POCACITO

european post-carbon cities of tomorrow

# UNDERSTANDING THE IMPACTS OF POST-CARBON CITIES IN 2050

IVL, CUNI AND AU

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| **BAU** | Business-as-usual |
| **COICOP** | Classification of Individual Consumption According to Purpose |
| **EE-MRIO** | Environmentally extended multi-regional input output analysis |
| **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 |
| **WP** | Work Package |

# ABSTRACT

The role of cities and their stakeholders in creating a sustainable low carbon society is becoming increasingly critical. It is generally expected that by 2050 the global population living in urban areas will be approaching 70%. Cities are already responsible for almost 80% of the global energy consumption and over 60% of greenhouse gas emissions.

In order to reduce the impacts of cities long term planning through visioning and the creation of actions and supporting policies is essential. However, equally crucial is the modelling of the proposed pathways and assessing and understanding the impacts of the scenarios. Methodologies to enable this are still in their infancy.

In this paper a suite of complementary methodologies are utilised to enable a comprehensive sustainability assessment of 2050 scenarios for 10 European cities. The aim is to compare a 2050 business as usual scenario (based on recent trends) with a 2050 post carbon (PC2050) scenario developed with city stakeholders. A key strength is that it applies both a production based approach and consumption (footprint) based accounting methodology to assess the impacts.

A semi-quantitative/qualitative indicator approach shows that nearly all cities will improve under Business As Usual (BAU) for most indicators but the performance is significantly improved under PC2050. However, the indicators concerning poverty level and urban sprawl are consistently poor performers. The analysis of the production based Greenhouse Gas (GHG) emissions shows that most cities approach carbon neutrality under PC2050 but will not fully achieve it, with only 3 cities being below 1 $tCO_2eq$/capita/year. However, of far greater concern is that the GHG footprint emissions rise under PC2050 for 8 of the 10 cities due to increased consumption with many cities above 10 $tCO_2e$/capita/year. A benefit-cost analysis compares the reduced cost burden due to premature deaths from air pollution with investment costs for renewable energy and energy efficient. It shows that under PC2050 the cost-benefits of reduced air pollution more than compensates for the investment costs. Investment costs are typically less than 1% of cumulative Gross Domestic Product (GDP) from 2018 to 2050.

Therefore policy needs to address not only immediate and concerted action on energy efficiency and localised renewable energy (to avoid system lock-in) but the value of green space and the disparity between rich and poor if future cities are to be liveable, healthy and carbon neutral places.

# 1 INTRODUCTION

It is well documented that the world's population is becoming increasingly urbanised, and that by 2050 more than 66% will live in urban areas[1] (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). At the same time cities are responsible for 85% of Gross Domestic Product (GDP; Gouldson et al. 2015a). Hence, cities are of critical importance in addressing climate change and sustainability.

A key challenge that remains for cities is how to identify suitable pathways to reach post-carbon status. The concept of post carbon cities "*builds upon issues beyond those of greenhouse gas (GHG) emissions, energy conservation and climate change, adding a broader set of concerns, including economic justice, behaviour change, wellbeing, land ownership, the role of capital and the state, and community self-management*" Chatteron (2013).

Subsequently, a further, yet underdeveloped, challenge is how to assess the impacts of the future city development on the complex socio-economic and ecological systems (Heinonen et al. 2015). Hence, understanding the impacts of these future city developments of cities on sustainability is critical in helping adaption, strategic decisions and appropriate policies.

There are a growing range of methods available to assess the current status of sustainability of cities from indexes such as the Siemens Green Index (EIU 2012), material flow analysis methods (OECD, 2008; Rosado et al. 2014), urban metabolism (Kennedy et al. 2010) coupled with life cycle analysis (Goldstein et al. 2013), through to assessing single indicators such as the carbon footprint and water footprint.

Often studies focus on single indicators, with energy consumption and GHG emissions (Minx et al. 2013) being high on the agenda of recent research. However, as Gouldson et al. (2015b) argue the body of research linking cities with GHG emissions is small when compared to research and studies performed at the national and international level. Nonetheless there are a growing number of city based studies that examine territorial emissions of cities (Kennedy et al. 2009; Kennedy et al. 2010; Glaeser and Kahn 2010; Bi et al. 2011) and initiatives such as the Covenant of Mayors for Climate and Energy (CoM 2016). There is a smaller yet growing literature that examines the carbon footprint of consumption (e.g. Jones and Kammen 2013; Lin et al. 2015; Minx et al. 2013; Feng et al. 2014). Recent studies such as Chen *et al.* (2016) which examined five Australian cities show that a significant share of total footprint emissions occur upstream and overseas. They found that over half of the embodied emissions occur from imports. Scott et al. (2013) used an environmentally extended multi-regional input-output models for estimating future consumption impacts, but this was performed at a national level.

Scenario analysis has evolved since the 1950's as a methodology to analyse future sustainability pathways and aid strategic decision making (Schoemaker, 2004 and Swart et al., 2004). The approach

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[1] As the UN (2014) note, there is currently no global definition for urban settlement, which varies widely across countries. The UN used data based on the concept of urban agglomeration or the population within the administrative boundaries of the cities.

was used by the US to investigate cold war scenarios and has since been used for several well-known environmental works including the Club of Rome's report "The Limits to Growth (Meadows et al. 1972). In terms of sustainability science, scenarios can be described as "coherent and plausible stories, told in words and numbers, about the possible co-evolutionary pathways of combined human and environmental systems" (Swart et al. 2004). Three different approaches are used within environmental sciences in scenario storyline development: exploratory, normative and business as usual (Rounsevell and Metzger, 2010). Since qualitative and quantitative scenario methods both have their advantages and disadvantages, they can be combined into such techniques as the so called Story and Simulation (SAS) approach. This has been used in numerous environmental scenario studies such as the Special Report on Emissions Scenarios of the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment and the GEO-4 Scenarios (Alcamo 2008).

In terms of the future impacts of cities other important aspects in addition to GHG emissions are land use changes of development and related eco-system services and recreational/health benefits/consequences (Gascon et al. 2016; Shanahan et al. 2015; Wolf and Robbins 2015). So too are the financial costs of scenarios/pathways and the related benefits.

The literature on costs and benefits of low GHG emission approaches is still developing and has often been performed at a high or global level (Kennedy and Corfee-Morlet, 2013; Erickson and Tempest 2014) with few studies examining scenarios for individual cities. Recently however, Gouldson et al. 2016) explored the economic case for low GHG responses in four cities. They reported that the required investments for reductions of 15-24% in GHG emissions (relative to BAU) would equate to 0.4-0.9% of GDP but result in savings in the form of reduced energy between 1.7% and 9.5%.

The objective of this paper is to apply a methodology to quantify and compare the impacts of two scenarios for the year 2050, Business-as-Usual (BAU) and Post-Carbon (PC2050), for each of 10 cities: Barcelona, Copenhagen, Istanbul, Lisbon, Litoměřice, Malmö, Milan/Turin, Rostock and Zagreb. The paper is part of an European Union (EU) funded project called "Post Carbon Cities of Tomorrow" (POCACITO), which involves working with the ten European cities to develop local strategies to reach post carbon status by 2050.

In previous POCACITO work, local stakeholders were engaged in a series of workshops involving a visioning and back-casting exercise to develop strategies, actions and milestones, for post carbon 2050 scenarios (see Nunez Ferrer et al. 2015). The combination of local stakeholder groups varied throughout the cities but included individuals from public and private organisations, local government administrators (energy, environmental, planning and transport) regional agencies and universities. This paper assesses and quantifies these PC2050 scenarios and compares them with BAU. It should be stressed that the paper does not set out to predict the future, but to learn from a comparison of two potential pathways and their outcomes.

The methodology aims to extend beyond GHG emissions. It combines a qualitative/semi-quantitative sustainability indicators assessment, quantitative assessment of GHG emissions using both production (territorial) and consumption based methodologies, land use changes, and a cost benefit analysis.

# 2 METHODOLOGY

The research presented in this paper builds on and utilises the work from the POCACITO series of workshops in each of the case study cities, discussed above. The methodology for the modelling and quantification of impacts consisted of three main components:

1. Identify key factors for assessment and quantification through the engagement of city stakeholders
2. Model the BAU and PC 2050 scenarios to quantify the defining city system components such as population, GDP, energy mix. This involved assessing the recent trends and relevant projects of the cities for BAU and interpreting the PC2050 scenarios created by city stakeholders.
3. Assess and quantify the impacts of the BAU and PC2050 scenarios. This included a:
   a. Semi-quantitative assessment using sustainability key performance indicators.
   b. Quantitative assessment of GHG emissions using both production based (territorial) and consumption based accounting methods.
   c. Assessment of land use changes
   d. A cost benefit analysis comparing the investment costs for renewable energy and energy efficiency with the benefits of reduced costs due to reduced deaths from reduction in air pollution.

## 2.1 IDENTIFYING THE KEY FACTORS

In order to identify the key factors for assessment and quantification, the initial stages of the Vester Sensitivity Model was used (Vester, 2004). This was also important as the number of variables that can be modelled in any assessment are limited.

The Sensitivity Model was selected because of its systems dynamics approach and therefore it is an appropriate tool to study the complex city systems (cf. Huang et al. 2009). It is also a participatory approach and therefore appropriate for the POCACITO project. However, only the first three stages of the nine stage process were utilised and adapted for use in stakeholder workshops at each city (See Harris et al. 2015, for further details). The main component utilised was the Impact Matrix which is created from 15-25 variables which define the city system. The variables run both vertically and horizontally in the matrix so that the impact or influence that one variable has on the other can be scored on a scale of zero to three. In this way the most important and influential variables can be identified.

The Impact Matrix was helpful in helping to identify key aspects and concerns for each city, but these were predominately homogenous and focused on issues of economics, energy, resource efficiency, awareness of citizens and mobility. It was therefore decided to adopt a common methodology and tools for each city. In retrospect the process was not necessary and will therefore not be discussed further in this paper, which rather focuses on the modelling and quantification of the scenarios' impacts.

## 2.2 MODELLING BAU AND POST-CARBON SCENARIOS

The modelling focussed on six main components that help to describe the essence of each city: population, energy use and production, transport, housing and building, GDP and industry. The metropolitan areas of the case study cities were the main focus for the production based (territorial) energy and GHG emissions due to it being the area where data was most consistently available.

The main stages of the modelling for each city can be summarised as (see Table 1 for an overview of the methodological aspects):

1) **Establishing current trends** – firstly developing and understanding the current trends (typically over the last 10-15 years) for the set of city components listed in Table 1. These are primarily derived from the POCACITO assessment "*Integrated Assessment Report*" (Selada et al. 2015) and additional literature where available and necessary;
2) **Projecting BAU** – BAU is projected from the current trends, and where appropriate considers progress made in relevant ongoing and planned projects.
3) **Modelling PC2050 –** is built from the qualitative scenarios developed in the frame of the POCACITO project (Núñez Ferrer et al. 2015). It is hence an interpretation and expansion of the visions, actions and milestones.

Table 1: Overview of calculation approach for the main components

| COMPONENT | BRIEF DESCRIPTION OF CALCULATION METHOD |
|---|---|
| Population | Population projections were based on data obtained from Oxford Economics, and country specific statistic data sources. For the difference between BAU and PC2050, we utilised data from the Shared Socio-Economic Pathways (SSP's) of the International Institute for Applied Systems Analysis (IIASA 2015). |
| Energy | Energy use and production used a range of data available from various sources to determine trends for that city. In general, we established a current trend and projected BAU using assumptions on changes in the key influence factors including population change, transport, residential sector, business and industry. The key document for providing a background reference scenario for BAU national energy use and production Capros et al. 2014.<br>PC 2050 was determined based on an interpretation of the post carbon scenarios and the associated actions and milestones. |
| Transport | Various sources were used. Data on total energy used by the transport sector and the modal share breakdown and trends was obtained from the POCACITO report "Integrated Assessment Report" (Selada et al. 2015). Assumptions are outlined in Annex 2 of Harris et al. (2015) and are based on the current trends for BAU and an interpretation of the degree of sustainable transport and the modal share for PC2050. |
| Housing and building | In most cases the trends of the residential and service sectors were used as a background to projecting the expected energy use of housing and buildings. This was adjusted depending on other qualitative information such as projects and policies for energy efficiency etc. For PC2050 an interpretation of the energy efficiency measures, and other actions were considered. |
| GDP | GDP was calculated from the trends provided by Selada et al. (2015) and supplementary data where required. In addition, the data projections obtained from Oxford Economics. |
| Business and Industry | Information on the industry mix and employment was highly variable, being very good in some cases, to very sparse in others. Current trends were generally projected to 2050 with some moderation due to expected limits to the trends (i.e. an expected ceiling to the growth of the service sector). |

## 2.3 ASSESSING THE IMPACTS OF THE SCENARIOS

The impacts methodology consists of the following five components:

1. Key Performance Indicator (KPI) assessment and qualitative analysis.
2. Energy production and consumption based GHG emissions.
3. Environmental footprint (using EE-MRIO).
4. Spatial modelling of city development for 2050.
5. Cost-benefit analysis.

The choice of this approach was to cover a range of potential impacts and to provide a comparison of investment costs with benefits. It was also influenced by data availability. For instance, we considered using a material flow analysis and urban metabolism approach, but the required data was not easily accessible for the ten case study cities. On the other hand several MRIO databases now exist which can be utilised for footprint analysis in combination with additional data such as household spending.

The following sections provide an overview of the methodological approach for each component. Further detail can be found in Harris et al. (2016b).

### 2.3.1 KEY PERFORMANCE INDICATOR ASSESSMENT AND QUALITATIVE ANALYSIS

This assessment utilises the set of sustainability KPI's developed in POCACITO (Selada *et al.* 2014) as a basis to model and project 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 further discussed in section 3.2.

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. The qualitative assessment is an extension and discussion of the analysis contained in the table.

### 2.3.2 ENERGY CONSUMPTION AND PRODUCTION BASED GHG EMISSIONS

Energy use and production trends were primarily derived from energy and GHG accounting reports of the cities. The data quality and availability on energy and GHG emissions for recent years ranged from good (comprehensive and for several years) to poor (only available for one year). Both current and projected BAU trends use different assumptions for key factors including population change, transport, residential sector, business and industry. A key background document used for the BAU reference scenario for energy use and production is the European Commission "EU Energy, Transport and GHG Emissions. Trends to 2050" report (Capros et al. 2014). Further details, as well as the assumptions underpinning the modelling approach, can be found in Harris et al. (2016a).

GHG emissions are then calculated using life cycle emission factors to cover the emissions associated with the following activities within the city territorial boundaries: transport, electricity use and energy use in buildings. We utilised the life cycle emission factors of the Covenant of Mayors (2014) as opposed to the standard IPCC emission factors to cover the full life cycle impacts of the energy use. This includes Scope 1, 2 and 3 (indirect) emissions (including $CO_2$, $CH_4$ and $N_20$) that occur throughout the value chain of the energy sources. GHG emissions from waste, i.e. from landfill and wastewater treatment are not included because consistent datasets were not available.

### 2.3.3 CONSUMPTION BASED ACCOUNTING /ENVIRONMENTAL FOOTPRINT (USING EE-MRIO)

Cities are not sustainable on their own but require a “hinterland” to support their consumption. In order to quantify the total environmental impacts of cities, it is important to include supply chains of products consumed within the cities. We define environmental footprint of a city as a footprint of all products consumed by the citizens[2], plus government expenditure. This aligns with previous research, which suggests including these two items would account for 70-80% of the environmental impact (Invanona 2015). Therefore, due to data limitations at the city level, in contrast to the national environmental footprint approach (Hertwich and Peters 2009) calculated using EE-MRIO we leave out expenditures of non-profit organizations serving households, changes in inventories and valuables and capital formation.

In order to quantify the environmental footprint of cities we combine household expenditure surveys (containing final demand of households) with Environmentally Extended Multi-Regional Input-Output analysis (EE-MRIO). EE-MRIO is widely used to calculate upstream environmental impacts resulting from the complete production chains of products, using the following matrix equation:

$$FP = F. (I - A)^{-1}.y$$

Where FP is the resulting footprint of products included in vector “y”, F is the intensity matrix containing environmental stressors for each economic sector per unit of sector output (rows are environmental stressors and columns are economic sectors), I is an identity matrix, A is the input technological coefficient matrix containing inputs of products per unit of sector output and y is a vector of final use products, which is replaced by city specific household consumption from household expenditure survey for each city.

In this analysis we utilised the product by product EE-MRIO table derived under the industry technology assumption (Eurostat 2008) from the supply and use tables established under the EU funded project CREEA (Wood et al. 2015). The city specific household consumption was obtained from local authority data sources for Milan, Copenhagen and Turin and from Oxford Economics (purchased under a confidential commercial license) for the rest of the cities.

For the modelling of the 2050 scenarios, the MRIO data for the global production system was aggregated into 13 broad regions, containing one each for the countries of the assessed cities (except for Zagreb, which is part of a broader region Rest of World – Europe within Exiobase) and four rest of the world regions (Japan, Rest of EU, Norway and Switzerland; BRICS; US; and RoW). We modelled direct input (technological) coefficients and environmental extensions globally and final consumption within the analysed cities. We assumed constant share of imports and constant share of countries for the origin of imports. The BAU scenario final demand of households was based on projections

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[2] This definition is equivalent to the standard definition of ecological footprint, i.e. the footprint is equal to domestic impacts plus the footprint of imports minus footprint of exports.

provided by Oxford Economics (data obtained on a commercial basis) to 2030, and extrapolated to 2050. Further adjustments were then made to the energy profile of the cities to align with the BAU modelling discussed above.

For the PC2050 scenario, we used the same underlying production system developed in the BAU modelling and focused on final consumption of cities. 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. The energy profile was then adjusted to reflect the modelled PC2050 scenarios. The modelling of the other (non-energy) product groups was based on the assumptions and modelling results of the report “Quantification of the Case Study Cities” (Harris et al. 2016).

The KPI analysis was also used to interpret the difference differences between BAU and PC2050. The final demand was then adjusted by assuming that a moderate change from BAU to PC2050 results in a 25% variation and a substantial change means 50% variation.

### 2.3.4 SPATIAL MODELLING OF CITY DEVELOPMENT FOR 2050

A spatially specific automated cellular model was applied to show possible future trends of urbanisation and population densities of the cities. The model is based on an assessment of historical changes from 2000 to 2012, which, based on future projections of populations change was applied to map the possible development until 2050 for the BAU and PC scenarios. For the spatial demarcation of the city boundaries, which refers here to the metropolitan regions, we applied the NUTS III[3] level except for Litoměřice and Malmö, where we applied the municipal boundaries. Historical change between 2000 and 2012 was mapped by combining land use data from Corine Land cover (EEA 2000, EEA 2012) with gridded population data derived from Landscan (U.S. Department of Energy). All spatial analyses were conducted at a cell size of 100x100 meters. Corine Land cover was aggregated into three major classes: Urban land, sea and other land (including forest, nature and agriculture). Overlaying land use and gridded population data for 2000 and for 2012, we identified five different trajectories of combined land use and population change (Table 2).

**Table 2: Identified land use and population changes for the period from 2000 to 2012**

| 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 |

To model the population distribution of the BAU and PC2050 scenarios we matched and extrapolated the modelled 2050 population (discussed in section 2.2) with the 2012 population distribution derived from Landscan. For the BAU scenario, we assumed that up until 2050 the same relationship between land use change and population change observed from 2000 to 2012 will be followed. For

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[3] 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.

example, in Copenhagen from 2000 to 2012 there was 12.78 km² of urban spread related to a population increase of 16,029, or 28.78 % of the total population increase of 55,705 (with the remainder resulting in densification). Under the BAU scenario, the 2050 population in Copenhagen is expected to increase by 324,105. Applying the historical change of a 28.78 % increase (92,000) results in urban spread of 74.36 km², with the remainder resulting in a densification. A similar method was used to model the areas of dis-densification. To localize types of urban change, we applied the automated cellular model (Fuglsang et al. 2013). The underlying assumption is that future change occurs at the same locations or close to those that have happened historically. 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. Urban spread was restricted from sea and from areas covered by Natura2000 designations. For the PC scenario, the only assumption 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

### 2.3.5 COST-BENEFIT ANALYSIS

A simplified approach is used due to data limitations and difficulties in transferring certain costs and benefits in literature to the case study cities. Notably, recent studies on the investment costs in the transport sector are either very general and at a global level (see: New Climate Economy, 2015) or very specific to the cities in question (see Gouldson 2015b). Neither could be applied robustly to the case study cities due to the particularities of existing transport structures and future urban plans. The scope of the analysis was therefore limited to investment costs in renewable energy and energy efficiency in buildings. For benefits the study is limited to the cost savings due to reduced deaths from air pollution.

For energy, four main renewable energy sources were mentioned in the scenarios and considered in the 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. Calculated this way the average costs for wind and solar energy used were 1400 EUR/kW and 581 EUR/KWp[4] of installed capacity, respectively (based on IEA 2013 and Fraunhofer ISE 2015).

Investment costs for buildings are based on the levels of energy reductions stipulated in or derived from the BAU and PC2050 scenarios. Costs are derived from a study by the Buildings Performance Institute Europe (BPIE 2011), which established average European costs depending on minor, moderate, deep or near Zero Emission Building renovations. Since no consist data was available on the current quality of the building stock, we applied the costs depending on the floor area in each city for the residential and service commercial area. These were derived from national averages per capita obtained from Entranze (2008).

The benefit analysis focused three aspects:

1. Health benefits of reduced pollution.

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[4] KWp = kilowatt peak, which refers to the output power of a solar module under full solar radiation.

2. Reduced energy expenditure (qualitative).
3. Jobs created from renewable energy and renovation of buildings.

Health benefits were calculated for the period 2018 to 2050 based on the level of reduced pollution from the energy and transport approach of the scenarios. This is based on the current costs of premature deaths from air pollution as reported as a percentage of GDP by WHO Regional Office for Europe and OECD (2015).Reduced energy expenditure was simply calculated as a percentage difference in energy consumption between the BAU and PC2050 scenarios.

The jobs created from the increase in renewable energy are based on figures by The International Renewable Energy Agency (IRENA 2013) and calculated for two stages: manufacturing, construction and installation (MCI); and operation and maintenance (O&M). Jobs created through building renovations are based on a conservative number of 12 jobs created for every million euros invested in renovation (Ürge-Vorsatz *et al.* 2010; Meijer *et al.* 2012).

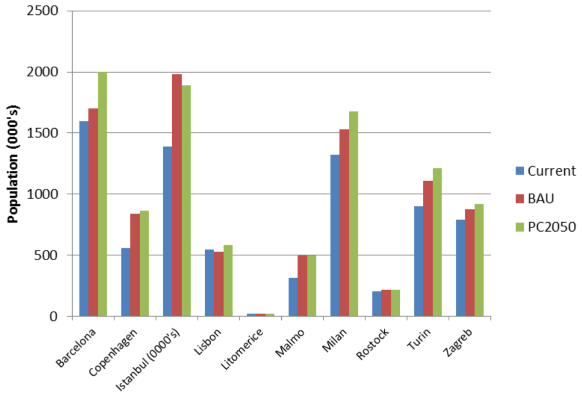
# 3 RESULTS AND DISCUSSION

## 3.1 MAIN CITY COMPONENT INDICATORS

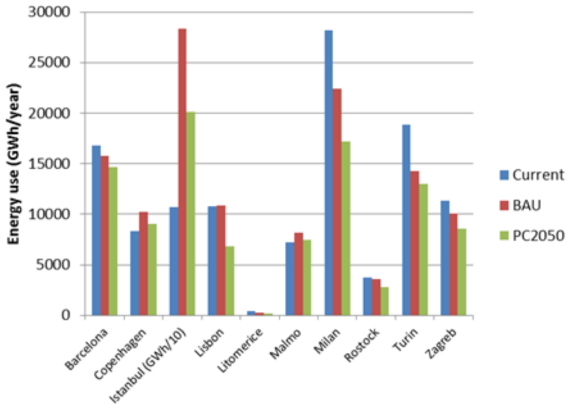
The modelling results for the main components of the case study cities are shown in Figure 1. Figure 1(a) shows that the population increases under both BAU and PC2050 for most cities, apart from Litomerice with a small reduction of 500 people. Population and GDP are generally higher in PC2050 than BAU due to the underlying assumptions utilised from the Shared Socioeconomic Pathways (IIASA 2015). The percentage GDP increase from the baseline year varies widely, ranging from only 17% increase in Turin to 194% increase in Istanbul under PC2050.

Total energy use of the cities (Figure 1.b) increases for four of the cities under BAU and three cities under PC2050. However, energy use per capita (Figure 1.c) declines in all cities under the PC2050 scenario. There is also a decrease in energy use per capita under BAU for all cities except Barcelona, Istanbul and Lisbon. This is related to increases in affluence for Istanbul, whilst Lisbon's profile remains fairly similar with a high transport energy share due to the population moving to the suburbs. In the PC2050 scenario, 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 reflects the room for energy efficiency improvements in the majority of cities. Energy use per capita of the transport systems (Figure 1.d) shows a large variation amongst the cities. Barcelona, Litomerice and Turin have the lowest transport energy per capita under PC2050 with less than 2 MWh per capita.

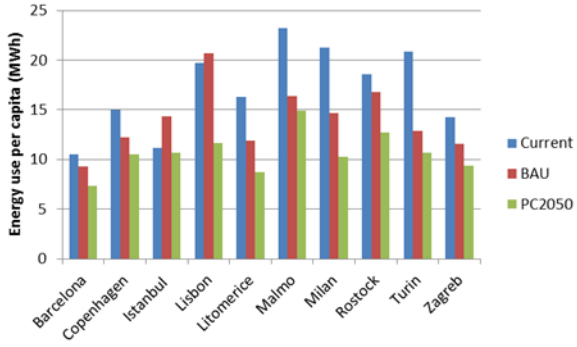
(a)


Population (000's)
2500
2000
1500
1000
500
0
Barcelona
Copenhagen
Istanbul (0000's)
Lisbon
Litomerice
Malmo
Milan
Rostock
Turin
Zagreb
Current
BAU
PC2050

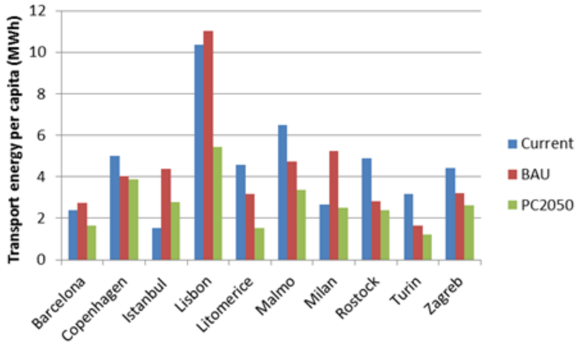
(b)


Energy use (GWh/year)
30000
25000
20000
15000
10000
5000
0
Barcelona
Copenhagen
Istanbul (GWh/10)
Lisbon
Litomerice
Malmo
Milan
Rostock
Turin
Zagreb
Current
BAU
PC2050

(c)


Energy use per capita (MWh)
25
20
15
10
5
0
Barcelona
Copenhagen
Istanbul
Lisbon
Litomerice
Malmo
Milan
Rostock
Turin
Zagreb
Current
BAU
PC2050

(d)


Transport energy per capita (MWh)
12
10
8
6
4
2
0
Barcelona
Copenhagen
Istanbul
Lisbon
Litomerice
Malmo
Milan
Rostock
Turin
Zagreb
Current
BAU
PC2050

(e)

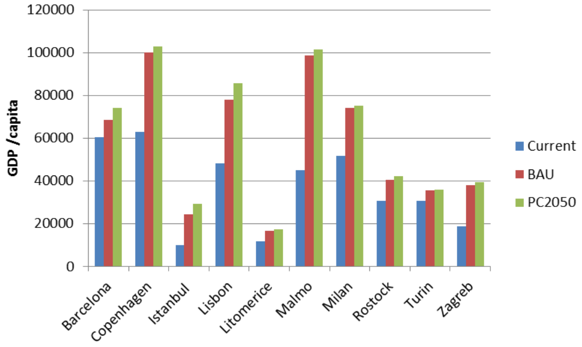

GDP /capita
120000
100000
80000
60000
40000
20000
0
Barcelona
Copenhagen
Istanbul
Lisbon
Litomerice
Malmo
Milan
Rostock
Turin
Zagreb
Current
BAU
PC2050

**Figure 1: Scenario modelling results of the main elements for the ten case study cities for current, BAU 2050 and PC 2050. (a) Population. (b) Energy consumption. (c) Energy use per capita. (d) Transport energy per capita. (e) GDP per capita.**

## 3.2 KEY PERFORMANCE INDICATOR IMPACTS

The KPI analysis is summarised in Table 3Table 1 and shows that most cities perform well across the different sustainability categories (environment, economy and social) for both the BAU and PC2050 scenarios. In particular there is good to excellent performance in most of the environmental and energy related indicators. The exception to this is the city of Istanbul, which due to a large increase in population and affluence, risks increasing overall energy use and GHG emissions. This is also linked to an assumed reliance on the national grid electricity supply (70% of electricity), which due to recent trends was modelled as still being dominated by fossil fuels (60%).

There is a clear difference between BAU and PC2050, with BAU in most cases only providing “likely positive” progress. Hence under BAU although the direction is positive, progress is likely to be too slow to achieve excellent results or post-carbon status.

Within the PC2050 scenarios and related actions, there was 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 for several cities is the poverty level 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 European and global cities (Tammaru et al. 2016), which is also linked to segregation of housing (a particular issue for Malmö).

## 3.3 ENERGY AND GHG EMISSIONS

The energy use results for the scenarios were discussed in Section 3.1. The associated GHG emissions calculated using life cycle emission factors are shown in Figure 2. The three standout 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 showing the lowest GHG emissions at 0.7 $tCO_2e$ per capita/year.

**Table 3: 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** | Ecosystem protected areas | + | + | N/A | N/A | + | ++ | + | + | N/A | N/A | + | ++ | 0 | + | 0 | 0 | 0 | 0 | - | 0 |
| | Energy intensity (toe/EUR) | + | + | + | ++ | - | 0 | + | ++ | + | + | + | ++ | + | ++ | + | ++ | + | ++ | + | ++ |
| | GHG intensity (GHG/EUR) | ++ | ++ | + | ++ | 0 | + | + | ++ | + | ++ | + | + | + | ++ | + | ++ | + | + | + | ++ |
| | Carbon intensity per person | ++ | ++ | + | ++ | - | + | + | ++ | + | ++ | + | ++ | + | ++ | + | ++ | + | + | + | ++ |
| | Exceedance of air quality limit | + | + | ++ | ++ | 0 | + | + | ++ | 0 | ++ | + | + | + | ++ | + | ++ | ++ | ++ | 0 | + |
| | Sustainable transportation | + | + | 0 | ++ | 0 | 0 | 0 | + | 0 | ++ | + | + | + | ++ | + | ++ | - | + | + | + |
| | Urban waste generation | + | + | ++ | + | - | - | + | + | 0 | ++ | + | ++ | + | + | + | + | + | + | + | ++ |
| | Urban waste recovery | + | + | ++ | ++ | + | + | - | - | 0 | ++ | ++ | ++ | + | + | + | + | ++ | ++ | + | ++ |
| | Water distribution losses | N/A | N/A | N/A | N/A | + | + | + | N/A | N/A | N/A | N/A | N/A | - | - | ++ | ++ | + | + | 0 | 0 |
| | Energy-efficient buildings | + | + | N/A | ++ | + | + | + | ++ | + | ++ | N/A | N/A | 0 | ++ | N/A | N/A | + | + | + | + |
| **Economy** | Level of wealth variation rate | ++ | ++ | ++ | ++ | ++ | + | + | + | ++ | ++ | ++ | ++ | ++ | ++ | + | + | + | + | ++ | ++ |
| | Business survival 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 of local auth. | + | + | 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** | Unemployment by gender | + | + | -- | N/A | + | + | - | N/A | N/A | N/A | ++ | ++ | - | + | 0 | 0 | - | 0 | N/A | N/A |
| | Poverty level | + | + | -- | N/A | + | ++ | + | + | - | 0 | 0 | 0 | - | - | - | 0 | - | - | + | + |
| | Tertiary education by gender | + | + | + | N/A | + | + | - | 0 | + | + | + | + | ++ | ++ | N/A | N/A | + | + | + | + |
| | Average life expectancy | + | + | ++ | ++ | N/A | N/A | + | + | + | + | ++ | ++ | ++ | ++ | + | + | ++ | ++ | + | + |
| | Green space availability | + | + | + | + | + | ++ | ++ | ++ | N/A | + | ++ | ++ | 0 | + | ++ | ++ | + | ++ | -- | 0 |

*(N/A = not available)*

| Legend | **Scoring of scenario projection compared to current situation** |
|---|---|
| ++ | Likely very positive |
| + | Likely positive |
| 0 | Likely neutral or similar to current situation |
| - | Likely negative |
| -- | Likely very negative |

Under PC2050 many cities are around 1 to 2 $tCO_2e$ per capita, with Turin and Istanbul being the highest. While the estimated emissions in PC2050 scenario are still high they represent a significant decrease (41%) compared to the BAU scenario. In fact, the low performance of Istanbul compared to the other cities reflects its specific situation (low GDP, higher need for economic growth) which also explains why, contrary to the other cities, the BAU scenario would lead to higher GHG emissions than currently. Applying the mitigation measures as defined in P2050 scenario would significantly contribute to a greener economic growth as further discussed in section 3.3.1.

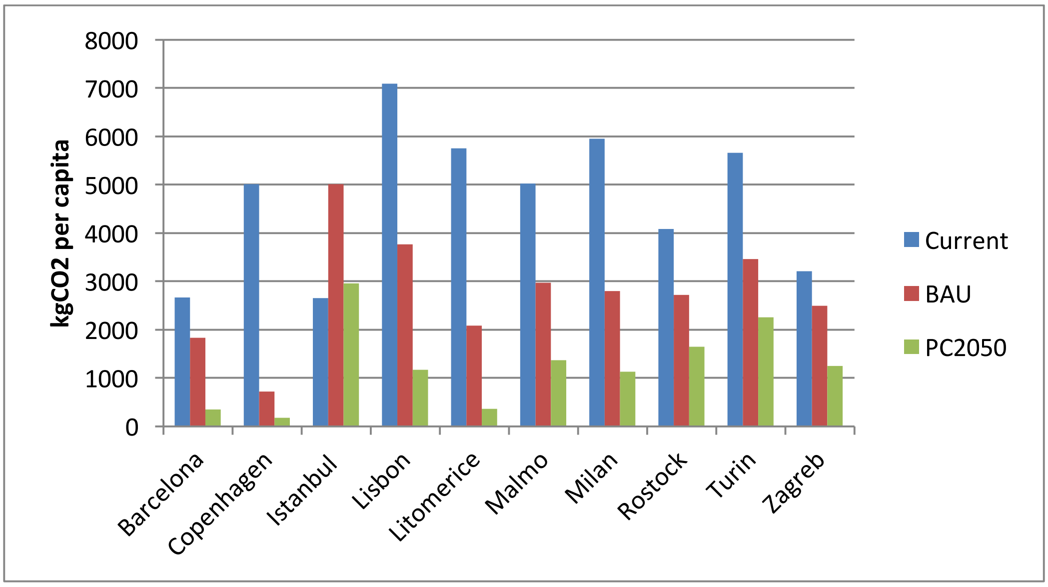


**Figure 2: GHG emissions per capita**

## 3.3.1 ECONOMIC OUTPUT PER UNIT OF GHG EMISSIONS

Figure 3 compares GHG emissions per Euro of GDP for the current situation and scenarios. It shows that all cities would improve under both BAU and PC2050. Hence, for all cities the GDP output 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 3 that by contrast shows economic output (Euro) per kilogram of emitted $CO_2e$. The outstanding performers under PC2050 appear to be Barcelona and Copenhagen. Copenhagen generates 581 EUR/ $kgCO_2e$ compared to 9.9 EUR/ $kgCO_2e$ for Istanbul, which is a similar to the current level for Milan and Malmö.

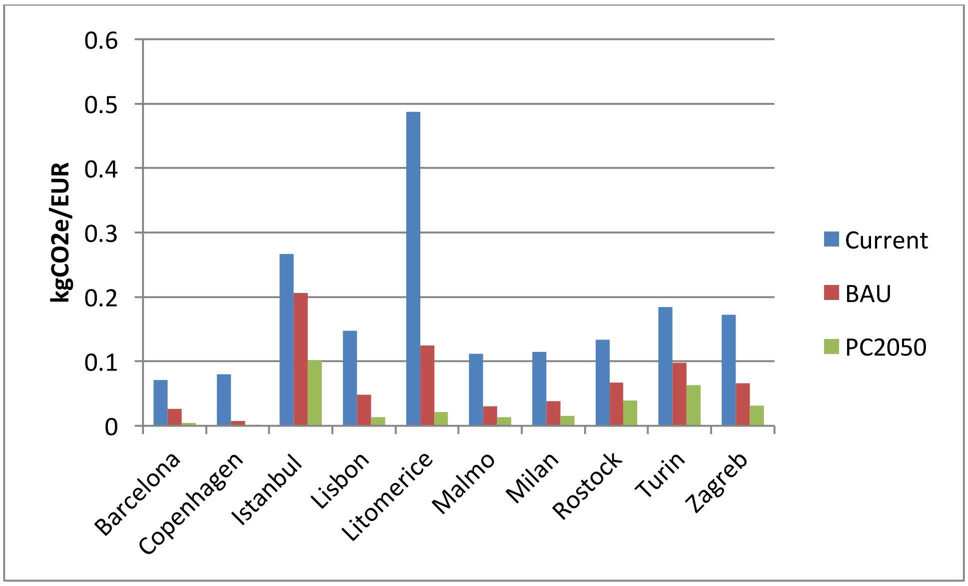


Figure 3: GHG emissions per EUR (GDP)

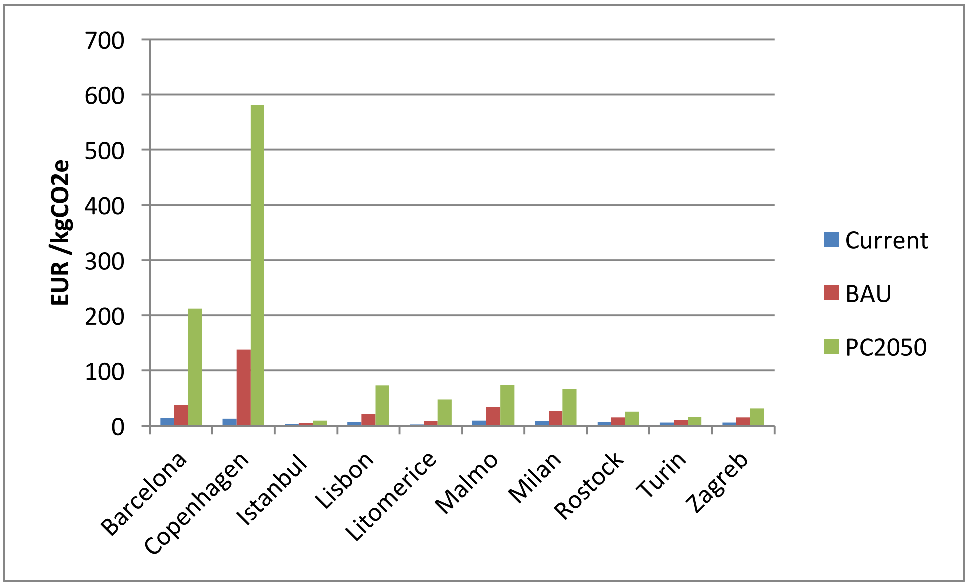


Figure 4: GDP (EUR) created for each kg of GHG emission

## 3.4 FOOTPRINT ANALYSIS (EE-MRIO)

The footprint analysis performed using EE-MRIO delivered very different results for GHG emissions than those calculated using the production based method (section 3.3). As discussed above, GHG emissions on a per capita basis decrease for most cities under both scenarios, 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 Milan and Turin, which both display 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 modelling challenges within the MRIO database. For example, the adjustments made to the energy profiles of the cities were complex (see section 2.3.3) and it was challenging to translate the cities territorial energy profile (which includes all energy use of the city) into a household expenditure.

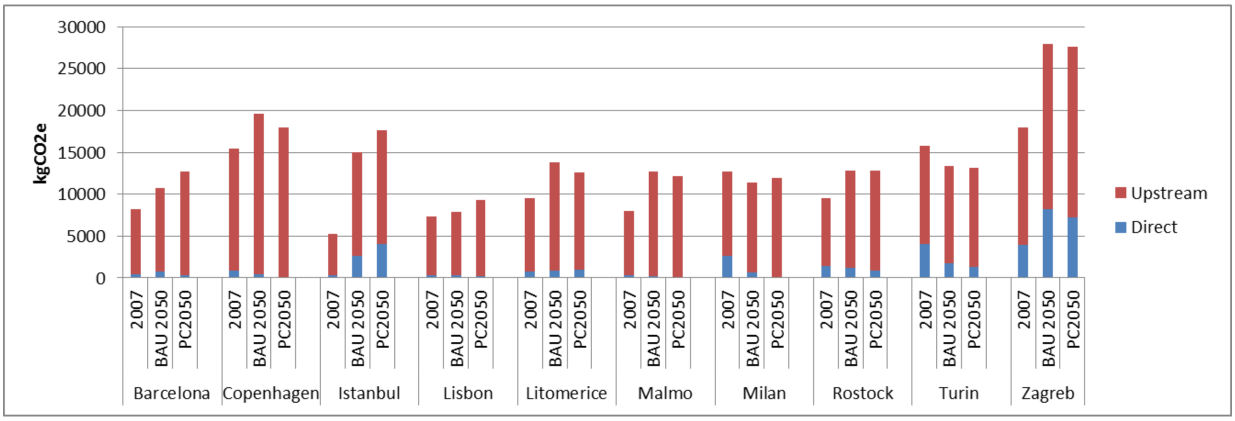


Figure 5: Direct and indirect GHG emissions for all case study cities for 2007, BAU and PC2050

The differences between the production based method and the MRIO footprint method are highlighted in Figure 6 and Figure 7, which shows the percentage increase in GHG emissions with respect to the 2007 baseline. This shows that in the production based 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 7 it can be seen that the total footprint emissions would increase for all cities except Milan and Turin. Under PC2050 the increase ranges from 234% in Istanbul to 16%, and the majority of the cities would experience an increase of between 30% and 50%.

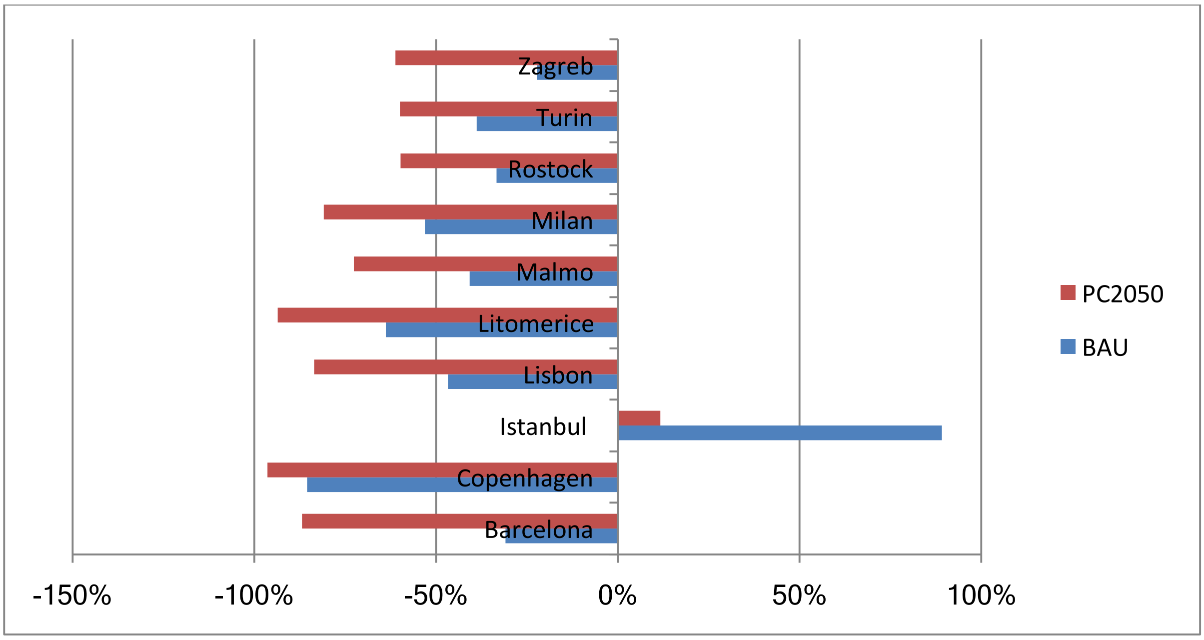


Figure 6: Percentage change in GHG emissions per capita from 2007 to BAU and PC2050 using production based calculation method

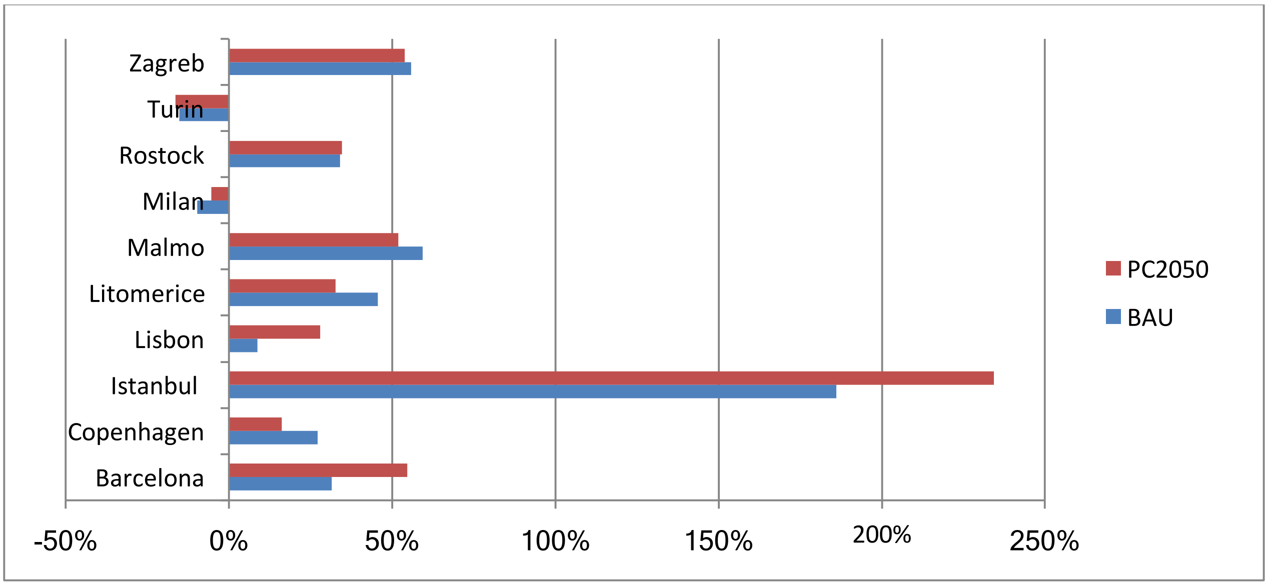


Figure 7: Percentage change in GHG emissions per capita from 2007 to BAU and PC2050 using footprint analysis

## 3.5 ECO-SYSTEM SERVICES - LAND USE CHANGES

The modelling of land use change indicates 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 NUTS III 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 further net development of non-urban land. Therefore densification is assumed to be a central policy for PC2050. The consequence of this is that the BAU outcome (Table 4) highlights the potential risk of future development to encroach on non-urban land. Table 4 shows that despite some cities experiencing population decline, all cities would experience development of currently non-urban area if current 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 4: Change in non-urban land cover (in km$^2$ and in percentage) calculated over the 2012 to 2050 period under the BAU scenario, for the 10 case study cities**

| | 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 in terms of benefits for health, well-being and quality of life (Davand et al. 2015; Gascon et al. 2015; Shanahan et al. 2015; Wolf and Robbins 2015). Secondly, research also shows that sprawling cities require more infrastructure and are therefore more resource intensive and less energy efficient (NCE, 2015). Therefore they 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.

## 3.6 SOCIO-ECONOMIC ANALYSIS

A summary of the discounted costs and benefits for all cities is shown in Table 5. 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), which limits the comparability of costs between the cities. Therefore the percentage of cumulative GDP (from 2018 to 2050) for the costs of energy efficiency improvements and additional renewable energy is also reported.

Table 5 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 estimated costs of the PC2050 in terms of cumulative GDP range from only 0.31% to 1.53% for Barcelona and Litoměřice respectively.

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

**Table 5: Costs and benefits comparison of the scenarios**

| (MEUR) | DISCOUNTED COSTS (DISCOUNT RATE 3%) | | % OF GDP | | DISCOUNTED BENEFITS (DISCOUNT RATE 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 |

The difference in total energy consumption of the cities between the PC2050 and BAU scenarios provides an approximation of the difference in total energy costs. Table 6 shows that PC2050 has lower energy consumption and therefore potentially lower costs in all cities. The highest reduction Lisbon with 37.5%, whilst the lowest Barcelona is demonstrative of low energy consumption per capita in both scenarios.

Table 7 shows the additional number of jobs due to the renewable energy installations and building renovations of PC2050 compared to BAU. It suggests significant jobs in manufacturing, construction and installation (MCI) for both types of improvement. The number of jobs expected to be created in the operation and maintenance (O&M) phase are fairly moderate for all cities. The high value for building renovation for Milan is due the target stipulated in the stakeholder visions of 60% increased efficiency in buildings.

Table 6: Estimation of potential reduced energy costs of PC2050 compared to BAU due to reduced energy consumption

| CITY | % REDUCTION IN ENERGY CONSUMPTION/COSTS |
|---|---|
| Barcelona | 7.2% |
| Copenhagen | 11.2% |
| Istanbul | 29.1% |
| Lisbon | 37.5% |
| Litomerice | 26.8% |
| Malmo | 9.0% |
| Milan | 23.3% |
| Rostock | 22.1% |
| Turin | 8.8% |
| Zagreb | 14.9% |

Table 7: Estimated additional number of PC2050jobs created compared to BAU

| | RENEWABLE ENERGY | | BUILDING RENOVATION |
|---|---|---|---|
| | MCI | O&M | MCI |
| Barcelona | 23665 | 310 | 82002 |
| Copenhagen | 9563 | 115 | 53674 |
| Istanbul | 331500 | 4649 | 427500 |
| Lisbon | 14600 | 209 | 32700 |
| Litomerice | 1164 | 13 | 1143 |
| Malmo | 10935 | 121 | 22764 |
| Milan | 38100 | 540 | 273000 |
| Rostock | 3424 | 61 | 13398 |
| Turin | 20237 | 324 | 55157 |
| Zagreb | 27054 | 367 | 32141 |

# 4 CONCLUSION

The modelling and assessment of scenarios presented in this paper aimed to learn from the examination of two alternative potential pathways for ten European case study cities and is not intended as a forecast of the future. The research yielded valuable insights about the potential future pathways, and also the strengths and limitations of the multi-methodological approach to assess and compare the impacts of BAU and PC2050.

The assessment of sustainability indicators showed that cities are moving in a positive direction, although much too slowly. By contrast, the situation is highly improved for nearly all indicators under a PC2050 scenario. Nonetheless, one of the primary targets for the city visions and scenarios, which is the creation of low or zero carbon societies, would not achieved under BAU or PC2050 for most of the case study cities (depending on how this is defined).

Under BAU, only Copenhagen would emit under 1 $tCO_2e$ per capita, with the highest emissions reaching 5 $tCO_2e$ per capita in Istanbul. The majority of cities would remain in the range of 2-4 $tCO_2e$ per capita, which indicates significant room to improve the energy efficiency measures of the PC2050 scenarios 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.

This result is not surprising: low carbon cities are possible but the challenge seems to be underestimated and compounded by the existing urban forms. 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.

When considering the consumption footprint there are even more worrying signs, with projected footprint impacts increasing under both BAU and PC2050 for eight of the ten cities. This is primarily linked to rising GDP and a corresponding increase in spending and consumption that was modelled in the MIRO analysis. Although it is hard to say whether the positive correlation between affluence, increased consumption spending and environmental impact will be as estimated in 2050, our modelling results suggest that expected advances in production efficiencies will not compensate for increased spending and carbon and environmental footprints will increase.

Hence the results highlight an important disparity between the traditional focus on territorial energy use (and local impacts) and those of the footprint (with global impacts). This suggests that the focus of future actions may be better placed on addressing the footprint of consumption than on local energy production and emissions.

Therefore one of the main conclusions of this study is the urgent need for cities and their populations to foster a circular economy approach. A circular economy aims to improve resource productivity by increasing the circular flows of products, and their related components and materials, through increased reuse, refurbishment, remanufacturing and recycling. Cities are key places for such an approach not only in order to limit the footprint of consumption, but also because cities are central places of innovation where circular economy solutions can emerge. Research into how cities can foster the circular economy is still in its infancy but there appear to be many opportunities. For example, through the provision of 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.

Urban sprawl and social issues are two other common concerns apparent in the scenarios. 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 according to our projections. The social indicators that were consistently poor performers in the KPI analysis were segregation of cultures and income class, and the growing disparity between rich and poor.

On a positive note, despite the cost-benefit 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). In addition, energy costs are significantly lower under PC2050 (by up to 45% for Lisbon) 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.

The estimated costs of providing renewable energy and energy efficient buildings in the PC2050 scenarios are less than 1% of cumulative GDP from 2018 to 2050 for nine out of the ten cities. The highest cost was 1.5% for the city of Litoměřice, which would achieve one of the lowest GHG emissions by 2050 (0.36 $tCO_2e$ per capita/year). In the other cities which would not achieve such low GHG emissions, there appears to be adequate economic ability to invest further in renewable energy and energy efficiency. This would also in any case lead to further benefits that would typically more than compensate for the expense.

In conclusion, the study showed that our multi-methodological approach was effective in assessing and comparing the performance of future city scenarios for a range of indicators. It also provided a useful sustainability assessment of the current status of the cities. Additionally, the research highlights how the PC2050 scenarios delineated by the city stakeholders could be improved.

A key strength was the inclusion of both production and consumption based GHG accounting which provided a valuable and illuminating comparison (both of the current situation and of the scenarios). It also brought the focus back onto some other sustainability indicators by highlighting the importance of other issues such as consumption and therefore lifestyle. Hence it strengthens the notion that focusing only on energy and GHG emissions is not sufficient.

Subsequently, the KPI analysis could be improved by additional indicators that help to capture lifestyle and consumption elements. Utilising the EE-MRIO framework and database to model future scenarios was challenging and not without a number of uncertainties. One improvement therefore could be in strengthening the modelling of the background global production model of the database, and develop a method for uncertainty analysis. The methodology could also be further strengthened by broadening the cost-benefit analysis but this would require better data availability.

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