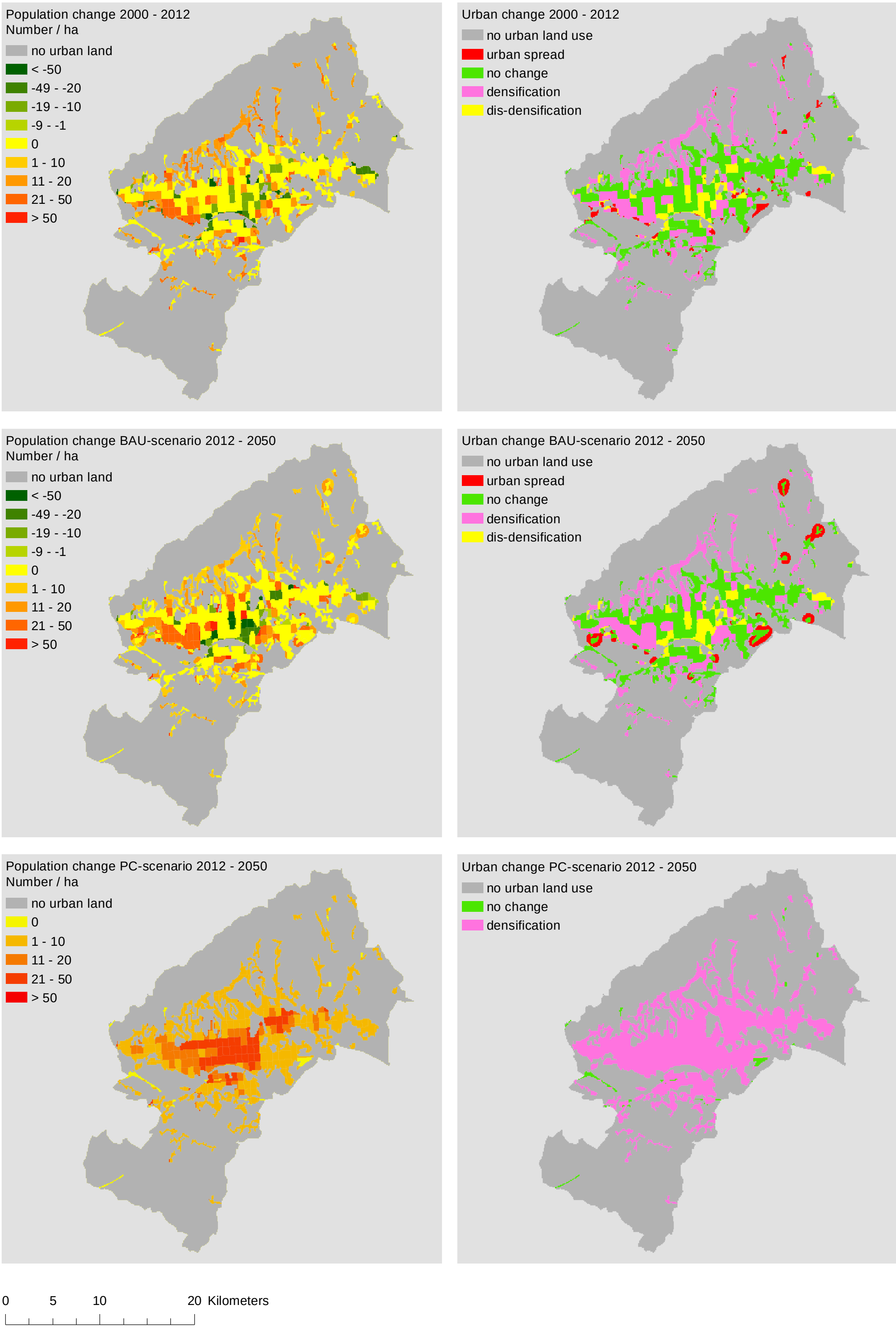

Figure 87: Population and urban change 2000-2012 and modelled for 2050, Zagreb

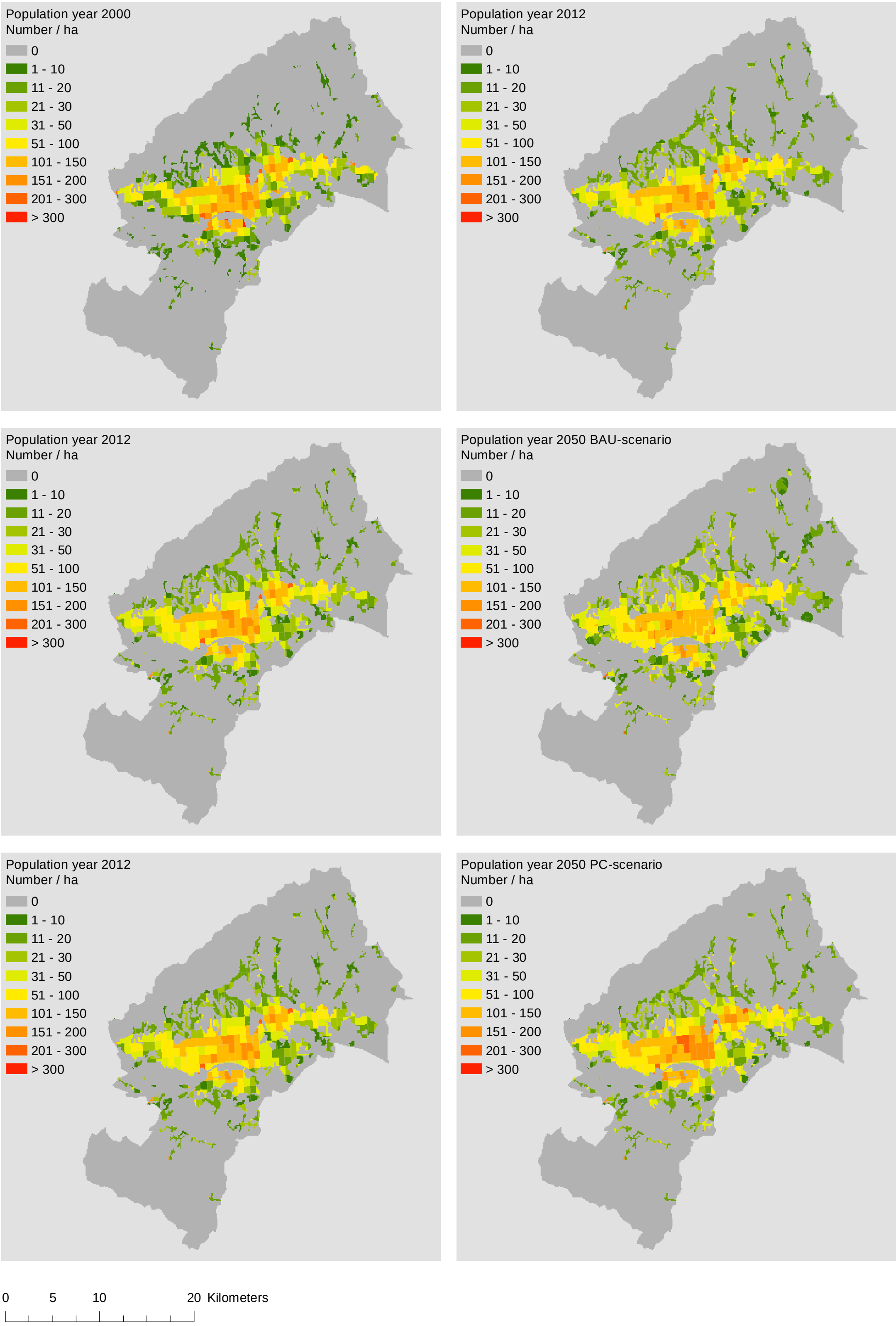

Figure 88: Population and urban change 2000-2012 and modelled for 2050, Zagreb (cont'd)

IV.XI.V SOCIO – ECONOMIC ASSESSMENT

INVESTMENT COSTS

The investment costs for renewable energy and building renovations, from 2018 to 2050, for each scenario are shown in Table 78. The total costs of PC2050 are 5,694 MEUR compared to 2,217 MEUR for BAU. However, the table also shows that these costs would represent only 0.76% of cumulative GDP (from 2018 to 2050) for the PC2050 scenario.

Table 78: Investment costs for BAU and PC2050 scenarios for Zagreb

Energy	MEUR (2016)
BAU	800
PC2050	2 385
Total costs for fossil free energy	3 660
Building renovations	
BAU	1 418
PC2050	3 309
Total costs (Energy and buildings)	
BAU	2 218
PC2050	5 694
Costs as % of cumulative GDP (2018 to 2050)	
BAU	0.30%
PC2050	0.76%

This translates into the following discounted costs as shown in Table 79 at various discounted rates from 2018 to 2050.

Table 79: Net costs for Zagreb scenarios investments at different discount rates (MEUR)

DISCOUNT RATE	1%	3%	5%
BAU costs (NPV)	1873	1385	1070
PC2050 costs (NPV)	4810	3557	2748

BENEFIT ANALYSIS

REDUCTION IN MORTALITIES DUE TO REDUCED AIR POLLUTION

The current costs of premature deaths from air pollution in Zagreb are estimated at 1,742 MEUR/year based on the 2010 cost of 10.8% of GDP for Croatia provided by WHO (WHO Regional Office for Europe and OECD, 2015).

The net benefits of BAU and PC2050 at different discount rates are shown in Table 80. The table shows the benefit of the change in mortality due to the change in air pollution. In addition to BAU and PC2050, it also compares the benefits that would be obtained if there was a linear progression from 2018 to no air pollution in 2050. The net benefits of the PC2050 scenario are 22,897 MEUR compared to 22,987 MEUR under BAU, but this falls some way short of the potential available if air pollution was reduced to zero by 2050. However, it means that the potential benefits of PC2050 from reduced premature deaths alone, are more than 6 times greater than the cost.

Table 80: Net benefits for Zagreb scenarios (2018-2050) due to reduced mortality and for no air pollution by 2050 (MEUR NPV)

	DISCOUNT RATE		
	0.8%	1.0%	1.2%
BAU	6 648	6 363	6 093
PC2050	23 932	22 897	21 914
No air pollution by 2050	36 293	34 738	33 260

INCREASED EMPLOYMENT

The potential for increased employment due to the use of renewable energy and building innovation is summarised in Table 81. Potential jobs for renewable energy are modest with 367 ongoing jobs from operation and maintenance, but contribute to over 27,000 jobs from manufacturing through to installation. The number of jobs created from the renovation of buildings is significant at 32,141.

Table 81: Benefits of PC2050 scenario compared to BAU for Zagreb

Additional PC2050 Jobs	MCI	O&M
Renewable energy	27054	367
Building renovation	32141	

REDUCTION IN ENERGY COSTS

PC2050 can be expected to have lower costs than BAU as a result of increased energy efficiency meaning that energy consumption is 14.4% lower. Currently (2008) Zagreb has 1.6% renewables in its energy mix and this is expected to increase to 20.5% in BAU and 55.0% in PC2050 (including 8% and 45% local renewables respectively). Hence there is the potential for much greater energy security and lower risks due to the volatility of fossil fuel prices.

In summary, there is potential for 14.4% reduction of costs in PC2050 due to reduced energy consumption and a further reduction related to the 34.5% additional renewable energy.

IV.XI.VI GAPS, RISKS AND CONCLUDING COMMENTS

The most prominent gaps for Zagreb under the current PC2050 scenario are as follows:

ENERGY AND ENVIRONMENT

Under the PC2050 scenario energy use is still very high especially in the building sector. Therefore it should be a priority to apply robust energy efficiency strategies such as renovations to reduce the energy consumption. This would reduce the energy production requirements and potentially the associated investment costs of renewable energy supply. In addition, a lower energy production would also have lower operating and maintenance costs. There were no mention of renovations or improving the energy efficiency of the current building stock in the measures derived in the vision and milestone workshops. There are several other weaknesses in the measures, which have resulted in the current PC2050 scenario that has been modelled that should be noted.

Inadequate actions and milestones were found for renewable energy which was simply stipulated as 50% renewable energy in 2030. However, there was no mention of how this was to be achieved or what form of renewable energy it should be. The transport goals did not include a mention of electric vehicles. However, the modelling of PC2050 contained in this report did model that half of the transport energy was derived from electricity, thereby improving the energy use and emissions of the transport sector. In order to completely electrify the transport sector an additional 1217 GWh hours of electricity would need to be provided.

Without further reductions in the energy demand of the building sector an additional 2500 GWh of renewable supply is required on top of the 3000 GWh wind/solar and 610 GWh of hydro power modelled here. In addition, a further 1000 GWh would be required if the carbon intensive national grid share was to be compensated for.

Finally, in order to further reduce the energy consumption of buildings there should be a strategy to support the use of energy efficient appliances throughout the city.

SOCIO-ECONOMIC

The data availability for many of the socio-economic indicators was poor, so one of the first actions required is to improve the tracking and availability of this information.

There appears to be good balance within Zagreb amongst the sexes in terms of education and employment. However, the poverty level is quite high at 20.5% (2013) and has increased over the last 5 years, which is of some concern and should be addressed in the strategic paper.

The cost-benefit analysis showed that the PC2050 scenario would cost 3,557 MEUR (NPV with discount rate of 3%) compared to 1,385 MEUR for BAU. This represents only 0.3% of the cumulative GDP (from 2018 to 2050) for BAU and 0.76% for PC2050. Meanwhile the cumulative benefits under PC2050 through reduced premature deaths caused by air pollution would be 22,897 MEUR.

URBAN SPRAWL

The KPI analysis showed that in terms of green space there is a strong cause for concern as the amount of forest has decreased significantly from 168.8 km^2 to 92.9, a reduction of 45%, over 6 years from 2006 to 2012. This suggests either considerable urban sprawl and/or deforestation for another cause

The land use analysis projected that, based on current trends, a population increase of 83,700 in the BAU scenario would result in further development (or urban sprawl) of 11.5 km^2 of currently non-urban land. Under PC2050 we have assumed that densification will occur and no urban sprawl will take place. However, with a projected increase of 153,000 under PC2050 there is a risk of significant further development of non-urban land, if policies do not address this and plan for densification. There is also a role for Zagreb Municipality to encourage further movement of the wider area of Zagreb County to the municipality. This is in order to reduce the risk of further urban sprawl but also to capitalise on the additional sustainability benefits of densification such as improved energy efficiency and reduced transport infrastructure and public services.

CIRCULAR ECONOMY AND CONSUMPTION

Zagreb was one of the few cities that recognised the importance of the circular economy approach, placing it as a strategic goal. The milestone was to conduct a survey of available local resources and new technologies for the circular economy. However, no further actions or measures were found, and hence this should be addressed in future policy. Options include increasing the facilities for reuse (e.g. through provision of locations to leave unwanted good for reuse) and repair (such as repair cafes), but also to support businesses and innovation in this area.

The EE-MRIO footprint analysis suggests that despite local GHG emissions and impacts decreasing by 61% under PC2050 to 1.2 tCO_2e per capita, there is a risk that the total footprint impacts of the city will increase by 54%. This is largely caused by a large increase in GDP which will potentially cause increased spending and consumption. This emphasises the need for policies to address lifestyles and consumption and promote a more circular economy.

V COMPARATIVE ANALYSIS AND DISCUSSION

This chapter compares the results of the cities for each of the assessment methodologies.

V.I.I KEY PERFORMANCE INDICATOR IMPACTS

The KPI modelling and analysis showed that most cities are performing well in most categories for both scenarios. Table 82 provides a comparison of the results for the case study cities. In particular there is good to excellent performance in most of the environmental and energy related indicators. The exception to this is Istanbul, which with its large increase in population, affluence, associated energy use, and limited progress in renewable energy, faces the risk of vastly increasing GHG emissions.

Despite the recent financial crisis and its impacts still being felt to some degree, many of the cities are continuing to develop well in terms of GDP. It is apparent however, that there is a clear difference between BAU and PC2050 with BAU, in most cases only providing "likely positive" progress. This suggests that whilst many cities are heading in a positive direction under BAU, progress is likely to be too slow to achieve excellent results or post-carbon status.

Within the PC2050 scenarios there appears to be a gap for most cities with some environmental factors such as waste recovery. This is partly a reflection of the methodology used in the research, with a limited number of workshops and limited revisions of the actions and milestones associated with the scenarios.

A key area of concern is the poverty level for several of the cities with likely negative progress projected for Litoměřice, Milan, Rostock and Turin under BAU. These cities also have either negative progress or no progress under PC2050. For the majority of other cities the progress under PC2050 is projected to be only minor with only Istanbul having very positive progress. This is a reflection of the increasing disparity between rich and poor in many global cities.

Table 82: Comparison of the semi-quantitative assessment of the POCACITO KPI's under BAU and PC2050 for all cities

	INDICATOR	Copenhagen		Barcelona		Istanbul		Lisbon		Litoměřice		Malmö		Milan		Rostock		Turin		Zagreb	
		BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050
Environment	Variation rate of ecosystem protected areas	+	+	N/A	N/A	+	++	+	+	N/A	N/A	+	++	0	+	0	0	0	0	-	0
	Energy intensity variation rate	+	+	+	++	-	0	+	++	+	+	+	++	+	++	+	++	+	++	+	++
	Variation rate of carbon emissions intensity	++	++	+	++	0	+	+	++	+	++	+	+	+	++	+	++	+	+	+	++
	Carbon intensity per person	++	++	+	++	-	+	+	++	+	++	+	++	+	++	+	++	+	+	+	++
	Variation rate of carbon emissions by sector	N/A	N/A	++	++	N/A	N/A	+	+	N/A	N/A	0	+	N/A	N/A	N/A	N/A	+	+	N/A	N/A
	Exceedance rate of air quality limit values	+	+	++	++	0	+	+	++	0	++	+	+	+	++	+	++	++	++	0	+
	Variation share of sustainable transportation	+	+	0	++	0	0	0	+	0	++	+	+	+	++	+	++	-	+	+	+
	Variation rate of urban waste generation	+	+	++	+	-	-	+	+	0	++	+	++	+	+	+	+	+	+	+	++
	Variation rate of	+	+	++	++	+	+	-	-	0	++	++	++	+	+	+	+	++	++	+	++

	INDICATOR	Copenhagen BAU 2050	Copenhagen PC 2050	Barcelona BAU 2050	Barcelona PC 2050	Istanbul BAU 2050	Istanbul PC 2050	Lisbon BAU 2050	Lisbon PC 2050	Litoměřice BAU 2050	Litoměřice PC 2050	Malmö BAU 2050	Malmö PC 2050	Milan BAU 2050	Milan PC 2050	Rostock BAU 2050	Rostock PC 2050	Turin BAU 2050	Turin PC 2050	Zagreb BAU 2050	Zagreb PC 2050
	urban waste recovery																				
	Water losses variation rate	N/A	N/A	N/A	N/A	+	+	+	N/A	N/A	N/A	N/A	N/A	-	-	++	++	+	+	0	0
	Energy-efficient buildings variation rate	+	+	N/A	++	+	+	+	++	+	++	N/A	N/A	0	++	N/A	N/A	+	+	+	+
	Urban density variation rate	N/A	N/A	N/A	N/A	N/A	N/A	+	+	+	+	+	+	+	+	+	+	+	+	0	+
Economy	Level of wealth variation rate	++	++	++	++	++	+	+	+	++	++	++	++	++	++	+	+	+	+	++	++
	Business survival variation rate	N/A	N/A	N/A	N/A	N/A	N/A	+	+	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	+	N/A	N/A
	Budget deficit variation rate	+	+	N/A	N/A	N/A	N/A	+	+	N/A	N/A	++	++	N/A	N/A	++	++	N/A	N/A	N/A	N/A
	Indebtedness level variation rate	+	+	N/A	N/A	0	0	+	+	N/A	N/A	++	++	++	++	++	++	0	0	N/A	N/A
	R&D intensity variation rate	+	+	N/A	N/A	-	-	+	+	-	-	++	++	+	+	+	+	+	+	N/A	N/A
Social	Variation rate of unemployment level by gender	+	+	--	N/A	+	+	-	N/A	N/A	N/A	++	++	-	+	0	0	-	0	N/A	N/A
	Variation rate of poverty level	+	+	--	N/A	+	++	+	+	-	0	0	0	-	-	-	0	-	-	+	+
	Variation rate of tertiary	+	+	+	N/A	+	+	-	0	+	+	+	+	++	++	N/A	N/A	+	+	+	+

INDICATOR	Copenhagen		Barcelona		Istanbul		Lisbon		Litoměřice		Malmö		Milan		Rostock		Turin		Zagreb	
	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050	BAU 2050	PC 2050
education level by gender																				
Variation rate of average life expectancy	+	+	++	++	N/A	N/A	+	+	+	+	++	++	++	++	+	+	++	++	+	+
Variation rate of green space availability	+	+	+	+	+	++	++	++	N/A	+	++	++	0	+	++	++	+	++	--	0
Existence of monitoring system for emissions reductions	+	+	++	++	0	0	0	0	N/A	N/A	++	++	++	++	N/A	N/A	N/A	N/A	N/A	N/A

(N/A = Not available (no data) or not enough data available to discern a trend)

V.I.II QUANTITATIVE ANALYSIS

ENERGY AND GHG EMISSIONS

The energy use per capita for the ten cities is compared in Figure 89. This shows that energy use per capita declines in terms for all cities under PC2050, while in BAU, only Istanbul and Lisbon see an increase in energy use. The increase in energy for Istanbul under BAU is due to the increasing use of energy and electricity in the residential sector (related to increases in GDP). Lisbon's increasing energy use under BAU is driven by increases in the transport sector, due to a population that is shifting to the suburbs and relies on cars. Energy use per capita under PC2050 declines at various rates due to the associated actions and milestones stipulated under the individual PC2050.

However, energy use is around 10 MWh per capita/year for the majority of cities, with Barcelona being the lowest at 6.8 MWh per capita/year. This suggests that there is much room for energy efficiency improvements in the majority of cities.

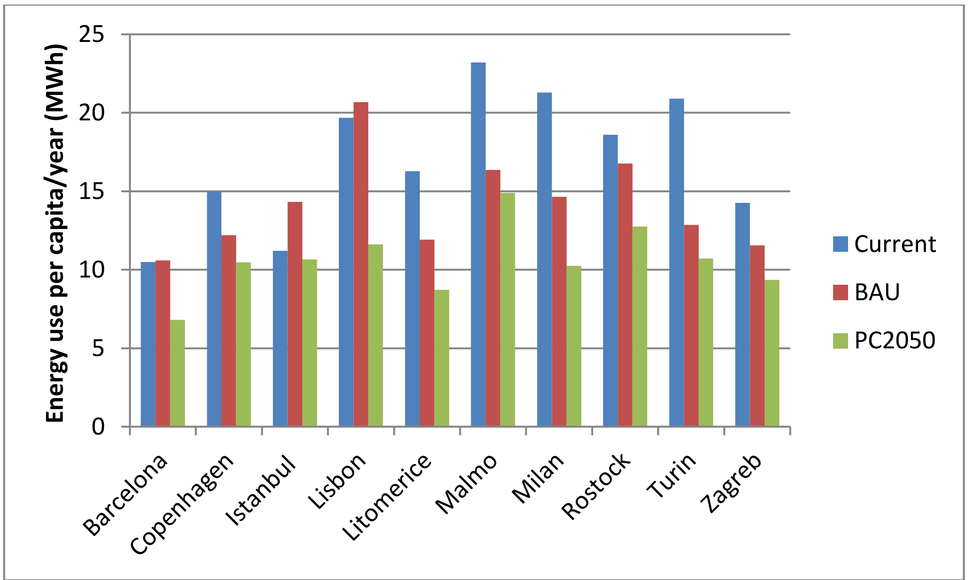

Figure 89: Energy use per capita currently compared to BAU and PC2050

High energy use does not necessarily translate into high GHG emissions as Figure 90 illustrates. The three outstanding performers under PC2050 are Barcelona, Copenhagen and Litoměřice, with 0.35 tCO_2e per capita/year, 0.18 tCO_2e per capita/year and 0.36 tCO_2e per capita/year, respectively. These cities are also the leading performers under BAU, with Copenhagen the lowest at 0.7 tCO_2e per capita/year.

Under PC2050 many cities are around 1 to 2 tCO_2e per capita/year, with Turin and Istanbul being the highest. This is primarily due to weak actions and milestones in the PC2050 workshops, and also partly due to poor data availability. Istanbul, which with its large increase in population, affluence, associated energy use, and limited progress in renewable energy, faces the risk of vastly increasing GHG emissions. This holds true even on a per capita basis under PC2050.

![POCACITO]

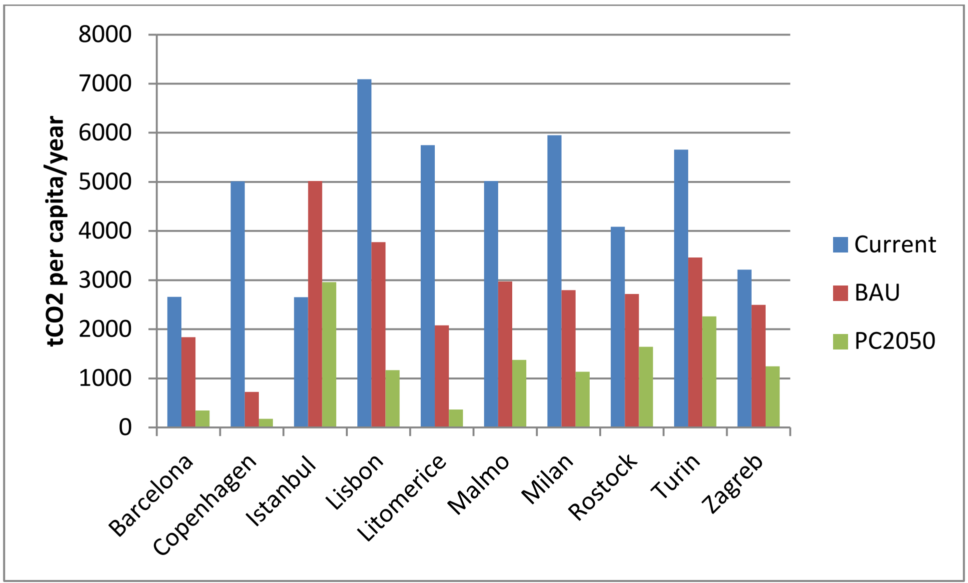

Figure 90: GHG emissions per capita

ECONOMIC OUTPUT PER UNIT OF GHG EMISSIONS

Figure 91 compares GHG emissions per EUR for the current situation and the scenarios and shows that for all cities there is improvement under both BAU and PC2050. Hence, for all cities the productivity per kgCO_2e is expected to improve under BAU and vastly improve under PC2050. In other words there is a decoupling of GHG emissions from economic output. This is further illustrated in Figure 92 that by contrast shows economic output (EUR) per kgCO_2e. Again the outstanding performers under PC2050 appear to be Barcelona and Copenhagen with Copenhagen generating 581 EUR/ kgCO_2e compared to 9.9 EUR/ kgCO_2e for the lowest performer, Istanbul. This is slightly more than the 2013 level for Milan and Malmö.

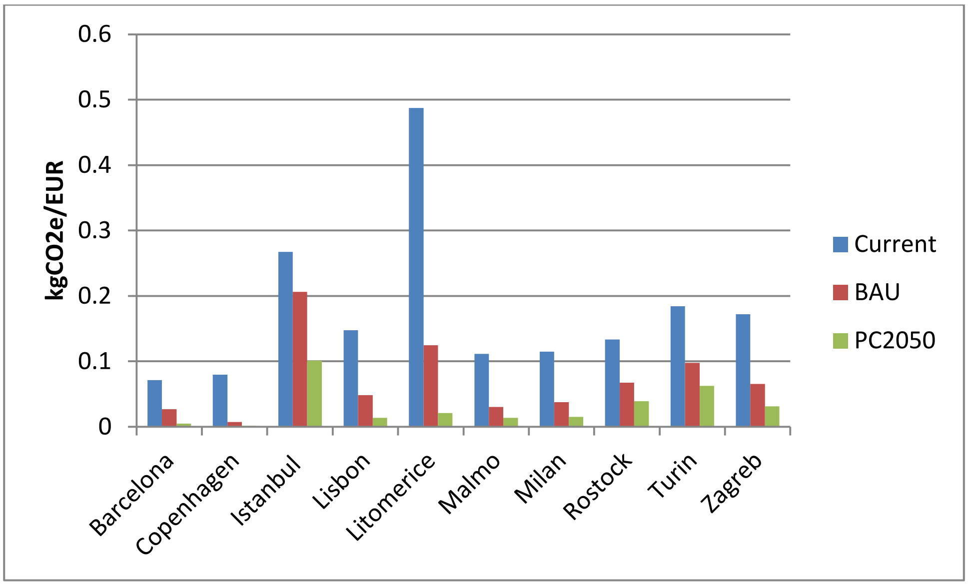

Figure 91: GHG emissions per EUR (GDP)

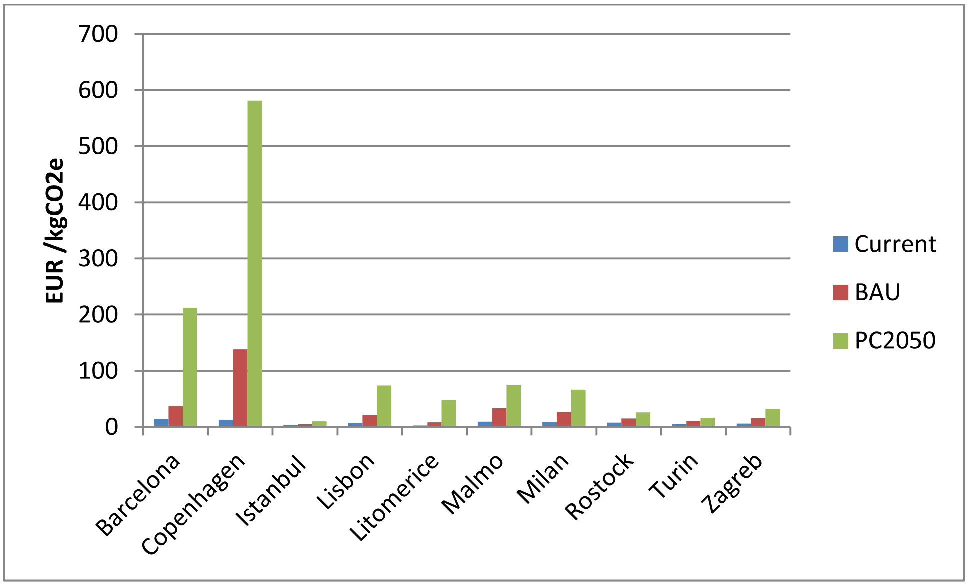

Figure 92: The amount of GDP (EUR) created for each kg of GHG emission

V.I.III FOOTPRINT ANALYSIS (EE-MRIO)

The footprint analysis performed using EE-MRIO delivered very different results for GHG emissions than for the territorial calculations. As discussed above, GHG emissions on a per capita basis decrease for the majority of cities under both BAU and PC2050 (but most dramatically under PC2050).

In comparison, Figure 93 shows that the total GHG emissions per capita increases for eight of the cities under BAU and PC2050. Despite direct emissions falling for the majority of cities under PC2050 the upstream emissions resulting from consumption increases markedly for these cities. The only exceptions are for Milan and Turin which both demonstrate a slight decrease. This is most probably linked to more modest increases in GDP per capita for these cities, but may also be due to limitations of the modelling within the MRIO database. In other words, the adjustments made to the energy profiles of the cities was complex and it was difficult to translate the cities energy profile (which includes all energy use of the city) into related to consumption. This was discussed further in the methodology section.

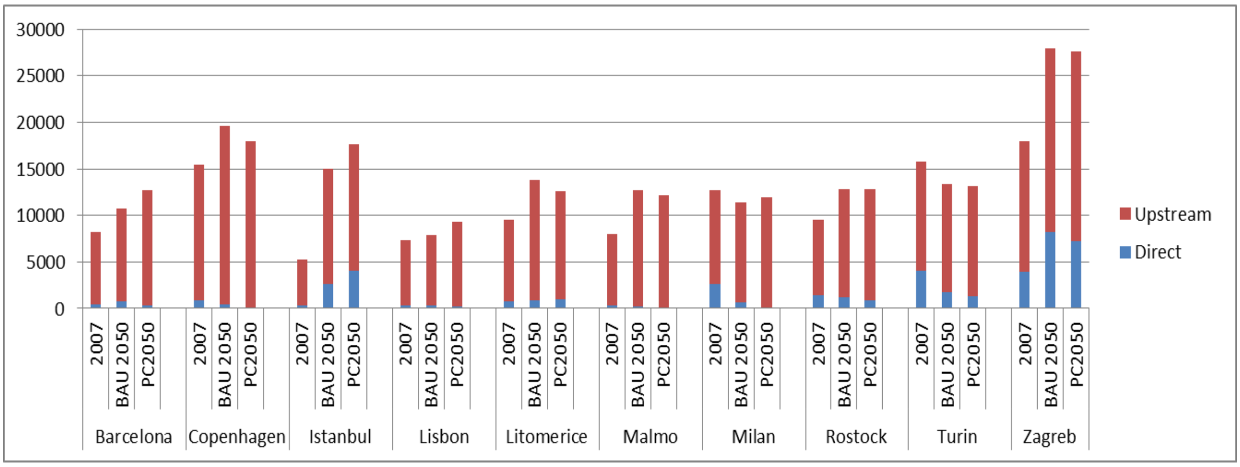

Figure 93: Direct and indirect GHG emissions for all case study cities for 2007, BAU and PC2050

In Figure 94 and Figure 95 the GHG emissions increases from the base years are compared using the standard territorial method and the MRIO footprint method. This shows that in the former traditional calculation method the GHG emissions per capita decrease for all cities (apart from Istanbul) in both scenarios. The decrease under PC2050 ranges from 60% for Rostock and Turin, up to 96% for Copenhagen.

Conversely, in Figure 95 it can be seen that the total footprint emissions increases for all cities apart from Milan and Turin. Under PC2050 the increase ranges from 234% in Istanbul to 16%, and the majority increase is between 30% and 50%.

This is partly due to the focus of the developed scenarios, in that the city scenarios were generally focussed on energy use and production, and not consumption. However, it also shows that without such a focus European cities risk falling well short of being low/zero carbon and will merely shift the emissions abroad unless consumption is specifically addressed. Recent studies such as Chen *et al.* (2016) which examined five Australian cities are also supporting the notion that a vast share of footprint emissions occur upstream and overseas. They found that over half of the embodied emissions occur from imports.

A further reason for the increasing GHG emissions of the scenarios is also down to the background modelling assumptions. These are derived from standard projections on 2050 efficiencies obtained from reports from international organisations such as the International Energy Agency, World Bank, EU and UN. The background productions system (i.e. the systems supporting the manufacturing of the products) is assumed to be the same for both BAU and PC2050 as we assume that the actions made by the ten case study cities will not impact on this background system.

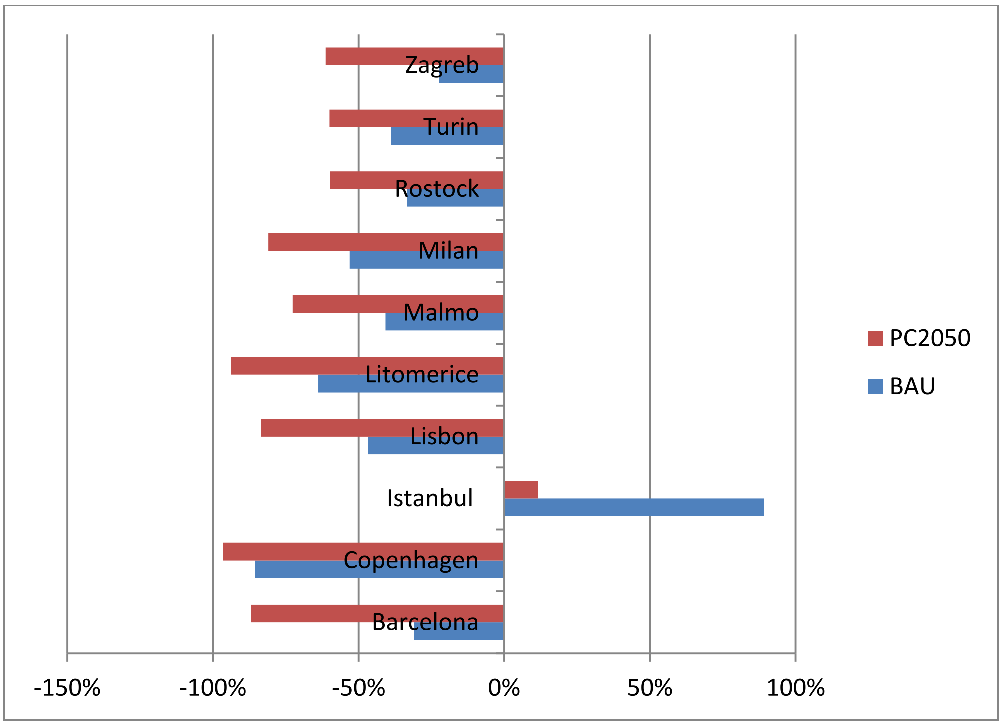

Figure 94: Percentage change in GHG emissions per capita from 2007 to BAU and PC2050 using standard territorial calculation method

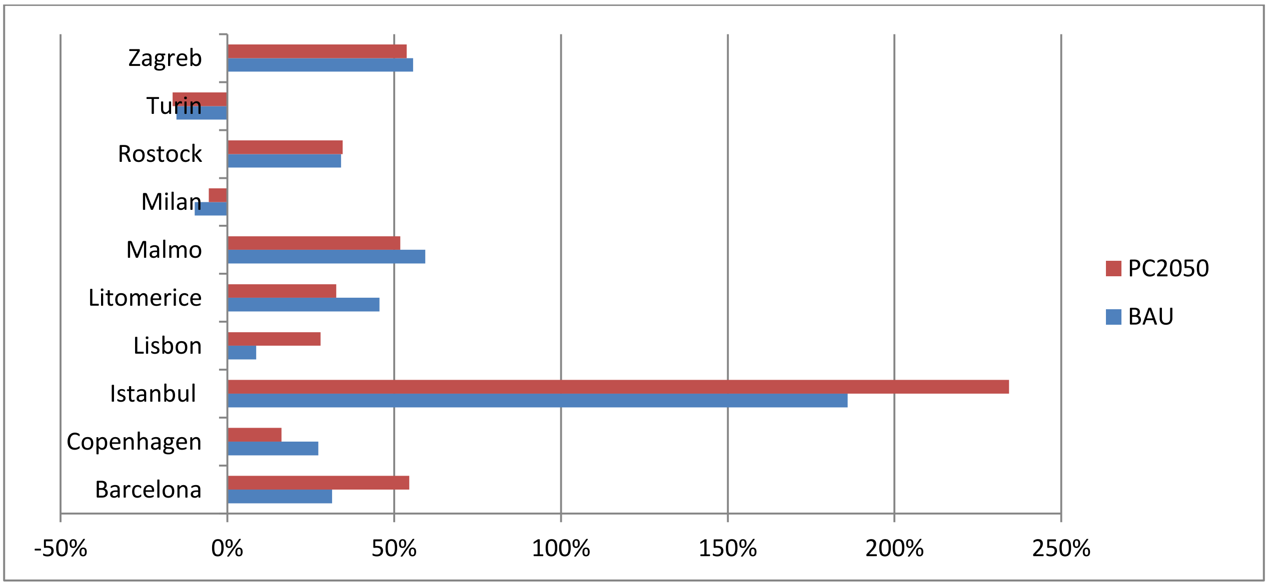

Figure 95: Percentage change in GHG emissions per capita from base year to BAU and PC2050 using footprint analysis

OTHER IMPACTS

Other impacts show a similar pattern of increases under both BAU and PC2050 due to increasing consumption.

UNCERTAINTIES AND LIMITATIONS

The research presented here is the first known attempt at using MRIO to model future scenarios of city strategies. Only one other study using EE-MRIO to study future scenarios was identified in a literature review. Scott *et al.* (2013) used the Eora MRIO database to model UK national consumption scenarios and their GHG emissions up until 2050 but no similar analysis has been identified for cities.

Using MRIO has several uncertainties and limitations aside from the general limitations of modelling future scenarios. One of the major criticisms of MRIO is that it is based on economic units and not on actual physical data. It therefore assumes proportionality in the allocation of resource flows to monetary structures (Bruckner et al, 2012). Hence the resource use related to trade and consumption in western countries, with high value to weight ratios, can be underestimated in comparison to emerging economies (Bruckner et al, 2012). For example, Steen-Olsen (2014) examined four of the most important global MRIO systems and found considerable sensitivity to background system detail and that sub-sectors within an aggregate MRIO sector can have widely ranging carbon multipliers.

The following lists some of the challenges and uncertainties that we met or identified:

- There were several challenges to modelling the background system in 2050 due to the need to adjust each global region for all 200 product groups, as well as for emissions intensities. The assumptions used were based on the best available literature but there may well be improvements in resource efficiency by 2050 (we hope) beyond those modelled. Manual adjustments made to the emissions intensities were based on an estimation of how the change in production recipes affects the environmental impacts.
- Aggregation of product groups – there is a limitation to the 2007 versions of the Exiobase database of 200 product groups that prevents some complex changes within the modelling exercise. For instance there was no specific category for district heating, or ability to model differences in some of the fuels used for district heating. The closest was “steam and hot water supply services” but using this led to high GHG emissions, which was not representative of some cities projected biomass fuel. We therefore utilised the most similar product group such as using “Products of forestry, logging and related services”.
- There appeared to be some bugs within the Exiobase database which produced higher than expected GHG emissions for some cities for 2050 compared to 2005. There was therefore a need to readjust some of the emissions intensities to counter this.
- The household consumption base data and projections to 2030 obtained from Oxford Economics, which was used as a basis to extrapolate trends to 2050, was limited to 42 COICOP[13] categories. It was therefore necessary to convert this into the 200 product groups, which may have increased uncertainties to some degree.
- This could be related to the fact that in some cases the data for the base year of household final demand did not match well with the data on the energy profile obtained from the energy and GHG emission reporting of the actual cities. This in part however, is also due to expected differences between household consumer spending and the energy profile of the city. This was overcome by striking a balance between the territorial energy profiles and the base year

[13] The Classification of individual consumption by purpose (COICOP) is nomenclature to classify individual consumption expenditures. It was developed by the United Nations Statistics Division.

of Exiobase. That is to say adjustments to the energy profile for 2050 were made by considering both the base year profile of Exiobase and the bottom-up projections made from the territorial energy data.

- Within the scope of the project, it was not possible to perform a sensitivity analysis (e.g. on different resource efficiencies of the global production system) on the model or background system due to the manual way the model was built and adjusted.

V.I.IV ECO-SYSTEM SERVICES

LAND USE CHANGES

In summary the analysis of land use change showed that all cities would experience various degrees of urban development and loss of non-urban land (continued urban sprawl). It should be noted that the analysis was performed for the wider NUTS III areas and greater metropolitan areas, to encompass the wide scale impacts that the economic activities of the cities. Most of the cities will experience densification in some parts, but also dis-densification where population declines.

Whilst the BAU scenarios were modelled by extending the trends of development from 2000 to 2012, the assumption for the PC2050 scenarios was that policies would ensure no net further development of non-urban land. Therefore densification would be a central policy for PC2050. The result of this is that the BAU results are of great interest as these illustrate the potential impact and encroachment of future development on non-urban land. Table 83 provides a summary of the analysis for the BAU scenarios. It shows that despite some cities experiencing population decline, all cities will experience development of currently non-urban area if trends continue. The cities with the highest potential for further loss of non-urban land, ranging from 43.7% to 19.9%, are Malmö, Istanbul, Copenhagen and Barcelona.

Table 83: Quantity and percentage of projected development for the case study cities under BAU

	Km^2 change 2012-2050 BAU	% change 2012-2050 BAU
Barcelona	161.0	19.9%
Copenhagen	74.4	23.6%
Istanbul	331.5	30.1%
Lisbon	64.4	10.6%
Litoměřice	0.1	1.9%
Malmö	37.4	43.7%
Milan	40.4	5.6%
Rostock	5.7	10.8%
Turin	32.6	7.1%
Zagreb	11.5	7.1%

This is of concern for two primary reasons. Firstly, the importance of green recreational areas and non-urban land is increasingly recognised by research for health, well-being and quality of life. Secondly, research also shows that sprawling cities require more infrastructure (and are therefore more resource intensive), are less energy efficient and have a higher carbon footprint than dense city areas.

Densification and urban sprawl were generally not well covered in the city visions and actions of POCACITO case study cities. herefore there is a need to ensure policies and strategies are developed to incorporate dense development.

The value of urban green areas is also supported in the analysis of recreational benefits for Malmö and Copenhagen, presented in the following section.

RECREATIONAL BENEFITS FROM URBAN GREEN AREAS (ASSESSING ECO-SYSTEM SERVICES)

The approach of this work was described in Section III.III.IIII.III.I and provides an analysis of recreational benefits for Malmö and Copenhagen. This was performed only for these two cities due to limitations in data and the project scope.

The linear regression model, used for the benefit transfer from Copenhagen to Malmö region, relates population density with the value per hectare per municipality. The relationship was used to derive values per ha in the Malmö region based on the areas of sites and population density in the Malmö region. The regression model showed a good statistical fit, explaining 73% of the variance in the underlying data. The results show a positive relationship between site values and population density.

Overall, results show that sites closer to urban centres are more valuable than sites further away. This is because of the more frequent visits to sites closer to home than further away combined with a more dense population in the inner cities. For Copenhagen (see Figure 96 and Table 84), recreation services from urban green areas range from 159,687 DKK/ha/yr in the innermost part of the city to 33,364 DKK/ha/yr for sites in the outskirts of Copenhagen. For the rest of Zealand, the average per hectare value is around 8,800 DKK/ha/yr. In a Post Carbon scenario where the city will further densify and urban sprawl is reduced, recreational values increase significantly more in the inner city than under a BAU scenario. In CPH1 (the inner most part of Copenhagen), per hectare values attain 1.9 MDKK/ha/yr compared to 1.7 MDKK/ha/yr (2014 prices). For CPH2, there are only marginal differences between the Post Carbon and the BAU scenarios with per hectare values around 2.3MDKK per year. For the more peripheral area of Copenhagen, the higher density of people with increases from 4 persons per hectare to between 75-77 persons per hectare in the PC and BAU scenarios, values increase from ca. 33,000DKK/ha/yr to between 679,000 DKK/yr/ha and 698,000 DKK/ha/yr, respectively.

Transferred site values of today range from 177,000 SEK/ha in Malmö municipality to 6,000 SEK/ha in Skurup municipality (see Figure 97 and Table 84). In a BAU scenario, recreation site values increase in Malmö by 32% to 234,000 SEK/ha. The largest increase is expected to be in Staffanstorp (66%) and Burlow (51%). In the post carbon scenario, recreation values increase in Malmö by 35% to 240,000SEK/ha. This is a much higher increase than in the BAU scenario, given a higher population density (25.6p/ha). Less pronounced increases are expected in Staffanstorp (60%) compared to the BAU scenario. However, an increase is seen in Burlöv (61%) due to a densification of existing urban areas.

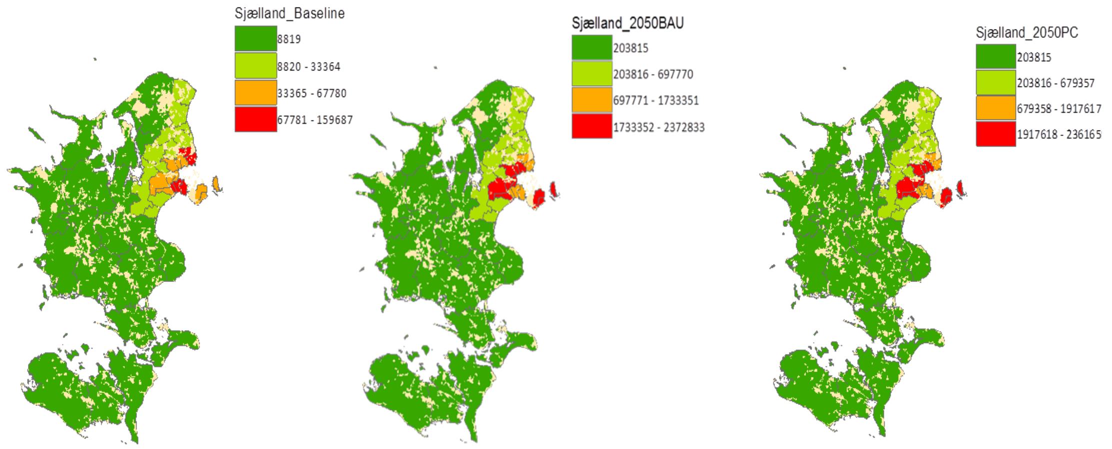

Figure 96: Recreational values (DKK) per ha at municipality level for Greater Copenhagen area under the BAU and PC2050 scenarios

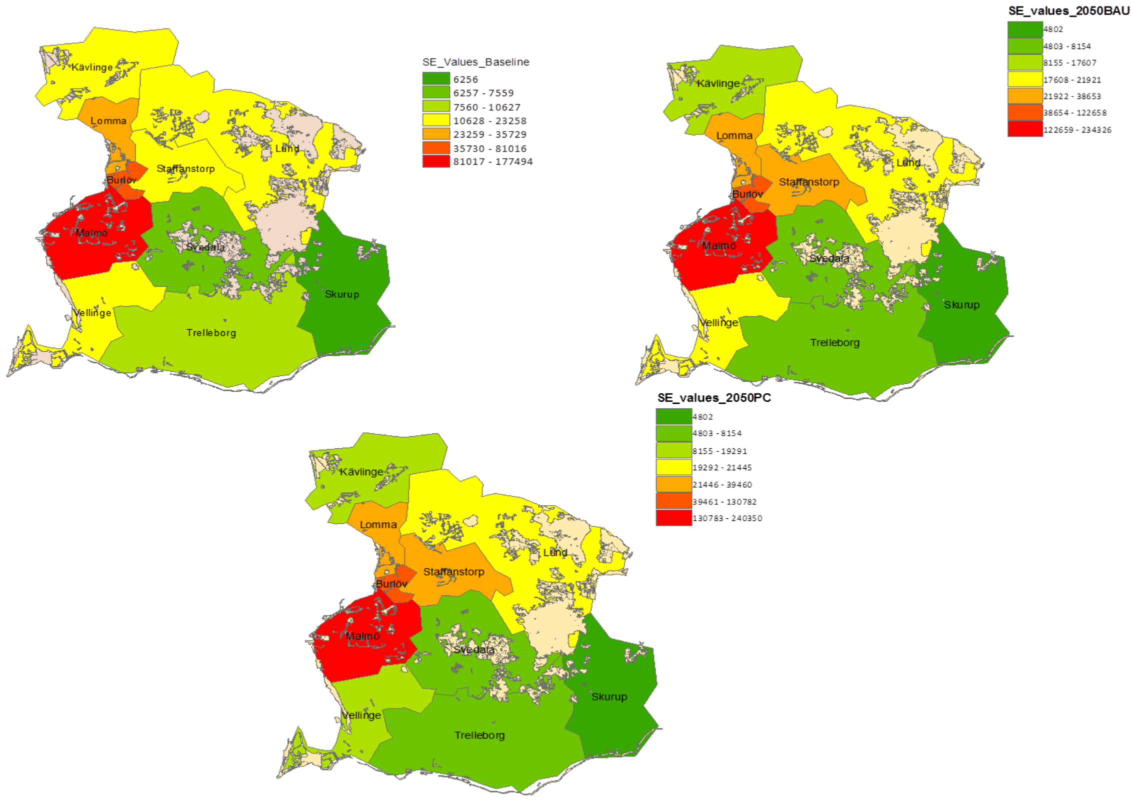

Figure 97: Recreational values (SEK) per ha at municipality level for Sweden under the BAU and PC2050 scenarios

Table 84: Recreational values per ha for regions in Copenhagen and Sweden

REGION	BASELINE 2012		BAU 2050		POST CARBON 2050	
	Population density (p/ha)	Values per area (DKK/ha/yr)	Population density (p/ha)	Values per area (DKK/ha/yr)	Population density (p/ha)	Values per area (DKK/ha/yr)
CPH1	14.48	159,687	35.55	1,733,351	41.11	1,917,617
CPH2	7.96	67,780	20.86	2,372,833	21.02	2,361,659
CPH3	3.59	33,364	6.09	697,770	5.83	679,357
Remaining Sjaelland + Lolland + Falster	0.81	8,819	1.01	203,815	1.01	203,815
Sweden						
Region	**Baseline 2012**		**BAU 2050**		**Post carbon 2050**	
	Population density (p/ha)	**Values per area (SEK/ha/yr)**	**Population density (p/ha)**	**Values per area (SEK/ha/yr)**	**Population density (p/ha)**	**Values per area (SEK/ha/yr)**
Staffanstrop	2.11	18,404	3.44	30,502	3.33	29,491
Burlöv	9.00	81,016	13.58	122,658	14.48	130,782
Vellinge	2.36	20,654	2.50	21,921	2.21	19,291
Kävlinge	1.93	16,763	2.02	17,607	2.02	17,607
Lomma	4.02	35,729	4.34	38,653	4.43	39,460
Svedala	0.92	7,559	0.97	8,066	0.88	7,225
Skurup	0.77	6,256	0.61	4,802	0.61	4,802
Malmö	19.62	177,494	25.87	234,326	26.54	240,350
Lund	2.64	23,258	2.44	21,445	2.44	21,445
Trelleborg	1.25	10,627	0.98	8,154	0.98	8,154

(CPH = Copenhagen)

V.I.V SOCIO-ECONOMIC ANALYSIS

A summary of the discounted costs and benefits for all cities is shown in Table 85. It also shows the percentage of cumulative GDP (from 2018 to 2050) for the costs of energy efficiency improvements and additional renewable energy. It shows that for all cities apart from Copenhagen, Istanbul and Malmö, the benefit-cost ratio is positive for BAU. Under PC2050 the benefit-cost is positive for all cities apart from Istanbul (due to poor air quality) with the ratio ranging from 0.6 to 6.4. The highest benefit-cost ratios occur for the cities of Zagreb, Barcelona, Milan and Litoměřice.

The range of costs for PC2050 is related to both the size of the city and the degree of actions stipulated in the city visions (which were used as a basis for the modelling). This limits the comparability of costs between the cities.

Although this needed to be a simplified cost-benefit analysis it shows that the return on costs is very positive for most cities, even though the only benefits that were costed in this analysis were based on changes in air-quality and premature deaths.

Table 85: Costs and benefits comparison of the scenarios

(MEUR)	DISCOUNTED COSTS (3%)		% OF GDP		DISCOUNTED BENEFITS (1%)		BENEFIT/COST RATIO	
	BAU	PC2050	BAU	PC2050	BAU	PC2050	BAU	PC2050
Barcelona	2792	6597	0.15%	0.31%	19 178	36 063	6.9	5.5
Copenhagen	2 291	4 397	0.18%	0.35%	-2 199	2 499	-1.0	0.6
Istanbul	19 644	32814	0.28%	0.45%	-438 731	-94 711	-22.3	-2.9
Lisbon	1064	2873	0.28%	0.69%	1 008	7 340	0.9	2.6
Litoměřice	66	132	0.77%	1.53%	294	447	4.5	3.4
Malmö	830	2 230	0.13%	0.35%	-154	2 258	-0.2	1.0
Milan	2 903	14 299	0.15%	0.73%	29 552	54 193	10.2	3.8
Rostock	528	1 085	0.34%	0.63%	808	2 179	1.5	2.0
Turin	1 768	4 869	0.26%	0.68%	8 313	13 968	4.7	2.9
Zagreb	1385	3557	0.30%	0.76%	6 363	22 897	4.6	6.4

VI CONCLUSION

The quantitative scenario assessment utilised several complementary methods to enable a thorough analysis and comparison of BAU and PC2050. In particular, the inclusion of both the standard territorial method of calculating GHG emissions and a footprint analysis using EE-MRIO has provided some valuable and enlightening results.

The assessment has shown that all cities are generally moving in a positive direction under BAU but would this would be vastly improved under the post carbon scenarios. The positive conclusion is therefore that progress is happening and under post carbon strategies a move beyond carbon is a real possibility.

However, taking a more critical stance, there are several factors which need further attention and a number of risks under both BAU and PC2050. Despite many cities approaching “zero carbon”, the strategies used as a basis for modelling still fall short in most cases of reaching zero carbon even in the traditional territorial sense.

In terms of reducing GHG emissions many city approaches are still only addressing the low hanging fruits – i.e. they are only now beginning to implement measures to reduce GHG emissions that occur within their territories or city boundaries – and to which they may have some “organisational control” i.e. electricity. Many cities also appear fail to apply a life cycle approach and life cycle emission factors in accounting for GHG emission quantities.

Naturally there is a need to begin with the low hanging fruit such as local energy efficiency and energy supply, but moving more towards a consumption and life cycle approach is not only necessary to avoid falsely claiming carbon neutrality, it is also necessary to avoid moving emissions abroad. The latter eventuality also encompasses moving jobs aboard, and reducing the opportunities to embrace a more holistic circular economy approach.

Therefore accounting for the full footprint emissions can help foster sustainability in two ways. Firstly, it represents the true picture of the impact of the city and helps identify where efforts should be targeted to reduce the total GHG emissions. Secondly, it promotes a smarter approach to providing consumable products, and no longer promotes moving production abroad. It can be argued that the physical proximity of the manufacturer and consumer allows greater opportunities for refurbishment and remanufacturing, capturing the value of the product components and reducing detrimental effects. Ultimately, this fosters lower negative impacts, in particular in terms of resource use and corresponding GHG emissions. Hence, from a sustainability point of view, there is a potential for more local jobs (social), more local production and less imports (economic) and reduced impacts (environmental).

Other risks and weaknesses to both BAU and PC2050 centre primarily on socio-economic conditions and piecemeal planning resulting in urban sprawl and associated inefficiencies (i.e. increased needed for infrastructure and transport). Whilst we have utilised the previous research of IIASA (IIASA, 2015) in assuming greater economic productivity of sustainable cities (i.e. translated as higher GDP), the main risk we refer to is the widening gap between the rich and poor and cultural segregation.

Although great gains can be made from improved public transport in terms of economic efficiency (e.g. through reduced congestion and improved connectability) the evidence from the case study cities suggests a limit to public transport utilisation. For example, in some cities (e.g. Malmö) recent progress has been made to shift the modal balance to sustainable forms, but there is much to suggest that some cities are approaching a saturation point (i.e. there has been a slowdown in the shift) and there is still a strong role for cars. The main point here is that cities need to be aware of an optimum balance between public transport, cycling, walking and car utilisation. There is therefore a need to increase support of more sustainable car transportation i.e. the shift to electric motorisation. This also holds true for public transport which can be a particularly large contributor to health damaging air pollution when diesel is the main fuel.

VI.I.I CRITICAL FACTORS

In summary we list some of the most prominent critical factors from the assessment:

1. **Post carbon status will not be reached by 2050 for the majority of case study cities under the current BAU trajectories**

   Only Copenhagen is under 1 tonne CO_2e per capita/year with the most extreme being up to 5 tonnes CO_2e per capita/year for Istanbul. The majority of cities are still in the range of 2-4 tonnes tonne CO_2e per capita/year.

2. **Post carbon status will also be missed under most PC2050 scenario's, due to weak actions and milestones**

   However, there is good potential to counter this in the individual city strategy papers.

3. **When consumption impacts/footprint analysis of the cities are assessed using EE-MRIO the projected impacts are even more pronounced and increase in eight out of ten cases**

   This is primarily linked to rising GDP and a corresponding increase in spending and consumption.

4. **There is a key role for cities to limit the footprint impact by fostering and promoting the circular economy.**

   Cities are the drivers of economic growth but are also the root driver of the majority of consumption. There are many ways in which a city can help foster a circular economy by providing the facilities and infrastructure required to reuse, repurpose, refurbish, and remanufacture, as well as the more traditional (but as yet not perfected or fully implemented) recycling. Cities can work together with businesses to enable this, but cities can also help foster new innovative businesses through appropriate policies.

5. **Energy and resource efficiency measures can significantly reduce the investment required in renewable energy**

   There are still significant opportunities to improve the energy efficiency measures of the PC2050 for most cities. This could be realised by embedding an energy efficiency approach in policy to foster concerted action on transport, buildings, appliances and the planning of infrastructure. Lowering the energy demand would subsequently reduce the requirements for installed capacity of renewable energy and its storage.

6. **The benefits of achieving post carbon status and a performance across sustainable KPI's far out weight the potential costs in most cases**

   Despite our analysis being simplified it shows that the benefit-cost ratio is positive in nine out of ten cities (although an improved PC2050 strategy for the remaining city, Istanbul, would also make this positive), and would be even more so if gaps are addressed. In addition, energy costs are significantly lower (by up to 45% for Lisbon) under PC2050 due to the increased emphasis on energy efficiency measures and the corresponding need for lower capacity. Furthermore, the PC2050 measures would create thousands of jobs related to the energy efficiency and renewable energy provisions.

   Despite factors such as smart grids and transport being omitted from the cost benefit analysis, a growing body of research supports the notion that benefits firmly outweigh costs for improved public transport (e.g. Rode and Floater, 2014; Litman, 2015) and smart grids (e.g. IEA, 2011b; The Climate Group, 2008).

7. **Effective and ambitious long term strategies for energy efficiency and renewable energy are required almost immediately**

   The task of developing enough renewable resources to supply most cities, particularly in a time of increasing electrification is enormous and should not be underestimated. However, there is a need for quick implementation of energy efficiency measures and renewable energy technologies to maximise benefits, improve health and well-being, and to avoid a potentially paralysing lock-in of sub-standard physical elements including buildings and transport.

8. **<u>Urban sprawl is a concern for all cities, even for those with a projected population decrease, with up to 43% of non-urban land being converted to urban land.</u>**
9. **<u>Social issues are consistently of concern and need addressing</u>**
   This is true not only for BAU but also for PC2050. One of the most important common KPI's with a poor performance in 2050 is the poverty level and the disparity between rich and poor.

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VIII ANNEX 1 - ASSUMPTIONS

This Appendix provides additional information on the assumptions and modelling methods used for the energy calculations.

VIII.I BARCELONA

VIII.I.I BAU

The current trends were used with caution because they closely follow potential fallout from the financial crisis. For example, energy use in Barcelona was growing until 2006, but then began to drop along with the GDP, which fell from 2008. However, the energy growth is consistent with the population growth 2001 in the municipality.

- Oxford economics shows that GDP returns to steady growth in 2014.
- Most energy decline was experienced in the transport and industry sectors, which again could be the result of the financial crisis. This is in line with the Province as well. This could also suggest that people travelled less to the city from the provinces.
- GDP by sector shows that the service sector has grown by almost 10% points, whilst industry has declined. (http://www.diba.cat/documents/471041/24663576/emissions+in+Barcelona_july+14.pdf/34110b21-ca61-4da6-acc2-d4f83695fc2a).
- This leads us to suggest that with a recovering GDP, energy consumption could increase again. The share of energy for transport could also increase to about the (pre-) financial crisis levels.
- Due to lack of data therefore we suggest that BAU energy consumption by sector is similar to 2005 with a greater share covered by the service sector.
- Service sector has continued to grow GDP whilst decreasing energy
- According to Oxford Economics population does not grow any further for the Province.
- EU energy trends predicts Spain's energy to be similar per resident as growth in final energy demand is similar to population
- According to the Barcelona Energy and Climate Plan: electricity share has increased from 37,2% to 44.3% (http://w110.bcn.cat/MediAmbient/Continguts/Vectors_Ambientals/Energia_i_qualitat_ambiental/Documents/Traduccions/PECQ_english_def01.pdf)
- Therefore we assume that:
    - the service sector continues to grow to 2050 but improves efficiency - therefore similar energy in total
    - industry recovers to 2005 levels with slightly increased efficiency 5%.
    - for the residential sector the increase in electrification cancels out efficiency increases and total energy demand per capita remains similar to the present level.

VIII.I.II PC2050 BARCELONA

The following assumptions were applied to the PC2050 scenario for the sectors:

- Residential: considers a 40% improvement in energy efficiency according to IEA.
- Services: also 40% efficiency.
- Industry: 20% efficiency improvement.
- Transport: shift to electric 60% of energy use.

VIII.II COPENHAGEN

VIII.II.I BAU

There is not enough reliable data and information available to identify a trend in energy demand. The trend from 2005 to 2014 suggests no overall change in energy use, despite 2014 being somewhat lower. Carbon emissions show a clear decline however.

Heating use has remained more or less stable but electricity seems to have been reduced. This could be due to milder weather according to energy and carbon review/ green account. http://kk.sites.itera.dk/apps/kk_pub2/pdf/1393_x6fHiBE3UX.pdf

In addition, the data is only available from 2008 to 2013 and therefore could be affected by the financial crisis.

Therefore the current projections have taken into account the projected population rise (54%) and assumed a modest energy efficiency increase of 22% – resulting in an average increase of 20% in energy.

Transport energy was not available and was calculated from the reported GHG emissions, by converting from a similar example (Malmö).

VIII.II.II PC2050 COPENHAGEN

Because a visioning workshop was not held in Copenhagen, the basis for the projection is the current 2025 carbon neutral vision of the city. The major difference is that we assume that the transport is also carbon neutral.

VIII.III ISTANBUL

There was insufficient data on energy use and production, and the current trends for Istanbul. However, enough data did exist to construct a reasonable approximation. To enable this additional data from national trends, available in literature and from Eurostat was used.

Electricity use for Istanbul was only available for the year 2013, but there were clear qualitative reports that electricity use has greatly increased, of the order of 78% over the previous decade.

VIII.III.I BAU

National data and trends of energy use was used as a basis and projected to 2050. This was then converted to energy use per capita. Istanbul energy was then calculated for 2013 based on the per capita figure. Using the known electricity use, the % of electricity could then be estimated.

Figures were available from WP3 on the percentage share of energy used for each sector (industry, services, transport, agriculture and others) for 2003 and 2008 – which was then used to calculate the energy use of each sector. These percentages were also used to estimate a trend for the sectors and the share of the total energy for BAU 2050.

The share of electricity could be estimated for 2013 from the available data and then projected to 2050.

VIII.III.II PC2050

To calculate the energy for PC2050, the BAU figures were used as a basis and the following assumptions were applied to each sector:

- Residential: a 40% improvement in energy efficiency.
- Services: also 40% efficiency improvement.
- Industry: 20% efficiency improvement.
- Transport: shift to electric vehicles for 60% of the transport energy.

These basic assumptions were derived from the literature (such as predictions of the IEA) on potential energy efficiency gains, combined with an assumed large potential for improvement within Istanbul.

VIII.IV LISBON

Data was available by sector for 2008 and 2012 for Lisbon city. This showed an increase in energy use.

VIII.IV.I BAU

The following assumptions were applied in the calculation of energy:

- Population declines by 4%.
- Industry energy demand has increased since 2004 but remains static through to 2050 (it is generally expected that services will increase in European countries).
- Energy use per person increases to 2050 in line with EU trends projections for Portugal (Capros 2014) at 3%.
- Whilst electricity use increases by 29.5%
- The current trends for energy use in the sectors are used as a basis and then adjusted by population.

VIII.IV.II PC2050

BAU energy use is used as a basis with the following assumptions:

- 50% of traffic is electric (using 40% of total traffic energy)
- Assume that efficiency of electric transportation is 40% of current levels.
- Whilst fossil fuel vehicles use 70% of current energy consumption levels.
- Energy efficiency of buildings is 70% of today for services and residential.
- Industry improves efficiency by 20%.

VIII.V LITOMĚŘICE

VIII.V.I BAU

- Geothermal supplies all heating needs of the city. This is seen as feasible as work is progressing well in drilling and development.
- Assume 20% improvement in building heating efficiency, and 20% improvement in energy efficiency of household appliances.

- Transport in PC 2050 uses 40% of the energy, but also energy using traffic is reduced by 30%.
- New hydroelectric power plant supplies 30 GWh per year.
- There are no data on energy consumed in transport, but there is an assessment of CO2 produced from transport based on regional values. This is used to estimate the energy for the transport sector.

VIII.V.II PC2050

- Geothermal supplies all of the heating and most of the electricity.
- Passive housing and buildings are the main focus for the PC vision.
  Hence heating of buildings and houses in the city as a whole is reduced by 50%. This is because some older buildings would remain.
- Electricity use decreases mostly due to appliances in BAU (80%) and 60% in PC.
- Due to success of geothermal power, a second plant is installed for district heating
- There is an assumed improved efficiency in use of natural gas.

VIII.VI MALMÖ

For energy calculations good data on sources and use was available for 2005 from Malmö Energi Strategi (2009). This was converted to 2013 using additional data, which then formed the basis for the calculation of the BAU and PC2050 scenarios.

VIII.VI.I BAU

Total energy has remained fairly stable since 1990, hovering around 7000 GWh, although with a spike in 2005 and 2006. This occurred despite the population increasing by about 34% from 1990 to 2013.

Despite the energy remaining fairly stable there appears to be a moderate increase of about 8-10% over the last 10 years.

With a similar population growth rate predicted until 2050, we therefore used this trend to suggest a conservative growth in total energy of 10% despite the population expected to increase by 60%. Thus we expect a considerable improvement in energy use of both existing buildings and new buildings. Recent developments such as Västra Hamen and Hyllie suggest that standards for energy efficiency are high and continually improving, thereby supporting this assumption.

The electricity share of energy will rise to 38% in 2050 following a similar trend to the national projection by Capros et al. (2014).

VIII.VI.II PC2050

In the PC2050 scenario the share of electricity of the total energy demand will rise to 67.8%. For energy use the following assumptions were applied for the relevant sectors:

- Housing has a 30% efficiency improvement on current stock and new accommodation for residents uses 40% of current energy.
- Industry and construction: 30% more efficient but 30% more manufacturing. Due to more innovation, location, population and circular economy.
- Transport: 1.3 more travellers using energy mode traffic, roughly half the new population. But traffic is 40 more efficient.

- Increase in services based on population factor but 20% more efficient

VIII.VII MILAN

Milan’s Sustainable Energy and Climate Action Plan (SEAP – produced for the Covenant of Mayors) was used as a basis, and supported with additional data from WP3 that provided figures for 2005 and 2010 for the sectors energy use.

According to Milan’s energy plan (SEAP) expected growth without actions would be about 4.5% every 5 years for the municipality. Figures for Milan show energy use grew 4.1% from 2005 to 2010. However, 2013 figures show a slight decline. We assume this to be due to financial crisis and apply a nominal energy growth rate of 2% every 5 years to 2050.

VIII.VII.I BAU

The following assumptions or effects were applied:

- Electricity use efficiency cancels increase.
- District heating network grows.
- Service grows but industry decreases at same rate.
- Transport energy demand remains at similar levels to the current level.

VIII.VII.II PC2050

The following assumptions or effects were applied:

- Residential: existing becomes 60% more efficiency whilst new dwellings use only 40% of energy as before
- Industry and tertiary: efficiency improves 30%
- Private transport is 20% of total energy and efficiency of electric cars is 60%
- Public transport: 20% more efficient than BAU due to focus on electric and smart technology, but (65/51) 27% more volume

For transport:

- Energy reduced in transport system by 20%
- Public transport increases to 65%
- Bicycles are 15% of modal share
- 80% of cars are electric or PHEV

VIII.VIII ROSTOCK

For Rostock the city’s Masterplan (Masterplan 100% Klimaschutz für die Hansestadt Rostock, Gicon, 2013) was used as a basis for the calculations and the scenarios “Trend” used for BAU and “Ambitious” used for PC2050.

However, the energy use was adjusted using the POCACITO population projections as these were viewed as more realistic. Rostock’s Masterplan was calculated on an assumed decline in population. But according to Oxford Economics projections and consultation with the case study team, the population is now expected to increase.

VIII.IX TURIN

The trends in Turin's Action Programme for Energy were used as a basis for the calculations. The calculation assumes that the commitments in TAPE are achieved and that similar reductions from 1991 to 2020 can be made up until 2050.

VIII.IX.I BAU

The following energy efficiency assumptions were applied to the sectors:

- Municipal and lighting – 10% improvement.
- Residential and tertiary – 30% improvement.
- Industry and transport – 20% improvement.

VIII.IX.II PC2050

The following energy efficiency assumptions were applied to the sectors:

- Municipal and lighting – 10% improvement.
- Residential - 40% improvement.
- Tertiary – 50% improvement.
- Industry – 20% improvement.
- Transport – 60% improvement.

VIII.X ZAGREB

Basic data was available for Zagreb for energy consumption by sector for 2008 and 2013. These were obtained from the Zagreb Sustainable Energy and Climate Action Plan (SEAP – produced for the Covenant of Mayors).

VIII.X.I BAU

Due to the limited amount of data and information on current trends and energy related projects only some basic assumptions could be applied and limited improvements assumed.

The trend of each sector from 2008 to 2013 was extrapolated and the energy consumption adjusted based on a percentage factor calculated by the expected population growth to 2050 (10.4% for BAU and 15.9% for PC2050), and the following assumptions for energy efficiency:

- Municipal: assumed to stay the same for all scenarios. Energy efficiency improvements are cancelled by an increased need for services due to population growth.
- Tertiary: 30% improvement in energy efficiency.
- Residential: limited to a 10% energy efficiency improvement due to limited information on current trend and situation.
- Transport: basic 30% improvement.
- Public lighting: the same as 2008, hence improvement in efficiency is cancelled by increased lighting for increased population.

A general assumption was first applied that there was a 30% improvement in overall energy use (based on current trend and assumed technological improvements suggested by IEA), which was then adjusted by a factor according to the expected population change.

VIII.X.II PC2050

The calculation was repeated as in BAU but with the following assumptions, derived from the PC2050 scenario:

- Municipal: assumed to stay the same for all scenarios. Energy efficiency improvements are cancelled by an increased need for services due to population growth.
- Tertiary: 40% improvement in energy efficiency.
- Residential: limited to a 30% energy efficiency improvement due to limited information on current trend and situation.
- Transport: basic 40% improvement. There was only limited mention of electric cars in the PC2050 scenario and hence we assume only limited improvements.

Public lighting: the same as 2008, hence improvement in efficiency is cancelled by increased lighting for increased population.

IX ANNEX II: SPATIAL MODELLING OF CITY DEVELOPMENT FOR 2050

Population and land use changes

Table 86 summarizes population and land use and changes between 2000 and 2012 and the projected changes for 2050 for the BAU and the PC scenarios. For most cities, the period between 2000 and 2012 was characterized by considerable population increases, urban spread and consequently decrease in non-urban land. Projected population changes for the BAU scenarios vary from slight population decreases to strong increases. Correspondingly, projected changes in land use vary. However, since the BAU scenario is based on the historical patterns in urban change, also negative population changes result in increases in urban land. Except from Istanbul, projected population changes for the PC scenario are slightly higher compared to the BAU scenario. Since the central assumption for the PC scenario is that population increase cannot result in urban spread, the PC scenario does not result in any land use change.

Trends in urban development

Table 87 summarizes results from the historical and the scenario analyses in more detail. Results are shown as change in km² and in population for the different types of urban development. For the period from 2000 to 2012 the results indicate, that population increases were followed by urban spread and concurrently by considerable areas with densification (population increases) but also areas with dis-densification (population decreases).

Spatial patterns of urban change

For each case city, the figures in the relevant sections show the spatial patterns of population change and types of urban change for the period from 2000 to 2012 and for 2012 to 2050 for the BAU and PC scenarios.

Table 86: Historic population and land use changes and projected changes for case cities

	2000	2012	Change 2000 - 2012	% change 2000 - 2012	2050 BAU	Change 2012 - 2050 BAU	% change 2012 - 2050 BAU	2050 PC	Change 2012 - 2050 PC	% change 2012 - 2050 PC
Copenhagen										
Population (in 1000)	1,158.5	1,214.2	55.7	4.8%	1,538.2	324.0	26.7%	1,589.0	374.7	30.9%
Urban land (km²)	302.1	314.9	12.8	4.2%	389.2	74.4	23.6%	314.9	0.0	0.0%
Non-urban land (km²)	325.2	312.4	-12.8	-3.9%	238.0	-74.4	-23.8%	312.4	0.0	0.0%
Istanbul										
Population (in 1000)	8,479.0	11,894.6	3,415.6	40.3%	17,162.9	5,268.3	44.3%	16,392.6	4,498.0	37.8%
Urban land (km²)	887.2	1,102.0	214.9	24.2%	1,433.5	331.5	30.1%	1,102.0	0.0	0.0%
Non-urban land (km²)	4,531.2	4,316.3	-214.9	-4.7%	3,984.8	-331.5	-7.7%	4,316.3	0.0	0.0%
Lisbon										
Population (in 1000)	2,423.3	2,780.0	356.7	14.7%	2,683.2	-96.9	-3.5%	2,970.6	190.5	6.9%
Urban land (km²)	472.0	607.6	135.6	28.7%	672.0	64.4	10.6%	607.6	0.0	0.0%
Non-urban land (km²)	2,381.1	2,245.5	-135.6	-5.7%	2,181.1	-64.4	-2.9%	2,245.5	0.0	0.0%
Malmö										
Population (in 1000)	266.9	291.3	24.5	9.2%	387.5	96.1	33.0%	398.7	107.3	36.8%
Urban land (km²)	76.0	85.6	9.5	12.5%	123.0	37.4	43.7%	85.6	0.0	0.0%
Non-urban land (km²)	102.8	93.3	-9.5	-9.3%	55.9	-37.4	-40.1%	93.3	0.0	0.0%
Milan										
Population (in 1000)	3,570.3	3,885.4	315.1	8.8%	4,094.9	209.4	5.4%	4,550.7	665.3	17.1%
Urban land (km²)	654.4	715.4	61.0	9.3%	755.7	40.4	5.6%	715.4	0.0	0.0%
Non-urban land (km²)	1,316.2	1,255.2	-61.0	-4.6%	1,214.8	-40.4	-3.2%	1,255.2	0.0	0.0%

	2000	2012	Change 2000 - 2012	% change 2000 - 2012	2050 BAU	Change 2012 - 2050 BAU	% change 2012 - 2050 BAU	2050 PC	Change 2012 - 2050 PC	% change 2012 - 2050 PC
Rostock										
Population (in 1000)	182.0	193.3	11.3	6.2%	205.1	11.8	6.1%	209.9	16.6	8.6%
Urban land (km²)	47.42	52.9	5.5	11.6%	58.7	5.7	10.8%	52.9	0.0	0.0%
Non-urban land (km²)	120.7	115.2	-5.5	-4.6%	109.5	-5.7	-5.0%	115.2	0.0	0.0%
Zagreb										
Population (in 1000)	741.9	795.3	53.4	7.2%	879.0	83.7	10.5%	948.3	153.0	19.2%
Urban land (km²)	154.7	162.1	7.3	4.7%	173.6	11.5	7.1%	162.1	0.0	0.0%
Non-urban land (km²)	486.5	479.1	-7.3	-1.5%	467.7	-11.5	-2.4%	479.1	0.0	0.0%
Turin										
Population (in 1000)	1,922.2	2,108.2	186.1	9.7%	2,079.1	-29.1	-1.4%	2,311.6	203.3	9.6%
Urban land (km²)	393.1	458.7	65.6	16.7%	491.3	32.6	7.1%	458.7	0.0	0.0%
Non-urban land (km²)	6,431.5	6,365.9	-65.6	-1.0%	6,333.3	-32.6	-0.5%	6,365.9	0.0	0.0%
Barcelona										
Population (in 1000)	4,477.3	5,327.2	849.9	19.0%	5,045.4	-281.7	-5.3%	5,402.1	75.0	1.4%
Urban land (km²)	607.7	807.5	199.9	32.9%	968.5	161.0	19.9%	807.5	0.0	0.0%
Non-urban land (km²)	7,125.3	6,925.5	-199.9	-2.8%	6,764.5	-161.0	-2.3%	6,925.5	0.0	0.0%
Litoměřice										
Population (in 1000)	26.3	23.7	-2.6	-10.1%	23.1	-0.5	-2.2%	25.0	1.3	5.6%
Urban land (km²)	5.2	5.9	0.6	11.6%	6.0	0.1	1.9%	5.9	0.0	0.0%
Non-urban land (km²)	13.2	12.5	-0.6	-4.6%	12.4	-0.1	-0.9%	12.5	0.0	0.0%

Table 87: Historic and projected changes for different types of urban change for case cities

		Change 2000-2012		BAU scenario		PC scenario	
Case city	Type of urban change	km²	population	km²	population	km²	population
Copen-hagen	Urban spread	12.8	16,029	74.4	92,963	0.0	0
	Urban no change	145.0	0	152.5	0	17.0	0
	Population densification	107.5	241,476	112.1	251,769	297.9	374,738
	Population dis-densification	49.6	-201,800	50.3	-20,752	0.0	0
	Non-urban	-12.8	0	-74.4	0	0.0	0
	Total		55,705		323,980		374,738
Istanbul	Urban spread	214.9	850,417	331.5	1,310,424	0.0	0
	Urban no change	133.0	0	171.1	0	80.2	0
	Population densification	592.5	3,953,475	743.1	4,958,841	1,021.8	4,497,983
	Population dis-densification	161.7	-1,388,254	187.9	-1,000,923	0.0	0
	Non-urban	-214.9	0	-331.5	0	0.0	0
	Total		3,415,638		5,268,342		4,497,983
Lisbon	Urban spread	135.6	230,132	64.4	109,128	0.0	0
	Urban no change	115.2	0	144.5	0	69.8	0
	Population densification	251.1	760,700	329.6	213,066	537.8	190,516
	Population dis-densification	105.7	-634,090	133.5	-419,067	0.0	0
	Non-urban	-135.6	0	-64.4	0	0.0	0
	Total		356,742		-96,873		190,516
Malmö	Urban spread	9.5	11,191	37.4	43,893	0.0	0
	Urban no change	44.6	0	50.9	0	9.0	0
	Population densification	21.8	48,969	24.7	55,600	76.6	107,343
	Population dis-densification	9.7	-35,676	9.9	-3,381	0.0	0
	Non-urban	-9.5	0	-37.4	0	0.0	0
	Total		24,484		96,112		107,343
Milan	Urban spread	61.0	190,267	40.4	126,094	0.0	0
	Urban no change	107.2	0	117.4	0	5.0	0
	Population densification	396.0	1,231,740	432.7	609,981	710.4	665,255
	Population dis-densification	151.2	-1,106,862	165.3	-526,632	0.0	0
	Non-urban	-61.0	0	-40.4	0	0.0	0
	Total		315,145		209,443		665,255
Rostock	Urban spread	5.5	9,487	5.7	9,924	0.0	0
	Urban no change	25.2	0	30.5	0	10.3	0
	Population densification	12.2	37,966	12.3	39,315	42.6	16,576
	Population dis-densification	10.0	-36,169	10.1	-37,487	0.0	0
	Non-urban	-5.5	0	-5.7	0	0.0	0
	Total		11,284		11,752		16,576

		Change 2000-2012		BAU scenario		PC scenario	
Case city	Type of urban change	km²	population	km²	population	km²	population
Zagreb	Urban spread	7.3	12,820	11.5	19,989	0.0	0
	Urban no change	79.9	0	83.6	0	3.8	0
	Population densification	58.9	109,807	61.7	115,354	158.3	153,004
	Population dis-densification	16.0	-69,242	16.8	-51,637	0.0	0
	Non-urban	-7.3	0	-11.5	0	0.0	0
	Total		53,385		83,706		153,004
Turin	Urban spread	65.6	152,127	32.6	75,820	0.0	0
	Urban no change	66.8	0	78.9	0	18.6	0
	Population densification	247.7	689,315	289.5	284,569	440.1	203,342
	Population dis-densification	78.6	-655,370	90.3	-389,493	0.0	0
	Non-urban	-65.6	0	-32.6	0	0.0	0
	Total		186,072		-29,104		203,342
Barce-lona	Urban spread	199.9	550,845	161.0	444,721	0.0	0
	Urban no change	79.5	0	121.3	0	100.4	0
	Population densification	338.8	1,513,493	451.2	752,169	707.1	74,964
	Population dis-densification	189.3	-1,214,455	235.1	-1,478,608	0.0	0
	Non-urban	-199.9	0	-161.0	0	0.0	0
	Total		849,883		-281,718		74,964
Litomě-řice	Urban spread	0.6	1,312	0.1	230	0.0	0
	Urban no change	0.8	0	0.9	0	0.1	0
	Population densification	1.3	3,628	1.5	4,044	5.8	1,332
	Population dis-densification	3.1	-7,586	3.5	-4,792	0.0	0
	Non-urban	-0.6	0	-0.1	0	0.0	0
	Total		-2,646		-518		1,332

X ANNEX III: OXFORD ECONOMICS BACKGROUND PROJECTIONS

Data on household consumption was purchased primarily for the MRIO analysis (to be reported in D5.3). But since it provided projections to 2030 for population change, GDP and employment, these were utilised as background data and the projections extended to 2050 (as discussed in Section I.II).

A brief explanation is provided below, written by Oxford Economics, on the methods used within its forecasting process for consumer spending by COICOP categories. Further detail cannot be provided due to the commercial sensitivity of the methodology.

X.I.I NATIONAL SPENDING

Both current and constant price spending by COICOP data for most countries comes from Eurostat, with time series generally ranging between 1980 and 2014, depending on the country. Before any forecasting takes place, data is checked for sensibility and some data points are removed or replaced with more appropriate estimated figures. The forecasts are then produced in four steps:

1) First, we estimate price equations for the 12 broad categories and forecast them to 2030 using national total consumption deflators and world commodity prices from our Global Model as drivers.

2) Once we have the price forecasts we then produce forecasts for the volumes of spending (i.e. at constant prices) by using total national consumption, population and the price forecast of each category. As a result, in each broad category the volumes are driven by their relative prices with an adjustment for the evolution of its historical share of total consumption.

3) The price deflators for each of the 12 broad categories are then applied to the constant price spending, producing current price spending.

4) Finally, spending in each of the detailed sub-category is forecast using a shirt-share model against its corresponding broad category.

X.I.II REGIONAL/CITY SPENDING

Oxford Economics have collected and incorporated regional/city level data into the historical series where it exists. However, data is significantly sparser at the sub-national level if not missing altogether (especially for developing countries). Therefore estimation of the historical series plays a greater role at the regional level. The approach adopted in producing regional estimates and forecasts considers the importance (i.e. share) of spending on a particular good/service in the region *relative to the country*. This "relative importance" is related to a series of economic and demographic factors which were analysed for a panel of countries with national and sub-national data:

1) Relative total consumption per capita: As total consumption per capita increases (due to rising average incomes) the share of spending on particular goods/services falls, while the share of spending on other goods/services rises. For example spending on food, a significant proportion of which would be classed as "necessities", falls as total consumption rises. Conversely, spending on more "luxury" items such as recreational services and hotels &

restaurants see their shares rise as total consumption rises. Thus, higher total consumption per capita in a region relative to the whole country results in a lower share of total expenditure on food in the region compared with the country, with the opposite being true for categories such as recreational services.

2) Relative share of population aged 18-34: A higher proportion of 18-34 year olds in the region's population (relative to the country) drives a higher share of spending on items such as education and hotels & catering in some countries.

3) Relative population density: A higher population density in the region leads to a greater share of spending on recreational services, and a lower share in transport services in some countries.

XI ANNEX IV: MODELLING ASSUMPTIONS FOR MRIO

This section lists the assumptions used to adjusted the coefficient table and emission intensities within the Exiobase data base.

The countries were divided into the following zones that contained industrialised countries and developing countries:

Industrialized Countries (IC) = Czech Republic, Germany, Denmark, Spain, Italy, Sweden, Japan, RoEU (rest of Europe) +NO+Switzerland and US.

Developing Counties (DC) = RoEU, Turkey, ROW (Rest of the World), BRICs (Brazil, Russia, India and China).

Changes in the emission intensities file were been made in accordance with the changes in the coefficient file and these are therefore not described separately.

COEFFICIENTS

ELECTRICITY MIX

Data for the electricity mix for EU countries are from "EU Energy, Transport and GHG emissions Trends to 2050" (Capros et al, 2014).

In the EU Energy, Transport and GHG emissions Trends to 2050 Solar-PV and Concentrated Solar Power is not separated. By 2050 It is assumed that Spain (50%) and Italy (10%) have CSP, Spain has a higher number as they are currently is a pioneers in the field. The other European countries are assumed to only use Solar-PV.

RoEU+No+Swizerland are assumed to have an electricity generation mix similar to the average for OECD – Europe in IEA World Energy Outlook (IEA, 2015), since no data was available. However, by comparing the energy mix for these countries the assumption seems reasonable.

Data for electricity generation mix for other countries are taken from the IEA World Energy Outlook 2015 (IEA, 2015) for the Current Policies Scenario. This data represent 2040 and not 2050. However the shares of respective energy source are assumed to be relatively similar.

ROW is calculated by subtracting the electricity use for BRICs from the electricity use for Non-OECD countries. Countries such as Australia and Canada should also be included in this data, however the electricity mixes of these two countries are similar to the average of Non-OECD and it will not imply any major inaccuracy.

RoEU the assumption is made that this area can be represented by Eastern Europe / Eurasia.

Turkey - no individual assessment of the country's future electricity mix was found and therefore two main assumptions were made. Firstly, Turkey are currently building several nuclear power plants, this implies that a considerable share of the future electricity mix will come from nuclear. Since the addition of nuclear will cover new demand for electricity it can be assumed that nuclear will take shares from all the other types of electricity generation sources. Secondly, with a relatively large share of nuclear Turkey will approach the average electricity mix of East Europe/Eurasia. Therefore the assumption was made that the development will be similar, but with a slightly higher share of hydropower and solar power due to the good conditions for these two energy sources.

TRANSMISSION AND DISTRIBUTION LOSSES

Data from IEA/OECD shows a high potential for non-OECD countries to reduce their transmission and distribution losses, by approximately 15% (IEA, 2014b). However, since the OECD countries have already approached best practice, no future decrease in losses has been assumed.

MOTOR VEHICLES, TRAILERS AND SEMI-TRAILERS

Due to the globalization of the vehicles market it is assumed that the same changes will occur all over the world. According to the document Lightweight, heavy impact McKinsey and Company (2012) there will be approximately a doubling of the use of aluminum on behalf of steal. Steal will also be replaced with HSS, resulting in an approximate reduction by 25%.

OTHER TRANSPORTATION SERVICES (LAND TRANSPORT)

According to Capros *et al.* (2014) the share of EV and HEV will increase, although from a very low level. These cars are also more energy efficient and therefore the total energy demand will decrease. Furthermore the ICE vehicles will become more energy efficient. Based on this data the assumption is made that:

- Use of fuel will be reduced with 25%
- Use of electricity will increase by 10 times
- Use of biofuels will double

It is assumed that there will be a similar development of vehicles in all the different regions/countries.

RAIL

It is assumed that ongoing electrification of the railway in many countries will continue resulting in a increased electricity use on behalf of other fuels.

In **EU + Japan** the electrification is assumed to increase. Hence, a reduction in fuel by 25%, also due to an increase in efficiency. Furthermore it is assumed that the increase in electricity use will be 50%.

In **DC** the electrification are assumed to increase, due to ongoing development. Fuel use reduction by 35% and electricity use increase by 50%.

The US is seen as an exception since they mainly use rail for freight transport and have a very low electrification today. This implies that there is a need for a paradigm shift for the electrification to increase which cannot be assumed in the BAU case.

AVIATION

According to the EU Trends document (Capros *et al*. 2014) biofuels will start penetrating the aviation fuel market slowly after 2035. Biofuels starts from a very low level, and will therefore increase by approximately 2000 times in order to have a market share. A certain degree of efficiency effect will probably reduce the fuel as well.

In DC the increase in use of biofuels will probably be lower as they often are a late follower.

SEA AND COASTAL TRANSPORTATION SERVICES

This industry works on a global market wherefore similar energy savings probably will be seen all over the world. The potential is relatively high and an assumption is made that the fuel consumption will be reduced by 25%.

NUCLEAR FUEL

There will be a general reduction for Germany as they are phasing out nuclear. In Turkey there will in contrary be an increase as they are starting to use nuclear power.

LABOR IN DEVELOPING COUNTRIES

In all types of industries in developing countries it is reasonable that the industries will be more technologically advanced in by 2050, hence approaching the same technological level and the same labor intensities as in Europe today. Therefor it was assumed that the ingredients connected to labor will be lower while the ingredients connected to a higher technological level such as fuel and electricity will increase. This is assumed to be the same for all labor intensive products.

The assumption is made that labor related ingredients in DC will be reduced with 15% while electricity and fuel will increase with 20% respective 15%.

WASTE MANAGEMENT

EU will have a ban for landfill by 2030. Hence the assumption is made that there will be no landfill by 2050 in EU. The cost will instead be added to incineration which is the next step in the Waste Hierarchy.

In the regions outside EU the legislation has not come as far as in the EU wherefore the assumption is that landfill will continue as today in the BAU case. Furthermore, a high increase in biogasification is seen as not likely in the BAU scenario.

FERTILIZERS

Low income (ROW, RoEurope) countries will by 2050 probably have increased their use of fertilizers aiming for current world average. It is therefore assumed that the use will be double for production of agricultural products. Included in ROW are except for low income countries also e.g. Canada and Australia. Both these two countries have, according to the World Bank, a fertilizer use below world average which makes it reasonable to include them in the increase.

In IC, changes in how the fertilizers are being used can be expected but probably no change in the amount of use.

AGRICULTURE

For agricultural production it is assumed that the fuel use will decrease by 10% in IC due to more effective engines. Also the use of biofuels will increase slightly.

In DC the fuel use will increase as for all other types of labor intensive work. See above.

CHEMICALS

According to UN- Global Industrial Energy Efficiency Benchmarking (UNIDO, 2010) the energy use can be decreased substantially by implementing today’s best practice. It is assumed that the energy use therefore can be lowered by 20% in IC and 30% DC. The potential is higher but every opportunity will probably not be taken in the BAU scenario.

In the developing countries it is also assumed that there will be an increased level of automatization resulting in a reduction in labor intensity – 10%.

FOOD PRODUCTION

In accordance with the UN- Global Industrial Energy Efficiency Benchmarking (UNIDO, 2010) all food production will reduce the electricity consumption by 5%. This is the case for both IC and DC.

PETROLEUM REFINERIES

In accordance with the UN- Global Industrial Energy Efficiency Benchmarking (UNIDO, 2010) there will be energy savings by 20% in IC and 30% in DC.

In DC it is also assumed to be a reduction in labor intensity by 10%

CEMENT ETC

In accordance with the UN- Global Industrial Energy Efficiency Benchmarking (UNIDO, 2010) there will be an energy saving by 20% in IC and an energy saving by 30% in DC.

In DC it is also assumed to be a reduction in labor intensity by 10%

PULP

In accordance with the UN- Global Industrial Energy Efficiency Benchmarking (UNIDO, 2010) there will be an energy saving by 10% in IC and an energy saving by 20% in DC.

METALS

For all types of metals it is assumed that in accordance with the UN- Global Industrial Energy Efficiency Benchmarking (UNIDO, 2010) there will be an energy saving by 10% in IC and an energy saving by 20% in DC.

MINING

For all types of mining it is assumed that the numbers are not changed in IC. Possible energy efficiency measures will probably be compensated by more difficult mining conditions, e.g. deeper mines and lower mineral content per ton ore etc.

For DC it is assumed that the labor intensity will be reduced by 10% and also the use of fuel and electricity will be reduced by 10%

EXTRACTION OF OIL AND GAS

As for mining, the assumption is made that energy efficiency measures will be cancelled out by more difficult extraction conditions in the future.