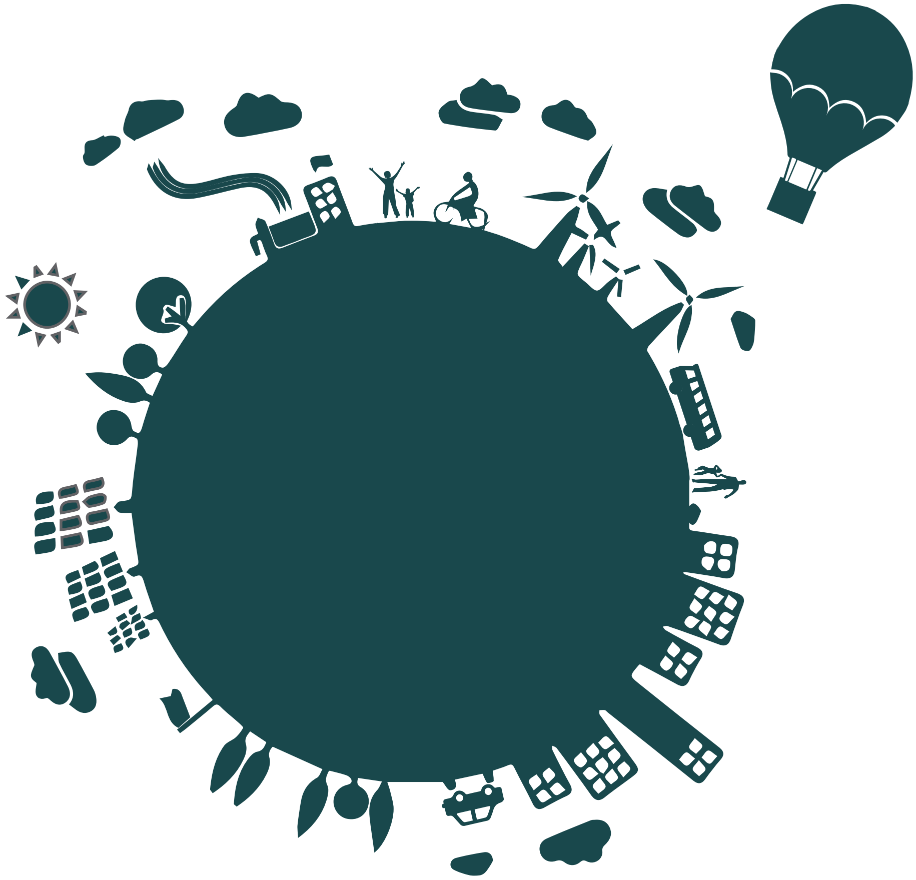
ELISA PESCE

# A CBA-based analysis for the retrofit of a reference district



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# A CBA-based analysis for the retrofit of a reference district

Politecnino di Torino
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*"The most important question that in most developments is not sufficiently answered is: 'What makes people truly happy?"*

Hein Struben, 2013

# Ringraziamenti

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## Abstract

Many studies are shifting their attention from the sustainability of a single building to the one of the entire urban system. This is the reason why we decided to focus on the research of policies that allow to achieve a more sustainable way of life for the entire urban system. Starting from the first chapter, we discuss the European and international targets designed to keep the emissions produced under certain levels and to have a shift to a decarbonised society. Moreover, we also analyse several case studies to categorize their main features and the measures applied to improve the sustainability at the district and urban level. In the second chapter, we describe manifold policies that can be applied to reach the reduction of fossil fuels consumptions and of the emissions while, in the third one, we analyse the structure of a cost-benefit analysis and the environmental, social and economic benefits that can be achieved with the application of these measures.

Afterwards, we focus on the creation of a reference district for the city of Turin, which can be representative for its entire urban system. Through the application of different sustainable policies on it, the aim is to compare the saving of energy consumptions and the emissions reduction. The sectors that we consider, and on which we are going to intervene, are the buildings, mobility, waste and street lighting sectors. Since the measures applied on different sectors are manifold, we create several scenarios, composed by one policy for each sector, on which we evaluate costs and benefits. After that, we calculate the economic indicators of the cost-benefit analysis, which allow to choose the best project from the environmental, social and economic point of view. This thesis shows which is the best scenario and that, if the proper measures are foreseen, we can also obtain an economic return for the whole society. Therefore, in a key sentence, the main and ambitious purpose of this thesis is to create a sustainable reference district for the city of Turin that can

be reproduced on its entire territory to develop in the future a sustainable way of life for its entire urban system.

# Introduction

In 2013, urban areas were estimated to produce the 70% of the total global $CO_2$ emissions with the major responsibility attributed to the buildings and industrial sectors, followed by the transport one. Furthermore, since the percentage of global population living in urban areas will increase over 75% by 2030, reaching the percentage of 70% of people living in cities by 2050, urban level will become fundamental to develop new sustainable models. This is the reason why we focused this thesis on the sustainable development of the entire urban system and not only on the single buildings sector. In this way, we could include more fields into our analysis, which represent the whole city and society.

This thesis work started with the draft of a paper concerning the main features of the sustainability at the urban scale connected to the definition of the cost-benefit analysis. This paper presents a literature review of references and European Commission guidelines related to the definition and features of nearly zero-energy districts, of post-carbon cities and of the cost-benefit analysis. Moreover, after having described the several steps of the cost-benefit analysis, the economic indicators to evaluate the performance of the projects are illustrated together with the co-benefits that can be achieve thanks to the application of sustainable policies at the district and urban level. The draft of this paper was relevant to outline the main topic of our thesis and to have a firm bibliographic basis.

Concerning the structure of the thesis, the first chapter describes the necessity to reduce the consumptions and the emissions for the entire world due to the issues connected to air pollution. Moreover, some European and international targets, with the aim to achieve a more sustainable society, are discussed. Indeed, for instance, due to the greenhouse gas (GHG) emissions effects on climate, one of the main European Union Council objective is to reduce them by 80-95% by 2050, compared to 1990 level, in order to keep climate change below 2°C. Milestones are 40% emissions cuts by 2030 and 60% by 2040. To achieve these results, sustainable measures have to be defined and applied as soon as possible to the urban systems. For this reason, at the end of the first chapter we study the main features of already existing examples of communities, districts, towns or cities that are following a sustainability development. Afterwards, the second chapter is entirely dedicated to the description of manifold urban sectors and their chance to improve their performances. We start from the description of the buildings sector, which is the most influent one concerning the energy consumption and the emissions production describing its current position and its possibility to improve its energy performances. Then, this chapter describes the possibility related to the production of energy thanks to renewable sources and its supply at district level. After that, we move our attention on the mobility and waste sector illustrating their current situation in terms of emissions and the possibility to shift their position to a decarbonized point of view. Lastly, we consider the public street lighting, and its chances to be part of this change, and the carbon capture and storage systems.

In the third chapter, we deeply analyze the cost-benefit analysis framework, illustrating in detail its steps and its economic indicators to estimate which is the best investment among the ones proposed. Indeed, the cost-benefit analysis has as a main goal, the evaluation of the costs and of the benefits in monetary value, comparing them and selecting the most sustainable investment from the environmental, social and economic point of view. Moreover, the chapter also includes the description of co-benefits that are achievable when sustainable policies are implemented at district and urban level. After this solid bibliographical resource, we start to apply in a practical design project the knowledge acquired.

The most challenging part of the thesis is the implementation of sustainable policies and of the cost-benefit analysis on one urban system. The main purpose is to create a district that can be representative for the urban system of Turin and on which we can apply sustainable policies in order to evaluate the reduction of its energy consumption and emissions production and to choose, thanks to the cost-benefit analysis, the best ones to reproduce in the entire city of Turin. We start with the definition of a reference district which, is designed considering a representative street framework of the city and an average number of buildings typologies. We also define the number of inhabitants of the district and the consumption and emissions of $CO_2$ and $PM_{10}$ of buildings sector. Then, as a district is not only composed by buildings, we also decide to include the mobility, waste and street lighting sectors in this analysis. For this reason, we define their main features, such as consumptions and emissions at the current state always considering the average values of the city of Turin. The next step is the application of several sustainable policies on these sectors to evaluate the improvement at the energy and emissions levels and to compare them with the current state. After that, we create different sustainable scenarios composed by one measure for each sector and we evaluate for each of them costs and benefits to proceed with the cost-benefit analysis. This analysis allows to choose the most social and economic sustainable scenario thanks to the results obtained by the economic indicators extrapolated. The scenario selected is the one that represents a sustainable reference district for the entire city of Turin. Indeed, it has the ambitious feature to be reproducible in the entire city, with the final aim to create a sustainable urban system for the whole area of Turin.

# INITIAL PAPER
# The definition of a cost-benefit analysis connected to the features of new sustainability at the urban scale

# The definition of a cost-benefit analysis connected to the features of new sustainability at the urban scale.

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**ABSTRACT**

The commitment EU Strategy 20-20-20 is approaching the expiry date, this is why the new EU 2050 targets have to be analysed. As a matter of fact, paying attention to the urban scale and not only to the building one is becoming constantly more essential to increase the energy efficiency in our built environment. In this paper, the main features of a nearly-zero energy district and a post-carbon city are investigated. Moreover, cost-benefits analysis is introduced to find out which real social and economic benefits these new districts and city models could offer. Indeed, the assessment of the economic feasibility has a crucial role in the social approval to reach a successful and efficient project. Furthermore, the use of GIS and BIM tools is increasing and it simplifies the interaction among experts with different skills and every single stage that is included in the hard challenge to design a sustainable district and city.

*Keywords: Nearly-zero energy district, Post carbon city, co-benefit, GIS.*

## 1. Introduction

The Europe 2020 Strategy is approaching the expiry date. EU member states have already achieved the reduction of 20% of greenhouse gas emissions and the increment of renewables energy by 20%, nevertheless the target of 20% regarding the energy efficiency has not be reached yet despite the efforts made. In February 2011 the European Union Council confirmed its objective to reduce its GHG emissions from 80% to 95% compared to 1990 levels by 2050, in order to meet the target identified by scientists to keep the climate change below 2°C [1], [2]. Under this perspective, in March 2011 the "Roadmap for moving to a competitive low-carbon economy in 2050" [3] was defined. Buildings are one of the biggest producers of GHG emissions, although the opportunities to save energy on them are numerous. Nowadays taking into account the stock of existing buildings is important because they represent the real cost-effective opportunity for energy and emissions savings. Indeed, in Europe only 1% of buildings is a new construction [4], [5]. Furthermore the real new challenge is to consider the socio-economic and environmental sustainability at the district and urban scale. This is because 50% of global population lives in urbanized areas, and this percentage will increase over 75% by 2030. Recently scholars have started to introduce and discuss in the literature new terms such as nearly-zero energy district (nZED) and post-carbon cities (PCC), see [4], [5], [6], [7], [8], [9], [10], [11], [12], [13] and references therein for a detailed analysis. The nearly-zero energy district is defined as a neighbourhood in which the energy, produced by the on-site renewable energy, covers the annual energy consumption for buildings and transports inside the district [6], while the post-carbon city includes the entire urban system and its decision to remove the use of carbon in every process. This concept deals with radical transformations of the city framework and a long-time strategy across all the main urban sectors is required [6]. A comprehensive study of the sectors which will be mainly involved in the transformation process has been proposed in the "Roadmap for moving to a competitive low-carbon economy in 2050" [3]. Without the purpose of being exhaustive, we may enumerate for instance the power sector, the mobility, the built environment, the air quality and the new green jobs.

Of course, these deep changes will have an enormous impact on different aspects of the city life, first of all on the inhabitants' way of life, but also on engineering, economic and environmental aspects. This article is focused on the new benefits that a community and a society can achieve with a sustainable point of view and to give them a quantification in monetary terms [14]. A cost-benefit analysis (CBA) method will be proposed in connection with the objective to generate a nearly-zero energy neighbourhood and a post-carbon vision of the city. The CBA is an analytical tool to assess the society's convenience and the social benefits that a specific change and planned project can produce. The European Commission in the "Guide to cost benefit analysis of investment projects" [15] highlights the importance to assess the socio-economic benefits in order to achieve a feasible project from the environmental, social and economic point of view [16]. Moreover this manuscript will highlight that nowadays the new technologies, such as Building Information Modelling (BIM) and Georeferenced Information System (GIS) tools [4] are enhancing the identification of critical aspects and benefits that a new energy planning may produce in the improvement of a sustainable society. These new approaches need several and precise data as input to calculate complex outputs and achieve good results [17].

## 2. Methodology

The theoretical aim of the following article is to explain how it is possible to apply a cost-benefit analysis on a nearly-zero energy district and a post carbon city. This literature review analysis starts from the study of the references listed in Tab. 1, in which the concept of nZED and post-carbon city is introduced. Moreover the European commission guidelines about these topics are articulated in Tab. 2. Then the literature review moves to the examination of the references and European Commission guidelines about cost-benefit analysis that are shown in Tab. 3 and Tab. 4, while in Tab. 5 the references concerning the GIS tool are pointed out. This literature review is organized as follows: section 2.1 describes in detail what a nearly-zero energy district is and which are the characteristics of a post-carbon city. In section 2.2 throughout a scheme, the various steps of a cost-benefit analysis methodology are listed and then described. Moreover the most important co-benefits that a society can achieve from the realization of new sustainable policies on the urban scale are described and categorized in economic, social and environmental sustainability. Section 2.3 highlights the importance of introducing in this complex urban projects new technologies like GIS tool in order to improve the quality and the feasibility of the final results. While in section 3, the part concerning the discussion and conclusion, a critical analysis regarding the references used in this literature review is carried out and an investigation of the already existing sustainable community, district and city with their features and the connected use of GIS has been categorised. Moreover the importance of thinking about new solutions for the forthcoming future and to make aware people about these topics is underlined.

**Tab. 1.** References connected to nearly-zero energy district and post-carbon cities.

| […] | Author | Title | Journal | Volume | Year | Pages |
|---|---|---|---|---|---|---|
| [1] | Hoglund-Isaksson et al. | EU low carbon roadmap 2050: Potentials and costs for mitigation of non-CO2 greenhouse gas emissions. | Energy strategy reviews | 1 | 2012 | 97-108 |
| [2] | Capros et al. | Model-based analysis of decarbonising the EU economy in the time horizon to 2050. | Energy strategy reviews | 1 | 2012 | 76-84 |
| [4] | Becchio et al. | The Role of Nearly-zero Energy Buildings in the Definition of Post- Carbon Cities. | Energy Procedia | 78 | 2015 | 687-692 |
| [5] | Becchio et al. | The role of nearly-zero energy buildings in the transition towards Post-Carbon Cities. | Sustainable cities and Society | 27 | 2016 | 324-337 |
| [6] | Marique et al. | A simplified framework to assess the feasibility of zero-energy at the neighbourhood/community scale. | Energy and buildings | 82 | 2014 | 114-122 |
| [8] | Chatterton | Towards an agenda for post-carbon cities: lessons from Liliac, the UK's first ecological, affordable cohousing community. | International Journal of Urban and Regional Research | 37 | 2013 | 1654-1674 |

| | | | | | | |
|---|---|---|---|---|---|---|
| [9] | Kennedy et al. | Rigorous classification and carbon accounting principles for low and Zero Carbon Cities. | Energy Policy | 39 | 2011 | 5259-5268 |
| [12] | Todorović | BPS, energy efficiency and renewable energy sources for buildings greening and zero energy cities planning. Harmony and ethics of sustainability. | Energy and Buildings | 48 | 2012 | 180-189 |
| [13] | Chance | Towards sustainable residential communities; the Beddington Zero Energy Development (BedZED) and beyond. | Environ-ment & Urbaniza-tion | 21 | 2009 | 527-544 |
| [19] | Ferrante | Energy retrofit to nearly zero and socio-oriented urban environments in the Mediterranean climate. | Sustai-nable Cities and Society | 13 | 2014 | 237-253 |
| [20] | Office of the De-puty Prime Minister | Low or zero carbon energy sources: strategic guide. | - | - | 2006 | - |
| [21] | Xie et al. | Study on the evaluation system of urban low carbon communities in Guangdong province. | Ecological indicators | 74 | 2017 | 500-515 |
| [22] | Heinberg | Renewable energy after COP21. Nine issues for climate leaders to think about on the journey home. | - | - | 2015 | - |
| [23] | Steemers | Energy and the city: density, buildings and transport. | Energy and buildings | 35 | 2003 | 3-14 |
| [24] | Flynn et al. | Eco-cities, governance and sustainable lifestyles: the case of the Sino-Singapore Tianjin Eco-City. | Habitat in-ternational | 53 | 2016 | 78-86 |
| [25] | Ibrahim | Livable eco-architecture. Masdar city, Arabian sustainable city. | Procedia. Social and behavioral sciences | 216 | 2016 | 46-55 |

**Tab. 2.** European Commission guidelines connected to nearly -zero energy district and post-carbon cities.

| […] | Author | Title | Year |
|---|---|---|---|
| [3] | European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. | A roadmap for moving to a competitive low carbon economy in 2050. | 2011 |
| [10] | Jensen et al. | Drawing lessons from good city practises: promoting post-carbon transitions. | 2016 |
| [11] | Ferrer et al. | POCACITO roadmap: a policy framework for post-carbon cities. | 2016 |
| [18] | European Commission | Europe 2020 : a strategy for smart, sustainable and inclusive growth. | 2010 |

**Tab. 3.** References connected to cost-benefit analysis.

| […] | Author | Title | Journal | Volume | Year | Pages |
|---|---|---|---|---|---|---|
| [6] | Marique et al. | A simplified framework to assess the feasibility of zero-energy at the neighbourhood/community scale. | Energy and buildings | 82 | 2014 | 114-122 |
| [7] | Marique et al. | From zero energy building to zero energy neighbourhood. Urban form and mobility matter. | - | - | 2013 | - |
| [14] | Becchio et al. | Proposal for a modified cost-optimal approach by introducing benefits evaluation. | Energy Procedia | 82 | 2015 | 445-451 |
| [16] | Becchio et al. | Cost benefit analysis and smart grid projects. | NEWDIST | - | 2016 | 278-287 |
| [26] | EPRI | Methodological approach for estimating the benefits and costs of smart grid demonstration projects. | - | - | 2010 | - |
| [27] | Cupertino | Cost-benefit analysis of carbon dioxide capture and storage considering the impact of two different climate change mitigation regimes. | Economics and Policy of Energy and the Environment | 86 | 2013 | 75-89 |

| | | | | | | |
|---|---|---|---|---|---|---|
| [28] | Beria et al. | Multicriteria versus cost-benefit analyis: a comparative perspective in the assessment of sustainable mobility. | European transport research review | 4 | 2012 | 137-152 |
| [29] | Groth et al. | A comparison of cost-benefit analysis of biomass and natural gas CHP projects in Denmark and the Netherlands. | Renewable energy | 86 | 2016 | 1095-1102 |
| [30] | Cabinet Office, Office of the Third Sector. | A guide to social return on investment. | - | - | 2009 | - |
| [31] | Dell'Anna | Evaluating co-benefits of nZED projects: methodological approach and experimentation in the city of Turin. | - | - | 2015 | - |
| [32] | Heefner et al. | Evaluating the co-benefits of low-income energy-efficiency programmes. | - | - | 2011 | - |
| [33] | Beria et al. | Comparing cost-benefit and multi-criteria analysis: the evaluation of neighbourhoods' sustainable mobility. | - | - | 2016 | - |
| [34] | Marique et al. | A method for evaluating transport energy consumption in suburban areas. | Environmental impact assessment | 33 | 2012 | 1-6 |
| [35] | Xing et al. | A framework model for assessing sustainability impacts of urban development. | Accounting forum | 33 | 2009 | 209-224 |
| [36] | Ryan et al. | Spreading the net: the multiple benefits of energy efficiency improvements. | - | - | 2012 | - |
| [37] | Zugravu | Green jobs – a co-benefit of EU climate policies: myths and realities. | - | - | 2011 | - |
| [38] | Korzhenevych et al. | Update of the handbook on the external costs of transport. | - | - | 2014 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| [39] | Sharifi et al. | A critical review of seven selected neighborhood sustainability assessment tools. | Environ-mental impact as-sessment review | 38 | 2013 | 73-87 |
| [40] | Han et al. | Construction and application of an assessment index system for evaluating the eco-community's sustainability. | Journal of forestry research | 19 | 2008 | 154-158 |
| [41] | Bisello et al. | Smart and sustainable planning for cities and regions. | - | - | 2015 | - |

**Tab. 4.** European Commission guidelines connected to the cost-benefit analysis.

| […] | Author | Title | Year |
|---|---|---|---|
| [15] | European Commission. Directorate-General for Regional and Urban policy. | Guide to cost-benefit analysis of investment projects. Economic appraisal tool for Cohesion Policy 2014-2020. | 2015 |
| [42] | Giordano et al. | Guidelines for conducting a cost-benefit analysis of smart grid projects. | 2012 |

**Tab. 5.** References connected to GIS tool.

| […] | Author | Title | Journal | Volume | Year | Pages |
|---|---|---|---|---|---|---|
| [17] | Delmastro et al. | The evaluation of buildings energy consumption and the optimization of district heating networks: a GIS-based model. | Energy environ eng. | 7 | 2016 | 343-351 |
| [43] | Jalaei et al. | Integrating building information (BIM) and LEED system at the conceptual design stage of sustainable buildings. | Sustainable cities and society | 18 | 2015 | 95-107 |
| [44] | Sieber et al. | Assessment of urban ecosystem services using ecosystem services reviews and GIS-based tools. | Procedia engineering | 115 | 2015 | 53-60 |
| [45] | Alsayyar et al. | Integrating Building Information Modeling (BIM) with sustainable universal design strategies to evaluate the costs and benefits of building projects. | - | - | 2015 | - |

2.1 Nearly-zero energy districts and post-carbon cities.

The feasibility of reaching zero-energy strategies at the building scale is known and undeniable [46] despite a lot of efforts still have to be made. Nowadays institutions and even citizens are becoming always more aware of the importance to achieve the targets imposed by the European Union to improve the quality of life in the cities. Indeed, the environmental and energy issues are ones of the actual major challenges, especially in the building sector that is one of the major
consumers of energy [7], [19]. All these issues have led to think about the need of a radical change in the human being behaviour towards the natural resources of the earth [20], [21], and the existence of a defined plan for each country has started to be considered essential [18], [22] to fight against the environmental problems. First of all, according to the "Roadmap for moving to a competitive low-carbon economy in 2050" [3], every single country should develop feasible strategies suitable with the specific features of its own country and cities in order to achieve in the future a more aggressive and well-planned solution. These new innovative strategies should require investments in different sectors such as energy, transport, industry, information and communication [5], [23]. Furthermore in the literature the assessment of the feasibility, to extend from the district up to the urban scale a zero-energy attitude, has started to be discussed in connection with the awareness of the need to change the human being behaviour, otherwise every improvement will be pointless. Taking into account a larger scale than the building one is more intriguing because the interactions between different buildings and sectors of the area can be analysed and only in this perspective new policies regarding the storage, connection to grids and the gap between the consumption and production peaks can be studied and implemented.

First, in a nearly-zero energy district (nZED) the interaction between the building of the neighbourhood and their location with respect to transport is considered [23]. The first goal of this kind of new community will be to reduce as much as possible the need of energy consumption, trying to cover with renewables sources the necessity of energy connected to transportation, home and electricity. Nevertheless an electric grid will always be present to provide energy when the on-site renewable energies are not sufficient . In addition, a neighbourhood scale perspective and its energy performance could even reduce the cost of the initial investment as suggested in [26].

On the other hand, the post carbon city signifies a rupture in the carbon-dependent urban system and expresses the willingness to achieve an environmental, economic and social sustainable way of living the city. The European Commission defines the concept as follows: "In a low-carbon society we will live and work in low-energy, low-emission buildings with intelligent heating and cooling systems. We will drive electric and hybrid cars and live in cleaner cities with less air pollution and better public transport" [3]. This shift to a new society requires first of all a deep reduction of carbon intensity use and multiple challenges concerning climate change, ecosystem degradation, social equity and economic pressures [4], [5]. Moreover, in the guidelines given in [11], published by European Union,

a post -carbon city has to be clean, green, cohesive and resilient. A cleaner and greener city will help improving the attractiveness of the city itself, while better air quality will have significant impact on the health of citizens and on the relative cost for the Heath national services [11].
Furthermore the sectors that have to be taken into account to outline the transition to a post-carbon city are manifold and complex to classify. In [10], the authors identify the energy sector, the built environment, the urban transport, the waste and the urban planning as key issues towards the transition to a post-carbon city, while in [3] factors such as raising land use productivity and new green jobs are added to the previous ones. The energy sector is regarding the possibility to reduce GHG emissions towards the end of the use of fossil fuels and transition to renewable energies. Wind, biomass and solar power has to become the new sources and district heating and local energy-saving technologies have to be installed. The new design of the built environment and urban planning can move to a more sustainable low-carbon lifestyle, such as the change to a non-motorised society and a promotion of pedestrian and bike-friendly infrastructure. To tackle the problem of waste, human beings should learn the importance of recycling and finally the agricultural policies should focus on the sustainable efficient gains and efficiency fertiliser use [3], [10]. These changes are only some of the most important ones towards the transition to a new sustainable vision at the urban scale. Achieving these results will be already an enormous challenge for the forthcoming future.

## 2.2 Cost-benefit analysis

### 2.2.1 Cost-benefit analysis steps

Cost-benefit analysis (CBA) is an analytical tool to evaluate an investment decided to improve the social welfare and to appraise the economic advantages and disadvantages by assessing its costs and benefits [15].According to the literature [26], a benefit is defined like an impact that have a positive effect on a firm, a household or a society in general. In the CBA every benefit associated to an investment or a policy is translated into monetary terms, or in other words in a cost, and even the non-market goods have to be quantified. Moreover with this type of analysis the best option identified among different alternatives policies can be chosen [29]. This is why this kind of economic evaluation is the proper one to assess the policy and changes that can be performed. The main feature of the cost-benefit analysis is the social surplus that consists in the difference between the joined effect of perceived utility and income distribution and the monetary cost or effort made to obtain such good. According to its main features, a CBA is usually used to analyse a large scale transformation project for the entire society or a certain socio-economic policy and to assess the social expenditure's efficiency translating all the effects into a common measure [28] .
In order to achieve a cost-benefit analysis some fundamental steps, as it is shown in Fig. 1, are included in the appraisal. First of all, the presentation of the socio-economic, institutional and political context of the project has to be defined, then the objectives and the project have to be clearly marked. Furthermore analysing the demand and its options permit to determine the technical

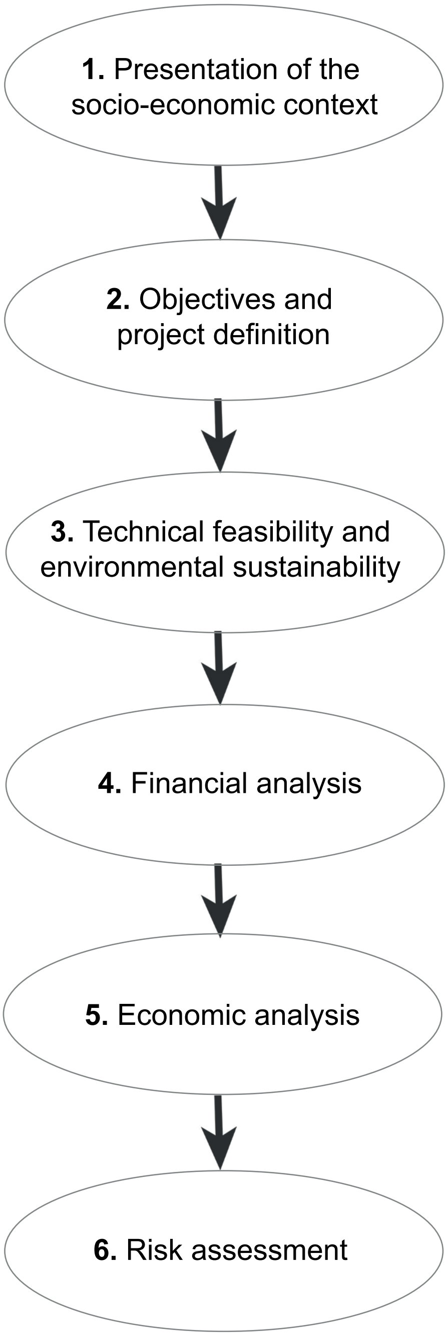



**Fig. 1.** Steps of a cost-benefit analysis.

feasibility and the environmental sustainability of the project. The next step is to begin the financial analysis that has to be carried out from the point of view of the infrastructure owner and it has to take into account only the cash inflows and outflows. First and foremost, the amount of the investment is defined and divided in initial investment, replacement costs and residual value. The replacement costs include the amount of money used to replace the short-life machinery during the reference period, while the residual value represent the residual potential of the remaining service whose economic life is not yet completely exhausted. Later, the definition of the total operating costs and revenues is required, especially the revenues are determined by cash in-flows paid by the users for that specific good or service. It is important to highlight the need to keep every project financially sustainable, in other words to be sure not to run out of cash during the entire investment. After the financial analysis, the economic one is expected. It differs from the previous one principally because it is focused on the economic welfare aspects. Moreover the financial analysis was taken from the point of view of a private investor, while the economic analysis considers the price values from the point of view of the society in general ad its environment, and all costs and benefits are expressed in monetary amounts [15], [27]. In the economic evaluation, direct benefits, non-market impacts and even externalities are taken into account. The direct benefits are usually estimated trough the concept of marginal Willingness-To-Pay (WTP) that measures the amount of people who would be willing to pay for a certain good [14], [15]. In the recent years, concerning the inclusion of non-market impacts in the economic calculation significant progress have been made. Whenever money quantification is not possible, at least these impacts have to be expressed in physical terms to give an idea of the influence of such factors.

After the quantification of every benefit the main indicators of the cost-benefit analysis, the Net Present Value (NPV) and the benefit/cost ratio (B/C), can be calculated. They are taken into account to measure the economic performance of the project. The first one aggregates all costs, revenues and impacts discounted and expresses the value in the current period and it can be written as in Eq.1 :

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \quad (1),$$

where N is the total number of periods, Rt is the net cash flow, in other words the difference between the cash inflow and the cash outflow referred at the t, i is the discount rate and t is the time of the cash flow. While the benefit/cost ratio corresponds to the discounted value of benefits, in other words of positive impacts, divided by the sum of discounted costs, in other words the negative impacts, as it is written is Eq. 2 :

$$\frac{B}{C} = \frac{\sum_i \frac{B_i}{(1+d)^i}}{\sum_i \frac{C_i}{(1+d)^i}} \quad (2),$$

where Bi are the benefits of the project I the year i, Ci are the costs of the project in the year i and d is the discount rate.
The benefit/cost ratio is associated with the Social Return on Investment (SROI) that is deduced by the sum of the discounted benefits by the sum of the discounted costs (Eq. 3) :

$$SROI = \frac{\sum_{t=0}^{N} \frac{B}{(1+r)^t}}{\sum_{t=0}^{N} \frac{C}{(1+r)^t}} \quad (3),$$

where B is the benefits flows, C the costs flows, r the discount social rate and t the time considered. SROI concept regards more about the value and the impacts return expressed in monetary measure [16], [30]. The last step of the cost-benefit analysis is the risk assessment that is characterized by different phases: the sensitivity analysis, the qualitative risk analysis, the probabilistic analysis and the risk prevention and mitigation. The sensitivity analysis is used when the results obtained from the economic analysis are connected to fundamental criterions whose future tendency can have a significant impact on the final results. Some examples of these criterions could be the increasing of the energy prices, the yearly population growth and the change of discount rate.
Then the qualitative risk analysis is characterized by the construction of a list and a risk matrix of potential adverse events trying to understand the complexities of the project.
For instance, delays in the construction time that could postpone the operational phase can be considered as an adverse event that can be inserted in the risk matrix. While the probabilistic risk analysis assigns a probability distribution to each variables of the previous sensitivity analysis. The final step is trying to carry out the risk prevention or mitigation during the entire phases of the project or policy [15].

### 2.2.2 Co-benefits

After the description of the methodology of the cost-benefit analysis, in this subsection we define the possible co-benefits that a certain policy and changes can produce on a society and its environment. The co-benefits differ from the benefits because they are connected to a more specific topic and to social-environmental policies. A large number of co-benefits that differ from each project and policy can be considered, especially depending on the type of research that the investor wants to conduct. In [15] the benefits generated by an investment project are classified in five main sectors: the transport, the environment, the energy, the broadband, and the research, development and innovation. To these factors others co-benefits that are consequences of the improved energy efficiency and connected to the improvement of the sustainability at the urban scale can be added, such as: energy savings, real estate market value, enhancement of indoor comfort, reduction of GHG emissions, health benefits, new green jobs and the energy security related to storage system [14], [16]. In this literature review we have classified the possible co-benefits regarding a nearly-zero energy district and a post-carbon city trying to divide them among environmental, social and economic positive impacts. It is possible to notice from the Fig. 2 that most of the co-benefits have an impact on more than one sector. In fact, the environmental, economic and social aspects are most of time connected one to each other and for this reason dividing them is quite hard.

With this analysis we want to underline that the society, from the single private inhabitant of a building to the citizen of the biggest cities, should understand that spend a large amount of money on the initial investment for a beneficial project can increase the co-benefits concerning the achievement of a new sustainable way of life. The researches and the studies, regarding the co-benefits, are increasing and demonstrating that it is possible to achieve a sustainable city from the economic, social and environmental point of view investing money and time in certain sustainable policies.

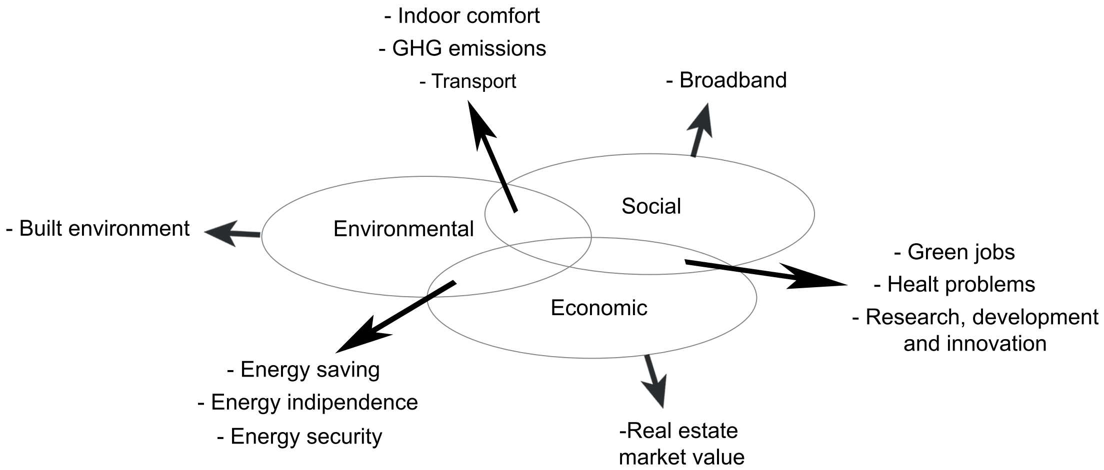



**Fig. 2.** Co-benefits and their impacts.

- Energy saving

First of all, with the target of designing a sustainable district up to the future post-carbon city, one of the most challenging results to achieve is to save as much energy as possible. The energy saving identifies one of the most important environmental-economic co-benefit and it follows from the increased energy efficiency that has to be reached in every sector that characterized the framework of a city. The cost reduction connected to the energy saving is expressed by the opportunity cost of the avoided energy input [16].

- Real estate market value

The real estate market value is even expected to increase with the design of green-labelled buildings because, as it is explained in [14], the willingness to pay more for a building and the better efficiency are strictly related. Analysing a big amount of buildings and their features it is possible to assess the willingness to pay for each variables. For instance, it is estimated that the willingness to pay for a different level of class, concerning the Energy Performance Certificate (EPC) is around 9.600 € [31].

- Indoor comfort

Another important co-benefit, that is connected with the improvement of buildings, is the enhancement of the indoor comfort. Indeed, as claimed by the authors in [14],occupants who does not feel comfortable usually take actions that entail the waste of energy such as having an incorrect behaviour connected to the natural air ventilation. Furthermore, a good air indoor quality implies the reduction of health problems with an indirect saving for the whole community. Preventing the possible health problems connected to humid buildings and "cold" houses could be a first step to reduce the future direct and indirect costs. Moreover, the decrease of energy unit cost is strictly connected to the increase of indoor temperature. In this case, to assess the increase of temperature inside the buildings, it is possible to evaluate the savings of energy consumption costs that it is possible to achieve in a certain building against the energy consumption in a counterfactual case at a "standard" comfort temperature.

- Reduction of GHG emissions and transport

The reduction of GHG emissions and a new design of public transport at the district and urban scale are related to achieve a better way of life. As it is underlined by the authors in [15], the transport has to be designed in a new sustainable way trying to reduce the amount of private means of transport, to increase the public one and to promote bike and pedestrian friendly strategies. The costs connected to the GHG emissions are even related to the health problems of every inhabitant of the city. These negative co-impacts are related to medical rehabilitation, injures and emergency services caused by accident and air, noise pollution and the climate change that every human being is experiencing. It is possible to assess the CO2 produced by each energy carrier throughout the Eq.4 :

$$M_{del,ICO2} = Q_{del,I} \times k_{em,I}[kgCO_2] \quad (4),$$

where Mdel,CO2 is the CO2 amount of energy carrier, Qdel,I is the specific production of energy carrier and kem,I is the CO2 emission factor. Then, this value has to be multiplied by the price per ton CO2 equivalent.

- Green jobs

Another positive co-impact that can be achieved according to the green economy market is the creation of new jobs connected to these new policies. For instance in [16] throughout the Eq. 5 and the shadow wage data, it is described how it is possible to quantify the co-benefit reached with the unemployment reduction.

$$SW = W \times (1 - t) \times (1 - u) \quad (5),$$

where W is a average annual salary, t is the income taxation and u is the unemployment rate of the region considered. Nowadays the creation of new jobs will be considered as a very positive externality, especially due to the expected loss of jobs due to automation in the industrial sector in the next decades.

- Energy independence

Concerning the energy production, investing on renewable energies and sources, has to become an essential challenge to try to substitute fossil fuels with renewable sources. Ensure a major energy independence for each single country is fundamental to avoid problems connected to political instability [15], [16].

- Energy security

Another important element that has to be included in the design of a future city and to its cost-benefit analysis is the presence of an energy storage system which will help to decrease the frequency of energy interruptions. Always from an energy management point of view, a crucial role will be played by the development of energy smart grids which are characterized by the integration of technologies. These devices control, throughout the digital information, the efficiency and optimization of the delivery of power and electricity.

### 2.3 BIM and GIS tools

Thinking about a nearly zero-energy neighbourhood or a post-carbon city, a digitized device controlling the entire transformation of the framework of the city, from the point of view of the design and the economic part, will be the real objective to achieve in the near future. Building Information Modeling (BIM) is starting to be used increasingly more to control every single stage and aspect of a project [43] in the building scale. Indeed, this tool has the potential to take relevant decisions from the beginning to the end of the construction's life to reach an economical and environmental sustainable building and to coordinate activities, time phases and people that are working in the building site with different skills. The advent of BIM is requiring always more skilled designers that are able to manage with multi-disciplinary information and to incorporate basic performance data from the first phases of the design project [43].

On the other hand, another software is becoming always more popular. In fact, GIS tool allows to exploit all the buildings and networks that are geo-referenced, to create a detailed GIS-Database with the characteristics of specific buildings and of a specific district, such as energy consumption and the potentials energy emissions and savings [16], [44]. If the data inserted in the device are of high quality, this method is considered very useful to provide energy saving on urban scale. In this case for instance, as the authors show in [17], the influence of each building heat demand can be obtained trying to optimize in the best way the heat network distribution. The importance of the quality, quantity and reliability of data has to be highlighted to achieve satisfactory and useful results [4]. The geo-referenced map can evidence the positive and negative features of the designed sustainable policy throughout the generation of thematic maps such as for instance the energy plan of an urban area or a district. After having proceeded to analyse the input of the spatial data and through a cost-optimization procedure, the best solution to take for a certain policy will be suggested [17].

## 3. Discussion and conclusion

This literature review highlights the importance of thinking about future policies in order to reach a sustainable society in which the quality of life will improve drastically. In the first part of the paper, the features of a nearly-zero neighbourhood and a post-carbon city are described, trying to emphasize the importance of moving the attention to an urban scale. Then, the importance of carrying out an economic sustainable policy to achieve sustainability at the urban scale is underlined. In fact the fundamental phases of a cost-benefit analysis are described, and even the possible co-benefits that a society can achieve with a liveable way of life are arranged. Then the possible interaction between a sustainable policy and GIS tool is explained. Concerning the literature review, in Fig. 3 is shown that the majority of the refences analysed are connected to the city scale.

While in Fig. 4, connected to the main co-benefits that are present in the analysed literature, we can notice that the reduction of GHG emissions and

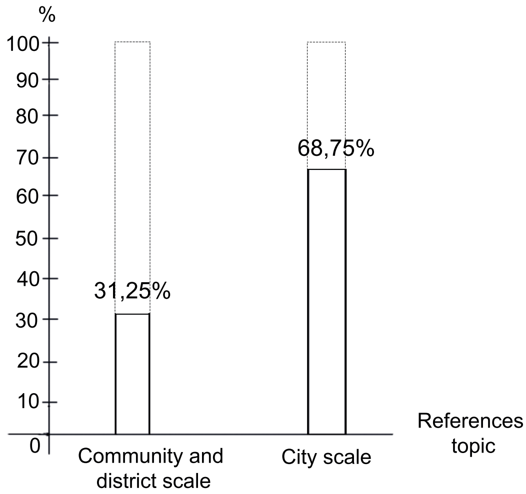



**Fig. 3.** Percentage of references connected to community and district scale and city scale.

transport and energy saving are the most investigated positive co-impacts. In fact, these co-benefits are the easiest one to quantify and moreover they represent the first change that has to be apply in a sustainable urban scale.

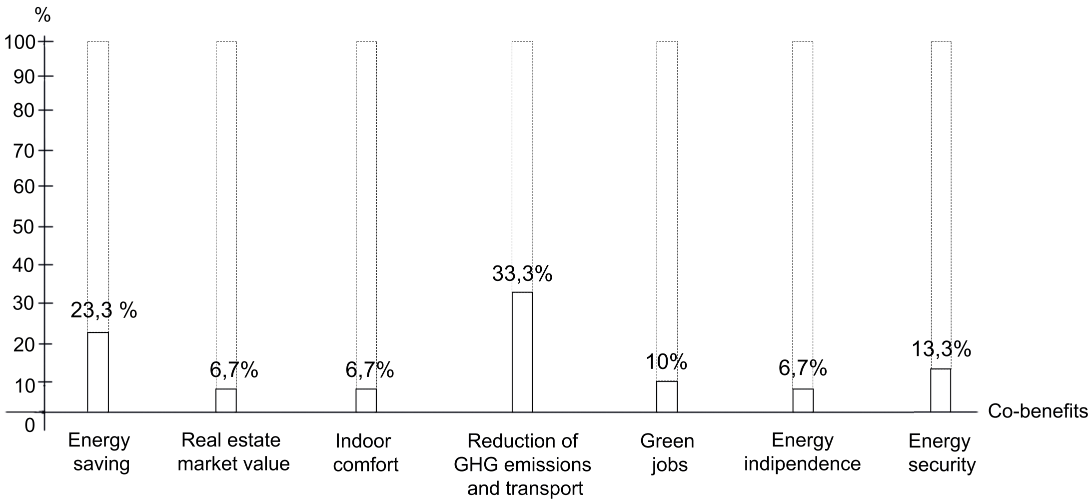



**Fig. 4.** Percentage of references connected to co-benefits.

In the foreseeable future the need to find some economic suitable policy to achieve a sustainable society is increasing. Existing studies concerning future challenges are now moving their attention from the building scale to a broader one, but a significant effort has to be made to find concrete solutions.

The analysis of the literature highlights the fact that a lot of theoretical solutions are clear in scholars' mind but they still have to be planned to be applicable in the existing cities. Some examples of post-carbon city and nearly-zero energy district and community are enunciated in Tab. 6.

**Tab. 6.** Examples of existing nearly-zero city, district and community.

| City | Country | Intervention scale | Populated | Main features | BIM | Monitored data | […] |
|---|---|---|---|---|---|---|---|
| Masdar City | United Arab Emirates | City | No | -Electric transport<br>-Photovoltaic and wind-installation | Yes | Yes | [25] |
| Sino-Singapore Tianjin | China | City | Yes | -Waste management<br>-Light-rail light system | Yes | Yes | [24] |
| Alessandria CONCERTO al Piano | Italy | District | Yes | -Eco-refurbishment<br>-Infrastructure improvement | -* | Yes | [48] |
| Liliac | United Kingdom | Community | 20 households | -Car segregation<br>-Green areas<br>-Co-housing | -* | Yes | [8] |
| Beddington Zero Energy Development | United Kingdom | Community | 99 households | -Transport, food production and waste<br>-Natural habitants and wild-life<br>-Health | -* | Yes | [13] |

*Not found data

From these examples we can understand that it is quite hard to completely renovate an already existing populated city. In fact, the city scale examples were built in the last decades as new construction. While it is easier to renovate in a sustainable way an already existing district. It was not possible to find any information concerning an economic evaluation or a cost-benefit analysis developed on these cases. Moreover the use of GIS is essential at the city and district scale, while in the community scale we could only speak about monitored data without a specific GIS-database. The data monitored are manifold and related to the positive and negative co-impacts. Moreover in [48], a big amount of sustainable community and district examples designed by European Union are enumerated.

In conclusion, the most crucial step in next years is to make aware citizens of the importance to change attitude towards these new challenges, not consider them as a insuperable obstacle to overcome, but as a positive objective to reach to live in a better city framework and society. From this point of view, starting from a district scale to an urban one, the possibility to increase the sustainability in the society will be concrete. The transparency towards citizens regarding these new sustainable policies will be the right key to explain them the social and economic gains that the entire society will receive from this new type of life. Moreover the environmental problem and the need of energy independence is there for all to be seen.

## 4. References


[1] L. Höglund-Isaksson , W. Winiwarter, P. Purohit, P. Rafaj, W. Schöpp, Z. Klimont, EU low carbon roadmap 2050: Potentials and costs for mitigation of non-CO 2 greenhouse gas emissions, Energy Strategy Reviews 1 (2012) 97–108.

[2] P. Capros, N. Tasios, A. De Vita, L. Mantzos, L. Paroussos, Model-based analysis of decarbonising the EU economy in the time horizon to 2050 Energy Strategy Reviews 1 (2012) 76–84.

[3] European commission, Roadmap for moving to a low-carbon economy in 2050, Brussels (2011).

[4] C. Becchio, S. P.Corgnati, C. Delmastro, V. Fabi P. Lombardi, The Role of Nearly-zero Energy Buildings in the Definition of Post- Carbon Cities, Energy Procedia 78 (2015) 687–692.

[5] C. Becchio, S.P. Corgnati, C. Delmastro, V. Fabi, P. Lombardi, The role of nearly-zero energy buildings in the transition towards Post-Carbon Cities, Sustainable Cities and Society 27 (2016) 324–337.

[6] A.F. Marique, S. Reiter, A simplified framework to assess the feasibility of zero-energy at the neighbourhood/ community scale, Energy and Buildings 82 (2014) 114–122.

[7] A. Marique , M. Penders, S. Reiter, 2013 From zero energy building to zero energy neighbourhood. Urban form and mobility matter, LEMA University of Liege, (2013).

[8] P. Chatterton, Towards an agenda for post-carbon cities: Lessons from lilac, the uk's first ecological, affordable cohousing community, International Journal Urban and Regional Research 37 (2013) 1654–1674.

[9] S. Kennedy, S. Sgouridis, Rigorous classification and carbon accounting principles for low and Zero Carbon Cities, Energy Policy 39 (2011) 5259–5268.

[10] A. Jensen, I. Stumpp, K. Kern, Drawing lessons from good city practises: promoting post-carbon transitions, POCACITO (2016).

[11] J.N. Ferrer, C. Stroia, N. Fujiwara, M. Alessi, POCACITO Roadmap: a policy framework for post-carbon cities, CEPS (2016).

[12] M.S. Todorovic, BPS, energy efficiency and renewable energy sources for buildings greening and zero energy cities planning. Harmony and ethics of sustainability, Energy and Buildings 48 (2012) 180–189.

[13] T. Chance, Towards sustainable residential communities; the Beddington Zero Energy Development (BedZED) and beyond, Environment & Urbanization 21 (2009) 527–544.

[14] C. Becchio, S.P. Corgnati, L. Orlietti, G. Spigliantini, Proposal for a modified cost-optimal approach by introducing benefits evaluation, Energy Procedia 82 (2015) 445–451.

[15] European Commission. Directorate-General for Regional and Urban policy, Guide to cost-benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014-2020, Brussels (2015).

[16] C. Becchio, S. P. Corgnati, F. Dell'Anna, Cost benefit analysis and smart grid projects, NEWDIST (2016) 278- 287.

[17] C. Delmastro, G. Mutani, L. Schranz, The evaluation of buildings energy consumption and the optimization of district heating networks: a GIS-based model, International Journal of Energy and Environmental Engineering 7 (2016) 343–51.
[18] European Commission, Europe 2020 : a strategy for smart, sustainable and inclusive growth. Communication from the Commission, European Commission (2010).
[19] A. Ferrante, Energy retrofit to nearly zero and socio-oriented urban environments in the Mediterranean climate, Sustainable Cities and Society 13 (2014) 237–253.
[20] Office of the deputy prima minister, Low or zero carbon energy sources: strategic guide (2016).
[21] Z. Xie, X. Gao, C. Feng, J. He, Study on the evaluation system of urban low carbon communities in Guangdong province, Ecological Indicators 74 (2017) 500–515.
[22] H. Richard, Renewable energy after COP21. Nine issues for climate leaders to think about on the journey home, Post Carbon Institute (2015).
[23] K. Steemers, Energy and the city: Density, buildings and transport, Energy and Buildings 35 (2003) 3-14.
[24] A. Flynn, L. Yu, P. Feindt, C. Chen, Eco-cities, governance and sustainable lifestyles: The case of the Sino-Singapore Tianjin Eco-City, Habitat International 53 (2016) 78–86.
[25] I. Ibrahim, Livable Eco-Architecture Masdar City, Arabian Sustainable City, Procedia – Social and Behavioral Sciences 216 (2016) 46–55.
[26] Electric Power Research Insitute, Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects, (2010).
[27] S. Cupertino, Cost-benefit analysis of carbon dioxide capture and storage considering the impact of two different climate change mitigation regimes, Economics and Policy of Energy and the Environment 1 (2013) 75-89.
[28] P. Beria, I. Maltese, I. Mariotti, Multicriteria versus Cost Benefit Analysis: A comparative perspective in the assessment of sustainable mobility, European transport research review 4 (2012) 137–152.
[29] T. Groth, B. Scholtens, A comparison of cost-benefit analysis biomass and natural gas CHP projects in Denmark and the Netherlands, Renewable Energy 86 (2016) 1095-1102.
[30] Cabinet Office, Office of the Third Sector, A guide to Social Return on Investment, Cabinet Office, Office of the Third Sector (2009).
[31] F. Dell'Anna, Evaluating co-benefits of nZED projects: methodological approach and experimentation in the city of Turin, Politecnico di Torino (2015).
[32] G. Heefner, N. Campbell, Evaluating the co-benefits of low-income energy-efficiency programmes, International Energy Agency (2011).
[33] P. Beria, I. Maltese, I. Mariotti, Comparing cost benefit and multi-criteria analysis: the evaluation of neighbourhoods' sustainable mobility, https://www.researchgate.net/publication/266869527 , May 2017.
[34] A. F. Marique, S. Reiter, A method for evaluating transport energy consumption in suburban areas, Environmental impact assessment review 33 (2012) 1–6.
[35] Y. Xing, R.M.W. Horner, M.A. El-Haram, J. Bebbington, A framework model for assessing sustainability impacts of urban development Accounting Forum 33 (2009) 209–224.
[36] L. Ryan, N. Campbell, Spreading the net: the multiple benefits of energy efficiency improvements, International

Energy Agency (2012).
[37] N. Zugravu, Green jobs - a co-benefit of EU climate policies: myths and realities, in: Energy efficiency first. The foundation of a low-carbon society, ECEEE 2011.
[38] A. Korzhenevych, N. Dehen, J. Bröcker, M. Holtkamp, H. Meier, Update of the handbook on external costs of transport, European Commission (2014).
[39] A. Sharifi, A. Murayama, A critical review of seven selected neighborhood sustainability assessment tools, Environmental impact assessment review 38 (2013) 73–87.
[40] Y. Han, L. Dai, X. Zhao, D. Yu, S. Wu, Constuction and application of an assessment index system for evaluating the eco-community's sustainability, Journal of forestry research 19 (2008) 154–158.
[41] A. Bisello, D. Vettorato, R. Stephens, P. Elisei, Smart and sustainable planning for cities and regions, Springer International (2015).
[42] V. Giordano, I. Onyeji, G. Fulli, M. Sánchez Jiménez, C. Filiou, Guidelines for conducting a cost-benefit analysis of smart grid projects, European Commission (2012).
[43] F. Jalaei, A. Jrade,Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings, Sustainable Cities and Society 18 (2015) 95–107.
[44] J. Sieber, M. Pons, Assessment of urban ecosystem services using ecosystem services reviews and GIS-based tools, Procedia Engineering 115 (2015) 53–60.
[45] B. Alsayyar, A. Jrade, Integrating building information modeling (BIM) with sustainable universal design strategies to evaluate the costs and benefits of building projects, 5th International/11th Construction Speciality Conference, (2015).
[46] V.M. Barthelmes, C. Becchio, M.C. Bottero, S.P. Corgnati, L'analisi del costo ottimale per la definizione di strategie di progettazione energetica: il caso di un "nearly-Zero Energy Building", Valori e valutazioni 16 (2016) 61–75.
[48] http://ec.europa.eu/energy/en/topics/technology-and-innovation, May 2017.

# CHAPTER 1
# European targets and sustainable development

# 1. European targets and sustainable development

Europe 2020 strategy targets for smart, sustainable and inclusive growth is approaching the expiry date. European Union member states have already achieved two of the three objectives that were set by European Union leaders in 2007 and enacted in legislation in 2009 [1]. Indeed, the reduction of 20% of greenhouse gas emissions, from 1990 levels, and the increment of renewable energy by 20% has been reached, while the target of 20% concerning the energy efficiency has not been achieved despite many efforts were made. Moreover, due to the greenhouse gas (GHG) emissions effects on climate, one of the main European Union Council objective is to reduce them by 80-95% by 2050, compared to 1990 level, in order to keep climate change below 2°C [2]. Milestones are 40% emissions cuts by 2030 and 60% by 2040. In 2013 was estimated that urban areas in the world produce almost 23.8 Gt, that stands for gigatons, of $CO_2$ emissions. This value represents 70% of total global production with the major responsibility attributes to building and industrial sectors, followed by transport one. This is one of the main reason why the attention has to be payed mainly on urban areas where the majority of human activities take place. The WHO, World Health Organisation, is monitoring the data of air quality of 1600 cities in 91 countries that show the steady or getting worse of air pollution quality in the majority of the developed and developing countries. Main causes, found out by WHO, are associated to coal-fired power, dependent on private vehicles and inefficient use of energies sources in residential buildings, despite the efforts already made in some urban areas [3].

Taking into account all these challenges, the European Commission released a "Roadmap for moving to a competitive low-carbon economy in 2050", in which the way to achieve a low carbon future is described. The biggest challenges will be the refurbishment of existing buildings, because in

Europe new buildings only cover 1% of the total amount of buildings stocks, and the expansion of new measures and interventions at the district and urban level. Furthermore, since the percentage of global population living in urban areas will increase over 75% by 2030, reaching the percentage of 70% of people living in cities by 2050 [4], urban level will become fundamental to develop new sustainable models.

The European Union and its member countries are part of UNFCC, United Nations Framework Convention on Climate Change, and also subscribe its Kyoto Protocol. UNFCC is an international environmental agreement that entered into force in 1994 with the aim to keep unvaried greenhouse gases emissions to prevent damages to environment and climate system. For this reason, annually greenhouses emissions, progress and new policies of European Union Members are monitored by United Nations towards greenhouse gas inventories, biennial reports and national communications. With Kyoto Protocol, first compulsory restrictions were given to the signatory members [5]. The aim of this agreement is to reduce GHG emissions and it expects to reduce the emissions of 18% by 2020 compared to 1990 levels, while EU and its members have undertaken to reduce, as it said before, of 20% the level. The greatest shortcoming of this agreement is the involvement of the only developed countries and the consequent coverage of only 14% of the total global emissions [6]. UNFCC has also moved forward with the Paris Agreement, an international agreement on climate changes that was achieved on 12nd December 2015. Connected to the Paris Agreement, in November 2017 in Bonn another meeting has taken place to discuss the different points of this covenant while, the fulfilment and the entrance into force of this agreement will be in 2020. The first aim of the signatories' members is to keep below 2°C the climate change, trying to succeed in reaching 1,5°C with respect to pre-industrial levels with the commitment to present national action plans and policies to reach the targets proposed.

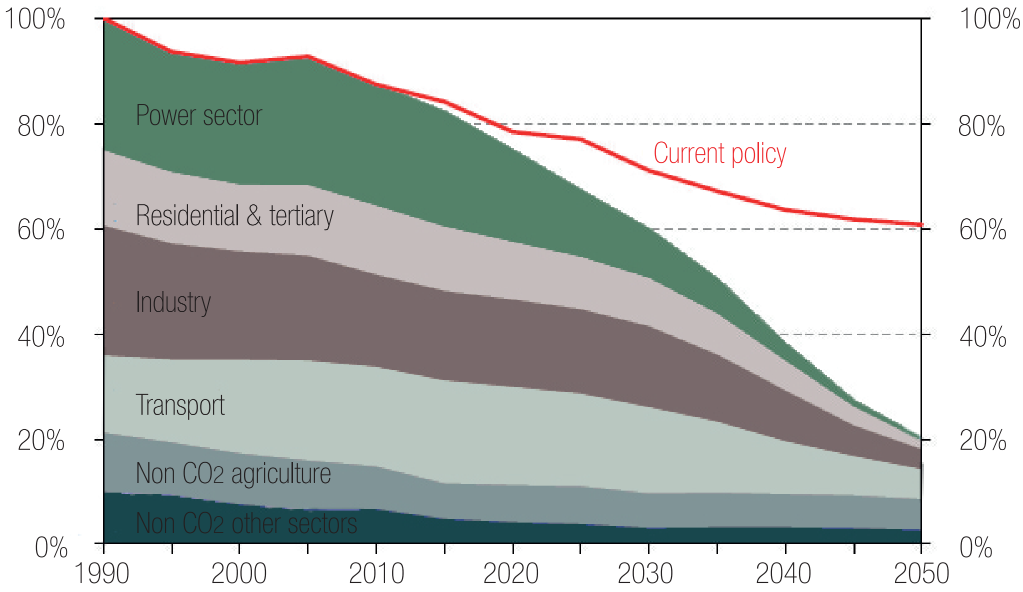
Furthermore, each member has to monitor and communicate its reached results in order to apply transparent politics and to establish always more challenging purposes. European Union and the other developed countries have also the task to invest in helping developing countries to reduce emissions [7]. Indeed, the geo-political areas of the world with the largest growth population, the most prosperous economic development and the consequently hugest increase of energy demand, are developing countries such as India, China and Africa. By 2050, 70% of urban Gross Domestic Product (GDP) will be produced by urban areas in China, Africa, India and non-OECD economies (Organisation for Economic Co-operation and Development). As a matter of fact, GDP of urban areas is considered vital to develop national competitive economy and, in these regions, where the urban areas are rapidly increasing, the GDP is expected to grow significantly. In 2013, urban GDP shares greater than 80% produced three-quarters of the total global GDP and these data confirms that urban areas will always have a great influence on global economy. That is why it is also important to invest in sustainable infrastructures and technologies in developing countries mostly paying attention on urban areas. The majority of urban GDP in developing countries can be mainly explained by the relocation of population from rural to urban areas due to the urban localization of more developed infrastructures and services. These emerging economies should try to promote sustainable plans and policies during their development to not create urban areas with inefficient plans and infrastructures that will influence the citizens life for the years to come. Cities in developing countries are still on time to not commit mistakes that will have negative impacts on the future generations, taking into account the fact that the decisions taken today will have effect in the long term [3].

To better analyse the climate change, three different scenarios have been constituted by the International Energy Agency: 2DS ,2°C scenario, 4DS, 4°C scenario and 6DS, 6°C scenario. They represent the temperature below which the climate change should be kept. Scientists and international community consider 2°C the threshold beyond which extremely and catastrophic changes of the environment can take place, and for this reason the one below which climate change has to be kept. The need to reduce GHG emissions trying to keep climate change below 2°C does not have to be underestimated. Indeed, the climate changes are in front of us every-day and are becoming always more difficult to be managed and forecasted. Furthermore, providing a better air quality in every city will create more liveable places with a better life expectancy. Scientists found out that the current global average temperature is 0.85°C higher than it was in the late 19th century and that human being activities are the main problem. Under the 6DS, in which the climate change is only kept below 6°C, the global primary energy use will grow by about 70% and the $CO_2$ emissions will have an increment of 50%. This scenario will become reality in case no action energy plans will be developed in urban areas in order to provide a better future to the world population [3]. Climate change is already influencing the entire planet and in the coming decades the situation will even get worse if the human being behaviour does not change. Climate change effects can act on urban systems with extreme weather conditions that can cause damages on buildings, infrastructures, energy plants and distribution systems. Moreover, urban areas on coastlines face direct risks to the always increasing temperatures that are causing ice melting with the consequent rising of the sea level. Weather changes have also consequences on agriculture, forestry, wildlife and furthermore on human being health due to the increment of the number of heat-related deaths and respiratory diseases [8].

To achieve these targets imposed by the different agreements, the most immediate and cost-effective way is to increase energy efficiency of buildings, thanks to a cutting of energy demand and a wider exploitation of renewable resources. Moreover, the need of well-planned and long-term strategies in every main urban sectors is required. Indeed, the interventions on building sectors only, is not considered enough to reach a sustainable society [4]. The task of developing new plans is really urgent, because postponing investments will mean higher initial costs and longer-term in the success of the policies. Indeed, after having realised an infrastructure or having implement a policy, the economic return on the investment has not an immediate impact and even the success on the environment become tangible after a couple of months [9].

As it is shown in the Figure 1, all sectors can contribute in reducing emissions and it is necessary that every possible action will be made from

Figure 1. EU GHG emissions towards an 80% domestic reduction (100%=1900)




Source: European Commission, A roadmap for moving to a competitive low carbon economy in 2050, 2011, Brussels.

every side. Definitely, power sector has the most powerful role in achieving this aim. Indeed, the replacement of use of fossil fuels with renewables resources, in addition to strong investments in smart grids will give a new perspective in the power production. Emissions from buildings could be reduced by 90% in 2050, thanks to the improvement of energy efficiency in old buildings and the construction of passive houses. Moreover, the substitution of electricity and renewable energy for fossil fuels will make the difference. In the industrial sector the technologies used will get cleaner and more efficient, while in the transport one the hybrid and electrical cars will become the new era of automotive. Furthermore, agriculture can cut emissions using different fertilisers and manure even if the global food demand will increase in the next decades [1]. Eventually, it is clear from the figure above, the difference between the percentage of emissions that will be produced by 2050 following the current policy or following the targets imposed.

Another assertive point is that, moving to a sustainable society should not to be considered by citizens as a large number of new rules to be followed. Instead, the human being behaviour has to change thanks to the awareness and the willingness to achieve a better quality of life, firstly trying to reduce illness and deaths due to air pollution. Moreover, living in a sustainable society will have positive impacts on the costs of healthcare, will decrease traffic congestions and will provide so many benefits that a happier and peaceful life will be the result. Beyond important co-benefits on quality air pollution, environment and health, new decarbonisation scenarios will have positive impacts on the economy of European Union and its countries, bringing new investments and reducing the dependency on the supply of fossil fuels from other areas of the world [9]. European Union and its members should start to consider fundamental these challenges for climate, economic and security reasons taking into account that every actions of today is already shaping the global environment of 2050 [9].

## 1.1. Sustainability at district level

Taking into account the targets imposed by the different agreements and European Union, due to the critical environmental situation that the entire planet is facing, policies and plans have to be developed in order to guarantee to future generations a better world where to live. Thinking about developing policies and plans, the district scale is a convenient unit of scale to evaluate and integrate sustainability in the different urban sectors. Indeed, districts are compact and large enough to have impacts on city and society, and concentrate resources and infrastructures to improve efficiency. Moreover, districts are small parts of urban areas, where the majority of current and future energy will concentrate [3], and that have all the intrinsic characteristics of the entire urban system with high density of population and representative types of buildings and infrastructures. Taking into account a larger scale, than the building one, can have an enormous impact on different aspects of the citizens every-day life and shows how many benefits a society can achieve from a new sustainable point of view. Furthermore, it is more convenient than building scale because the interactions between buildings with different functions and the different areas of the city is more complex and can give a more efficient result [10].

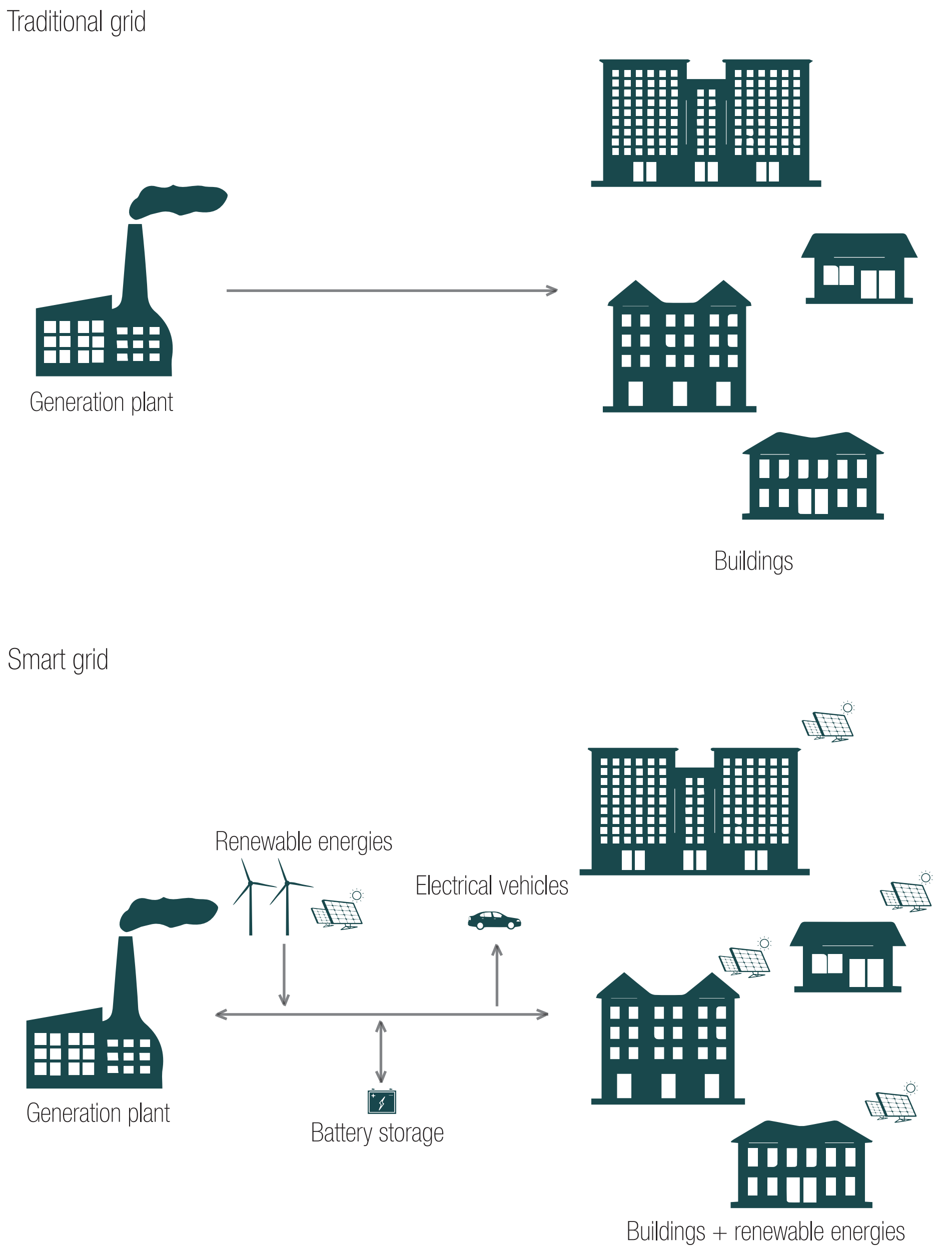
Integrating projects and infrastructures that generally work separately, such as district heating, buildings and mobility, will be the right way to jointed-up frameworks. Every knowledge that will come out with sustainable districts could be implemented and used to design post carbon cities, that are one of the biggest challenges that society should reach by 2050. The European Commission defines in this way the new concept of a more sustainable society in a large scale: “In a low-carbon society we will live and work in low-energy, low-emission buildings with intelligent heating and cooling systems. We will drive electric and hybrid cars and live in cleaner cities with less air pollution and better public transport" [2].

Smart sustainable districts are also characterized by a sustainable lifestyle and a new way of interacting, communicate and live the build environment trying to enjoy the city thanks to low carbon mobility, such as car and bike-sharing with new bike lanes, and public green spaces. With the addition of new technologies, it will be possible to have more efficient buildings, better water, waste management, accessibility and interactions of huge number of data. Indeed, collecting data will be a great chance to monitor the energy waste and savings connected to every action taken in everyday life [11]. First of all, the most important step will be to increase the energy efficiency of the district starting from buildings, that should become zero-energy buildings and should produce more energy than they use. Another important step will be to include new technologies in smart sustainable districts in order to develop new ways to produce and use energy and to control and monitor the changes and improvements during the years. The use of information and communication technologies (ICT) will provide the use of new technologies and communication means to control, store, manipulate and transmit information. This could be useful when applications on our smartphones will check directly data of residential buildings or will show to citizens the best way to reach on time the desired place moving with public means of transport [9], [12].

Furthermore, it is fundamental to understand that the conventional electrical grid was characterized by the simple transfer of electricity from the generation place to the different buildings and users of this service, while an energy supply sustainable system [3] will be developed to produce energy towards cleaner sources and to supply cleaner and more secure electricity, heat and fuels towards new networks. In a nearly zero energy district (nzeD), the grid will be more complex and incorporated with various smart grid technologies trying to maximize the efficiency, giving benefits to the entire community and including energy supply and end-user. Indeed, smart cities will be characterized by different energy supply networks, such as electrical, heating and cooling one, that will be directly connected one to each other thanks to a smart storage and supply grid [3]. For instance, the smart grid will control and monitor the production and distribution of electricity, storages, electrical vehicles, public illumination and cogeneration system. That is why renewable energy will be connected to the grid before arriving to the final users [13].

Indeed, the idea is to create larger centralised systems, which are the main producer of energy, and smaller decentralised systems that have to interact directly among them. For this reason, the distribution grid has to become smarter and more developed while the storage, distribution and transmission of energy have to become increasingly more integrated to meet the necessity of the growing number of producers and demands. The new producers will be small decentralised systems, and they will generate local renewable energy. An example of these new producers are photovoltaic and solar panel system installed in private residential buildings. Nevertheless, since these new local producers will not be sufficient to satisfy the total energy request of the buildings, mainly due to the discontinuity of the renewable sources, there will be still the necessity of a central producer capable of meeting the energy request in case of need. Therefore, the presence of local producers will not imply the disappearance of centralised producers, but the future goal to address is to make the local ones increasingly more independent from the larger ones. Among the future demands we can enumerate the electrical vehicles recharge stations, as well as buildings which will be then simultaneously producers and demands.

Figure 2. Traditional grid vs. smart grid




Trying to respect the targets imposed by European Union and to develop a better society and environment where to live in the future, a well-organized strategy has to be developed in order to solve the challenges that every stakeholders will face during the design phase of a sustainable district. Firstly, precise goals have to be defined to achieve improvement in an easier and faster way. Setting goals with the idea that the design phase is not the only important part of this process, but that a sustainable project has also to keep high its performances during the use phase, permits to think about future in a more aware and informed way. Furthermore, occupants of the area have to be informed of every step of the innovations coming and involved in the decision process. In fact, a non-acceptance from the citizens side and a consequently wrong use of new technologies and infrastructures could cause the inefficiency and failure of the project. Involving the future users from the beginning will be the right way to have a working project in the present and in the future. To define goals, involving citizens and design a well-structured plan is essential. Furthermore, finding the right team composed by people with different and various knowledge and skills is assertive to generate an articulated project such as a sustainable district. Moreover, beyond architecture, engineering and construction, every sustainable project has to be completely embedded in the context in which it has to be design. The designers have to try to understand perfectly, interests, ambitions and needs of local citizens analysing the natural, environmental and urban structure of that area in order to organize a project that perfectly fits the features of that place. Moreover, the initial investment will be significant and a business model in a long-term will be fundamental to support the ambitions of the project from the beginning and during the entire use phase. Sharing knowledge, having a strong communication between members team and plan time to acquire skills and to implement new innovative solutions is the right solution to develop sustainability in the future cities of the entire world. Furthermore, the changes that the area will experience during the years has to be taken into account to establish neighbourhoods that can perform also in the future. Therefore, the projects have to be flexible and changeable at the needs and desires of the occupants. Identifying strong and weak points, thanks to monitoring systems such as performances of single buildings and infrastructures, community development and satisfaction level of people that live and work in the area, permit to improve projects from every different sectors point of view [14].

To sum up, as it is described in [9], energy efficiency has to drastically increase, the targets imposed by 2020 has to be reached with the collaboration of the entire society and a strengthen awareness and involvement of citizens has to be developed. Furthermore, the international collaboration and the continuous growing interests towards these topics will be the right path to develop a better world in a faster way. The change will be guided by the improvement of thermal efficiency, mostly connected to residential, public buildings and industrial sector, thanks to the use of renewable energies, smart grid, combined cooling and heating system and the avoid, shift and improvement policies in the transport, mobility sector and all the other fields [3].

As already said, to achieve a sustainable development we have to improve the current situation on urban system and on its various fields. That is why measures, policies and interventions that are applied on already existing cities can be an example to reproduce on other areas. Before starting the description of the numerous possible interventions and measures on various urban fields in the next chapter, it was useful to focus the attention on real urban systems around the world on which measures were applied to improve their sustainability. These case studies were selected among a large number and analysed, extrapolating the major measures that were applied on them. In the Table 1 the main features of each case studies are enumerated, focusing the attention on the unit scale on which the measures were applied, on the distinction between already existing and built area or new area and on the actions that are characterizing the specific area.

Table 1. Case studies analysed.

| | Unit scale | Population | Already exisitng/ New construction | Actions | Active population | Monitored data | Bibliography |
|---|---|---|---|---|---|---|---|
| Xihe community, Bexi city | Community | Populated | Already exisitng | - Aritifcial environment<br>- Population situation<br>- Purchasing power<br>- Traffic design employment rate<br>- Planners : more efforts in community plan<br>- Resident : more partecipation in community construction<br>- Ecological engineering : flexibility used in community construction | It has to be implementd | Assessment index method | [15] |
| Amsterdam | City | City proper: 851.373<br>Urban area: 1.351.587<br>Metropolitan area: 2.410.960 | Already exisitng | - Constant development of Ict-based projects<br>- Reduction $CO_2$ emissions<br>- Reduction of energy wastage<br>- Sustainable economic growth<br>- Change citizens' behaviours to induce more sustainable life-styles<br>- Living spaces, working spaces, mobility, public spaces | Living lab methodology | 'Expanded business case' | [16] |

| | Unit scale | Population | Already exisitng/ New construction | Actions | Active population | Monitored data | Bibliography |
|---|---|---|---|---|---|---|---|
| Queen Elizabeth Olympic Park, London | District | Before : Olympic Park<br>Now : residential area | Already exisitng area with 10.000 new homes and a new social and economic hub | - Efficient, smart, low-carbon, resilient energy system<br>- Smart park, greening and rehabilitation of the environment<br>- Inclusive design<br>- High environmental performance<br>- Resource efficiency in buildings | Involvement of local community | Sensors throughout the park to collect data such as air quality and micro-climate picture | [11] |
| Moabit, West Berlin | District | Populated | Already exisitng: residential and industrial district | - Sustainable water management<br>- Energy efficiency<br>- Low carbon mobility | Active networks of citizen and company initiatives | District data atlas | [11] |

| | Unit scale | Population | Already exisitng/ New construction | Actions | Active population | Monitored data | Bibliography |
|---|---|---|---|---|---|---|---|
| Utrecth - The new center | District | Populated | Regeneration of an already existing district | - Less and slower traffic, and clean personal mobility<br>- Energy neutral construction<br>- Efficient water management and greening<br>- Attractive trough sustainable energy<br>- Model for sustainable and healthy power<br>- Use of local produced re-newable power<br>- Hybrid integrated systems for heating and cooling at district level | - | Not constructed yet | [17] |
| Les Docks De-Saint-Ouen Sur-Seine | District | Populated | Regeneration of an already existing district | - Tyre waste collection<br>- Creation of a district heating system<br>- Rain water management<br>- New sustainable buildings and a new park | Public reunions with citizens | Not constructed yet | [18] |

| | Unit scale | Population | Already exisitng/ New construction | Actions | Active population | Monitored data | Bibliography |
|---|---|---|---|---|---|---|---|
| Oristà, Spain | Village | 601 inhabitants | Already existing | - Reduction GHG emissions<br>- Information of energy consumption of the buildings and facilities<br>- Energy efficiency improvement<br>- Renewal of vehicles among the private ones, promotion of car sharing, electric charging points<br>- Implementation of renewable energy, district heating, cooling plant, smart grid<br>- Waste and water management | - | Access to data of energy consumption | [19] |

| | Unit scale | Population | Already exisitng/ New construction | Actions | Active population | Monitored data | Bibliography |
|---|---|---|---|---|---|---|---|
| Isorella, Italy | Village | 4.074 inhabitants | Already exisitng | - Reduction $CO_2$ emissions thank to improvement of energy efficiency of public buildings and installation of photovoltaic panel systems<br>- Hybrid or electric cars adiministration, recharge electrical cars stations, more bike paths<br>- Education courses to sensitize citizens<br>- Green public procurement (trying to be a positive example for citizens) | Community involvement and raise awareness of citizens | Monitoring system | [20] |
| Bagnolo Mella, Italy | Town | 12.625 inhabitants | Already exisitng | - Reduction $CO_2$ emissions<br>- Improvement of energy efficiency of public buildings<br>- Hybrid or electrical cars in public administration<br>- More bikepaths<br>- Photovoltaic panel systems<br>- Education courses to sensitize citizens<br>- Green public procurement (trying to be a positve example for citizens) | Raise awareness of citizens | Monitoring system | [21] |

## 1.2. Bibliography

[1] EC (European Commission), 2020 climate & energy package, 2017. Available at: https://ec.europa.eu/clima/policies/strategies/2020_en#tab-0-0, last access: November 2017.

[2] EC (European Commission), A roadmap for moving to a competitive low carbon economy in 2050, 2011.

[3] IEA (International Energy Agency), Energy Technology Perspectives 2016 – Towards Sustainable Urban Energy Systems, Paris, 2016.

[4] C. Becchio, S. P. Corgnati, C. Delmastro, V. Fabi, and P. Lombardi, The role of nearly-zero energy buildings in the transition towards Post-Carbon Cities, Sustainable Cities and Society 27 (2016) 324–337.

[5] UN (United Nations), The Paris Agreement, 2015. Available at: http://unfccc.int/paris_agreement/items/9485.php, last access: November 2017.

[6] European Council, International agreements on climate action, 2017. Available at: http://www.consilium.europa.eu/it/policies/climate-change/international-agreements-climate-action/, last access: November 2017.

[7] European Council, Paris Agreement on climate change. Available at: http://www.consilium.europa.eu/it/policies/climate-change/timeline/, last access: November 2017.

[8] EC (European Commission), Climate action, 2017. Available at: https://ec.europa.eu/clima/index_en, last access: October 2017.

[9] European Commission, Energy roadmap 2050, Belgium, 2012.

[10] A. Marique, M. Penders, and S. Reiter, From zero energy building to zero energy neighbourhood. Urban form and mobility matter. At PLEA 2013 - 29th Conference, Sustainable Architecture a Renewable Future, no. September, (2013) 1–6.

[11] Climate-KIC, Smart Sustainable Districts (SSD). Available at: http://www.climate-kic.org/wp-content/uploads/2016/04/SSD-Extract-V2.pdf, last access: October 2017.

[12] S. Maier, Smart energy systems for smart city districts: case study Reininghaus District, Energy, Sustainability and Society 6 (2016).

[13] F. Dell'Anna, Evaluating co-benefits of nZED projects: methodological approach and experimentation in the city of Turin, Polytechnic of Turin, 2015.

[14] Except integrated sustainability, WWF, Lafarge, Sustainable urban districts 2015 global review. Strategies to accelerate sustainable urban development, 2015. Available at: http://media.except.nl/media/uploaded_files/asset_files/WWF_SustainableDistricts_v28_web.pdf , last access: October 2017.

[15] Y. Han, L. Dai, X. Zhao, D. Yu, and S. Wu, Constuction and application of an assessment index system for evaluating the eco-community's sustainability, Journal of Forest Research 19 (2008) 154–158.

[16] L. Mora and R. Bolici, How to become a smart city: learning from Amsterdam, in Smart and Sustainable Planning for Cities and Regions, 2017, pp. 251–266.

[17] Climate-KIC, Smart Sustainable Districts - Utrecht Beurskwartier. Available at: http://ssd-utrecht.nl/about-smart-sustainable-districts/the-ssd-project/, last access: October 2017.

[18] Les Docks De Saint-Ouen-Sur-Seine. Available at: http://docks-saintouen.fr/, last access: October 2017.

[19] Global Covenant of Mayors for Climate & Energy, SECAP Summary report - Oristà. Available at: https://www.globalcovenantofmayors.org/cities/orista/, last access: October 2017.

[20] Covenant of Mayors for Climate & Energy, Comune di Isorella - Piano di azione per l'energia sostenibile e il clima (PAESC). Available at: www.covenantofmayors.eu., last access: October 2017.

[21] Covenant of Mayors for Climate & Energy, Città di Bagnolo Mella - Piano di azione per l'energia sostenibile e il clima (PAESC). Available at: www.covenantofmayors.eu., last access: October 2017.

# CHAPTER 2
# How to achieve a sustainable district

## 2. How to achieve a sustainable district

The concept of sustainable urban energy system is fundamental to understand how an urban district interacts with the rest of the city. An urban energy system is composed by different urban components that are constituted by several interconnected networks and components that produce and use energy. A transition to a sustainable urban system can increase the access to clean energy, reduce the exposure to air and acoustic pollution, increase the energy security due to the reduction of the dependence on other countries and achieve new important benefits. Probably, among these reasons, the most important ones are two human health challenges: energy poverty and air pollution. The first one refers to the lack of accessibility to clean energy for cooking and heating. Indeed, the access to cleaner commercial fuels, such as low-carbon electricity and natural gas, has to be a priority for all countries. Indeed, almost 20% of global urban inhabitants, mostly concentrated in low- and middle-income countries, is currently living in dramatic conditions without access to primary energy services. The second most important problem is the outdoor air pollution that is widespread from poor to developing and already developed countries. In 2012, WHO has estimated that, globally, 3.7 million deaths were caused by air pollution and that the most affected areas were the Western Pacific and Southeast Asian regions [1].

Furthermore, an urban sustainable system meets certain requirements that characterize its structure and framework. First of all, the population density of an urban area determines how different energy components work individually and interactively among them. For instance, densely populated areas are characterized by high demand of fast and frequent urban transport means, while in the low density urban areas buses are preferred. Another characteristic is the building stock that can be older, as it happens for most of the buildings in Europe, and newer. Older buildings will be the cause of huge amount of energy waste and in this case, even the components of urban energy system, will be outdated and difficult to adapt to new technologies. While in the newer building stocks the efficiency will be higher, and the innovations will be easily accessible. Moreover, land use is another factor to take into account because generally urban sprawl is connected to higher energy waste and inefficient means of transport. Even the economic structure of an urban system can be relevant to understand which policies can be applied or not in certain situations. Indeed, areas in which industrial sector is highly developed use more energy with respect to areas characterized by services in which the energy use is not even constant during the entire day, having a specific hourly energy demand profile. Eventually, climate is also characterizing the urban system because the need of heating and cooling system will determine the framework of supply grids [1].

Taking into account all these characteristics, creating macro-groups of cities and areas will be possible and useful to identify policies and plans that will be applicable to each macro groups. Starting points to activate policies will be really different depending on the characteristics of the areas in which the actions are taken, but sharing knowledge of every single innovation reached will be the right way to achieve sustainability in the entire world. Moreover, knowing and analysing every policy and plan that can be apply in the different sectors will be essential to demonstrate the fulfilment of a smart sustainable district. The flexibility of these plans has always to be taken into account, due to the fact that the policies applied on a district, have also to be adaptable to the city in which the district is. Indeed, in facing these huge challenges, thinking about borders is not the right way to deal with problems [1]. The vision has always to be global, policies can be applied to areas, cities or districts and if they will be considered innovative and useful they will become a positive example that can be reproduced. Every energy and sectorial planning will require an integration into spatial and urban planning [2]. In the following chapter we have analysed some of the fields that can influence the urban system and its features describing their current characteristic and the possible policies that can be applied on them.

## 2.1. Energy retrofit of buildings

It is well-known that nowadays building sector is one of the major energy consumers and air pollutants producers together with transport and power sector. Moreover, the biggest issues will be observed in urban areas due to the increasing rate of urbanization [3]. It is counted that global buildings sector is responsible for 30% of global final energy consumption and that one third of the global emissions of carbon dioxide pollutants is coming from it [1], [3]. Indeed, achieving positive results in energy efficiency of buildings is important to reach the uptake of nearly-zero energy district and sustainable urban systems. The fundamental steps that have to be taken to improve the current energy efficiency of buildings in urban areas are the deep energy renovations of existing buildings, the design of zero-energy new buildings, and energy-efficient heating and cooling systems. The most challenging issue is the achievement of efficient District Heating and Cooling (DHC) in combination with the use of heat pumps and renewable sources that will really allow to make buildings part of a wider sustainable urban system [1].

Energy efficiency is then considered the most important goal to reach the targets imposed by agreements and European Union legislations. For this reason, huge investments have already started to be implemented [1]. The energy retrofit of buildings has to become a priority due to the characteristics of European buildings stock. Indeed, Europe is characterized by a low demolition rate and old low energy efficient buildings that imply the necessity to renovate them [3]. Another challenge in the retrofit, is the respect of rules connected to restoration of buildings of historical-artistical relevant important that are widely present in Europe and Italy. In these cases, the ability of specialists of different sectors have to be pooled and integrated. Even though physical characteristics and pattern buildings are manifold in every urban system, it is possible to enumerate several common building types. Indeed, in wide energy retrofit, reference buildings are taking into account to categorise and standardised the typologies of interventions that are available [3]. To evaluate energy performances of a large number of buildings, in order to define retrofit measures and policies, two typologies of classification are possible. The first one is a top-down approach that start from the determination of every single feature and energy performance data to find a connection between different buildings. While, the second one is a bottom-up approach that determine the entire performance of a building stock evaluating the single-building level [4]. These measures are different and defined by intrinsic features of each building such as number and behaviour of occupants, material used in construction phase, local climate, demand of heating and cooling and energy loads refrigeration and water heating [1].

Furthermore, health and well-being benefits are strictly connected to energy efficiency investments. Indeed, health diseases related to pollution will decrease, the creation of new employment will be possible and the cheapest energy services will help the reduction of energy poverty in certain cities [1]. It is important to consider that residential and public buildings are at a turning point in which from being highly-energy-demanding elements have to be transformed in highly-efficient micro energy-hubs that produce, storage and consume energy as a conventional energy system. A more developed independence in the production of energy will also be beneficial in energy bills for private consumers [5]. Even in this transformation, the awareness of citizens about certain topics is fundamental to develop a correct and aware behaviour.

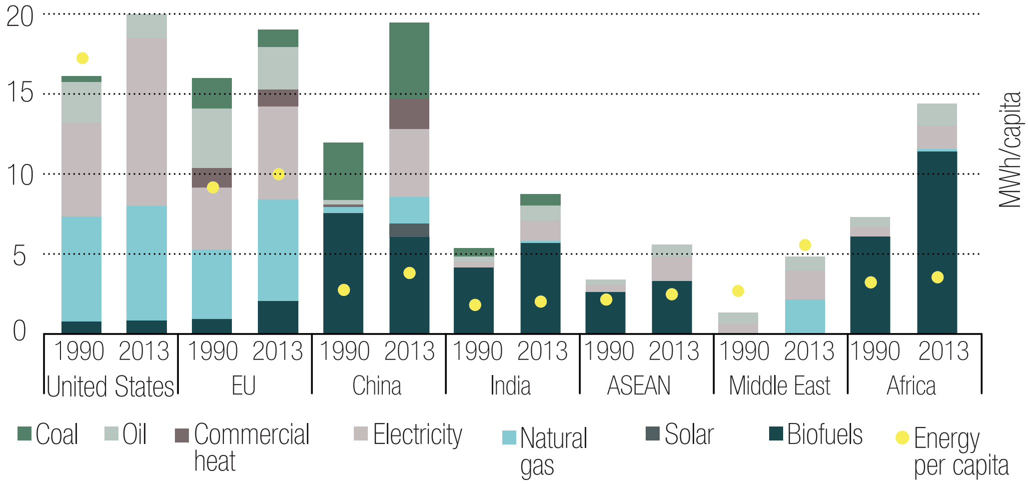
Connected to new construction buildings, the recast of the Directive on the energy performance of buildings (Directive 2010/31/EU) imposes that new buildings have to be nearly-zero energy building from 2020, and new public buildings have to address this requirement from 2018. Zero-energy buildings (ZEBs) have to follow the commitment to have zero carbon emissions on an annual basis. European Union is making the effort to develop measures, policies and financial investments to promote the transformation of already existing building in nearly-zero energy buildings. The uptake of these buildings will be possible with the reduction of energy demand, the increment of renewable energies exploitation and the use of appropriate technologies to facilitate this task. Recently the most frequent issue connected to nearly-zero energy buildings is the life-cycle Assessment (LCA) of the construction materials embodied in the buildings. It is important that construction products and techniques have an high optimization potential, in order to reduce the environmental impact of the building from the construction phase to the disposal of the materials at the building end-life [6].

### 2.1.1. Current and future situation

Buildings sector is one of the most influencing field in the global climate change due to its high consume of energy and emissions of air pollutants. Global buildings sector is responsible for 30% of global final energy consumption and it emits one third of the global emissions of carbon dioxide pollutants [1], [3]. Buildings are also the demanders of half of the total amount of electricity consumed and residential subsector is accountable for nearly three-quarters of building energy use. The 2DS, 2°C scenario, in this sector consists in the exploitation of highly efficient building energy technologies and in deep retrofit of existing buildings before 2050. The largest energy-consuming end use is the space heating of buildings that accounts for more than one-third of global energy use. While talking about space cooling, the portion of energy demand is currently smaller, but it is forecasted it will significantly increase, mostly in warm-climate emerging economies [1]. Significant efforts have to be made in both developed and developing countries. In the first ones because of the high level of consumption per person, while in the developing countries because of the increasing rate of urbanisation, as it is shown in the Figure 1.

Indeed, urbanisation in developing countries is associated with the increase of urban population and a consequent increment of the consumption connected to heating, cooling and electricity demand. Developing countries will play a fundamental role due to the increase of population that is expected to be around 40% by 2050 [1].It is relevant to notice that energy demand in building sector is not only influenced by factors that are connected to intrinsic features of building, but it is first and foremost related to different

Figure 1. Comparison of energy per capita in different world areas and periods.



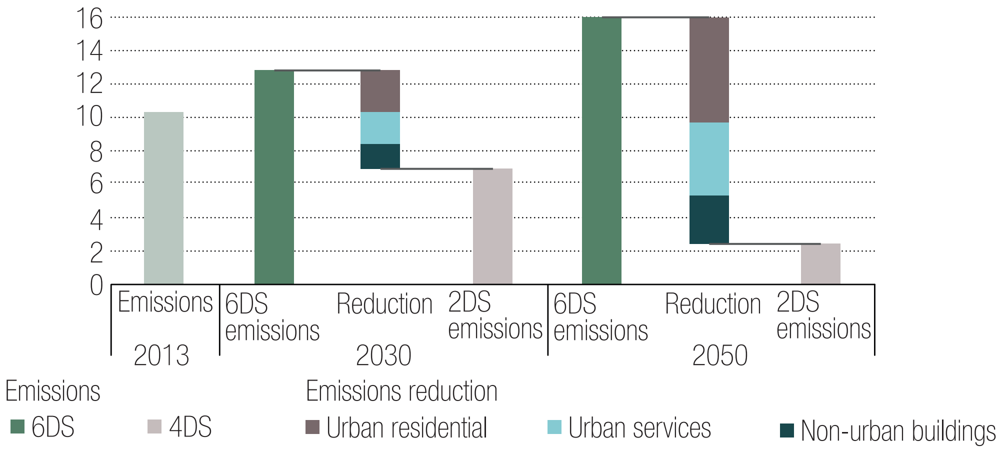

Source: IEA (International Energy Agency), Energy technology perspectives 2016. Towards sustainable urban energy system, Paris, 2016.

countries, social, economic, demographic and geographic characteristics of each world area.

According to 2DS, global building energy should decrease more than 75% having a reduction of consumption of 30% and a decrease by 40% of urban space heating and space cooling demand compared with the 6DS in 2050. Concerning the measures taken to raise energy efficiency of buildings under 2DS, envelope improvements are responsible for nearly 80% of savings in urban building space heating and cooling, while the uptake of high-efficiency lighting is reducing the consumption by 35% and energy-efficient cooking equipment will reduce consume nearly by 20% compared to 6DS by 2050. Regarding the global electricity consumption with the development of 2DS, there will be a decrease of 33% in 2050 compared with the 6DS. In developing countries, energy-efficiency measures and the consequent saving in electricity consumption will be assertive to develop the current electrical grid, improving its affordability. Consequently, thanks to renewable sources and the installation of solar thermal water heaters, there will be an improvement in access to energy services and comfort. Clearly, in a 2DS, the consumption of fossil fuels should decrease by 50%, while the urban solar thermal consumption connected to urban buildings sector will increase by 1000% over 2013 level [1].

Furthermore, urban buildings sector and its consumption are strictly connected to $CO_2$ emissions as it is shown in Figure 2. In case no policies will be develop and the 6DS will take place, the emissions will increase from nearly 10 $GtCO_2$ in 2013 to 16 $GtCO_2$ in 2050, where $GtCO_2$ means gigatons of $CO_2$. On the other hand, in the 2DS urban building $CO_2$ emissions will decrease by 85% compared to 6DS with the contribution of 65% of residential subsector and three-quarters of urban buildings of total building sector reduction. For this reason, it is fundamental to promote measures and policies to improve the current energy-efficiency of buildings.

Figure 2. Reduction of emissions from 6DS to 2DS.




Source: IEA (International Energy Agency), Energy technology perspectives 2016. Towards sustainable urban energy system, Paris, 2016.

### 2.1.2. Policies and measures

The transition in building sector from highly-energy consuming systems based on the use of fossil fuels to more dependent energy systems centralised on renewable sources is the main goal of the next decades. As it is described in [5], the challenge will be transforming buildings from demanders of energy to highly-efficient micro energy-hubs. Micro-energy hubs can be defined as a building or a group of buildings, which are connected to a wider energy system, that is able to produce, store and consume energy in an efficient way [5]. In [5], the authors enumerate ten principles are enumerated to achieve this micro energy-hubs. These principles are:

- to maximise buildings' energy efficiency;
- to increase renewable sources use and self-consumption;
- to boost energy storage;

- to incorporate demand response capacity in the building stock;
- to eliminate the use of fossil fuels in heating and cooling system;
- to self-control of end-use of energy via smart meters;
- to render dynamic price signals available for all consumers;
- to foster business models;
- to create innovative interconnected district;
- to promote the uptake of infrastructure for electrical vehicles.

Instead in [7], some policy instruments are listed such as energy performance and urban planning regulations, financial loans and investments, information, training and demonstration buildings, energy taxes and the promotion of energy audits.

The most important result that has to be reached is the maximisation of buildings' energy efficiency. This is achievable thanks to a drastic reduction of energy demand from heating and cooling spaces of buildings [1], [5]. The reduction of overall seasonal and daily peak load is required and moreover, an efficient building system should be capable to shift end-user heating and cooling demand. Indeed, well-designed and high-performance buildings are able to keep the desired indoor temperature for a longer period thanks to an appropriate preheating or precooling [5]. Energy thermal demand of a building is influenced by several factors such as local climate, pattern of the building, user behaviours, building orientation, shape of urban environment and technology and material choices. Even though energy improvement performance is reachable in an easier way in new construction buildings, the results obtained in already existing buildings have to be as similar as possible to the new ones. Indeed, even in already existing buildings, it is possible to achieve heating performance loads of 40 kWh/m² to 60 kWh/m², compared with typical loads that are around 150 kWh/m² or higher. While results of nearly-zero energy buildings or passivhaus standards, with heating load ranges of 15-25 kWh/m², are technically reachable but not convenient from the economic point of view. Maybe in the future, thanks to more promotion, research and development in this field, even these results will become achievable [1]. Retrofit and renovation of buildings are relevant mainly in areas where cold and hot temperatures are really tightening. Right now, especially in developing countries, individual component replacements or small renovations in buildings are usually accomplished. The challenge is to provide policies and measures that promote more assertive improvements in order to achieve major long-term cost-effective investments. The missing steps are policies that can cover every building stock, but their realization is quite complex due to the huge variety of features of buildings and to external factors such as historical-artistical protection laws. Groups of energy efficiency measures could be a solution to scale-up policies boosted at national and urban scale. Thanks to a wider diffusion, the overall payback period can be shorter and both short-term and longer-term measures, includes deep renovation, can be accomplish from private and public building owners, as suggested in [1].

National policies could influence the use of national land-use planning frameworks and can provide fiscal policies and energy taxes. Indeed, financial incentives can be implemented at national and local level to better promote the use of new renewable sources and technologies that allow the reduction of energy consumption of buildings. The first aim of these financial incentives is to empower citizens' motivation with a proper communication. Express the willingness of authorities of the commitment to achieve success in energy field can be seen as a clear signal and can boost private buildings owner to follow the public authorities. Meanwhile, it will be more complex to favour the reception of the increment of energy taxes. If we want to take this path, a good communication plan has to be developed in order to ensure citizens understanding and awareness, with a consequent change of their behaviour. Indeed, the promotion of good energy measures will start from a coherent policy that also covers the retrofit of public buildings and shows to citizens data monitored to make concrete the real benefits of these investments [7]. The increment of data information and awareness will be essential to define both national and local policies. Indeed, increasing the awareness of building energy needs and opportunities will help to better understand the possible options of energy-efficiency technologies adaptable to every typology of buildings [1].

Urban areas and their policies could be essential to achieve the desired result. First of all, the awareness of citizens and building users have to be increased in order to change and shape their behaviour to use in a proper way these innovative energetic systems. Indeed, even if technologies are the most advanced ones, it is important to use them in a proper way to have the best possible result. Building codes are expected to be among the most efficient instruments to define features of new constructed buildings. For instance, orientation of the building, its shape to reduce as much as possible its thermal loads, electrical appliance, technologies and materials chosen have to follow strict rules to increase the performance of buildings as much as possible. Cities should also guide these changes towards new policies and regulations. Starting from the retrofit of public buildings and with demonstration projects, local institutions can be a positive example to promote the expansion of energy-efficient technologies and good building practises in urban areas [1]. Concerning energy efficiency, energy demand in the space cooling of buildings plays a key role. The possibility to generate energy to cool spaces from renewable sources is always a good choice. Moreover, some innovative technologies and building envelopes are available to reduce the energy need for cooling. In certain area of the world with particular climate, it is possible to refresh air with natural and night-time ventilation strategies that are implemented by specific architectural patterns and shapes, where reflective roadways and pavements help to decrease urban temperature [1]. Buildings' heating and cooling demand should be satisfied by electricity to allow the transition to a low-carbon society, with the significant reduction of fossil fuels use. Individual heat pumps together with district heating has to become the mainstream as heat supply solution [5]. Another capacity that can be developed in buildings is energy storage to absorb or release energy when needed. Accumulating thermal and electrical energy produced with renewable sources allows energy system to be more cost-effective. The storage can offset daily and seasonally varying energy demand and supply. Home batteries are trying to kick-start in the global market and it is forecasted that their cost could drop by 70% over the next 15 years [5].

The awareness of building envelope technologies importance is significantly increasing. Even if attention in the construction, renovation, air sealing of building envelope and efficient windows is improving, it is important to continue the research to enhance the knowledge and achieve better installation practises. The International Energy Agency (IEA) has develop in 2013 a technology roadmap, called Energy Efficient Building Envelopes, explaining policies, investments and regulations to develop efficient buildings envelops in both new and old buildings. Solve air leakages is a primary request in world areas where high or low temperatures allows hot or fresh air infiltration and exfiltration. Regarding windows performance several technologies have been developed such as low-emission glass coatings, solar control glass and double glazed or triple glazed windows. Low-emission glass coating can reduce heat loss by 33% to 40% in winter and heat gain by over 50% in summer thanks to its radiant barrier. Similarly, solar control glass features fit with hot and sunny weather because they reject solar heat transmitting high levels of solar light. Both typologies of glasses can be modulated depending on the necessity and the orientation of every specific building. In developed countries double glazed windows with low-emission glass are quite diffused, while triple glazed windows are trying now to emerge in the market. In developing countries, still single glaze windows are diffused [1].

Furthermore, nearly-zero energy buildings (nZEBs) and zero-energy buildings (ZEBs) policies are increasing in urban areas and are spreading out the idea to strive for buildings in which energy demand is really low and renewable energy sources are exploited as much as possible to generate always more energy-independent buildings. It is easy to develop this idea in single-family houses in non-urban areas, while in urban areas with a dense building stock the use of renewable sources is more complex. This is why space management is a challenge that has not to be underestimate. Nevertheless, the uptake of heat pumps, biomass boilers, photovoltaic and solar thermal panels is evident [1]. On-site or nearby-building installed technologies are part of the wider energy grid of an urban area. Rather than buy energy from the grid, consumers can produce their own energy autonomously saving money. Moreover, in this way they are more aware of their consumption and they can better control their energy system. Smart meters are one of the best instruments to enable end-users to control, monitor and manage their consumptions. Indeed, real-time data are provided and allow consumer to modulate their energy use, achieve a more efficient use of energy and mitigating the picks of the grid. A project with the use of smart meters in Ireland has already started in order to analyse the real benefits that are achievable with this policy. It was counted that, participants with a smart meter, reduce their consumption by 3,2% overall and by 11,3% at peak times. If this policy will be implemented, a reduction of 150.000 tons of $CO_2$ per year will be possible [5]. Energy Management System (EMS) such as smart meters, smart thermostats and lighting controls are demand response for commercial and residential market. Demand response is currently not so developed in Europe, but with smartphones is already possible to monitor home appliances and thermostats. To develop these technologies is important the involvement of private investments. For instance, Nest succeeds in USA to reduce of 55% the energy used in residential air conditions during peak times. Indeed, Nest Labs and Austin Energy together with "Rush Hour Reward" project was successful thanks to its user friendly solution in which users are awarded and peak loads are reduced [5].

Different global and European networks are trying to promote the development of policies connected to the reduction of energy consumption of buildings and $CO_2$ emissions. For instance, the European Strategic Energy Technology Plan (SET-Plan) aims to expand low-carbon technologies. It takes into account different field to reach a smart city included the building sector [6], [8]. Another example is The C40 Cities Climate Leadership Group that groups cities and megacities that try to reduce emissions and climate change. For instance, Paris wants to reduce by 30% by 2020 compared with 2004 levels energy consumption and $CO_2$ emissions in municipal buildings [1].

Starting from enforcement of mandatory policies in each country, following with energy efficiency technologies such as innovate building envelopes and renewable heating and cooling system [1], the idea is to transform new and old buildings in energy efficient system, as they are the biggest infrastructure investment that we have in the planet [5].

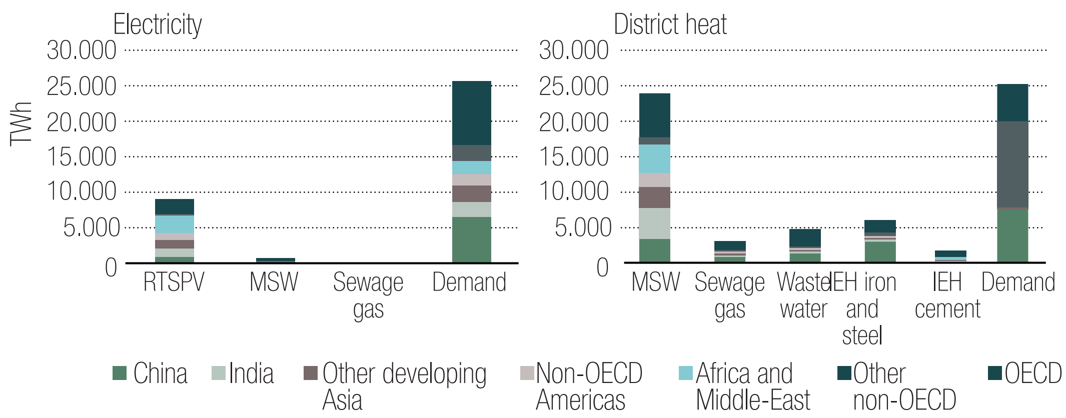
## 2.2. Production of energy with renewable sources

The largest challenge of the next decades is to find sustainable solutions that will involve the entire planet, starting from cities that will be the place where majority of people will live by 2050. Reaching sustainable way of life at the urban scale, and not only at the building ones will be the right direction to achieve a better society and environment where to live for future generations. For these reasons, the description of the main features of a nearly-zero energy district is fundamental. Indeed, districts are small parts of a city that can reflect in themselves all the intrinsic characteristics of a city. International, national, regional and city level should work together to carry out more energy efficiency solutions at the different urban scale [5].

As already underlined, urban areas are producer of around two-thirds of global final energy use. The challenge is that they are the major electricity demander with 75% of electricity demand in 2013. The exploitation of clean local sources will be assertive to meet energy, heating and cooling needs of cities. Urban form and factors such city framework, building patterns and population density are significantly important to determine use of renewable resources. Indeed, the potential of solar photovoltaic system or solar thermal panels to electricity produce and warm water are influenced by rooftop areas of facades of buildings [1]. The challenge is that in sprawled cities the possibility to use these technologies is high thanks to wide free spaces, while in densely populated cities, where the demand for energy is sizeable, the production of energy towards PV and solar thermal systems is more difficult due to cities framework. Indeed, space issue and its management will be another debate point in the transformation of already existing districts and cities. Even District Heating and Cooling systems (DHC) are economic sustainable if they can cover high heat or cooling demand densities. Electricity generation and DHC are two fundamental steps that have to be discussed and implemented in order to maximize energy efficiency and sustainable way of thinking. Integrating urban planning infrastructure connected to energy can help to exploit local renewable sources that are deployed in the local area. Moreover, a nearly zero energy district network will become an active distribution grid thanks to the interconnection with different supply chains and energy sources, improvement of monitoring and control systems and the use of demand response technologies to better manage peak loads [1].

Different policies actions can be supported connecting to the potential of solar photovoltaic and solar panel systems, waste-to-energy plants, wastewater energy recovery plants and industrial excess heat. Local energy sources are more cost-effective compared to current supply options that are located outside cities [1]. In [1], the potential for electricity and district heating generation in cites are analysed in the 2DS. As it is shown in Figure 3, concerning the electricity demand, a consistent part of the demand will be covered by solar photovoltaic system, while regarding the district heat generation Municipal Solid Waste (MSW) can almost cover the entire global demand.

Figure 3. Comparison of energy per capita in different world areas and periods.




Source: IEA (International Energy Agency), Energy technology perspectives 2016. Towards sustainable urban energy system, Paris, 2016.

Moreover, another way to address the problem of air pollutants and $CO_2$ is the installation of carbon dioxide capture and storage system that allow the separation of CO2, isolating it from the atmosphere [9].

### 2.2.1. Production of energy in districts

Starting to analyse the possibilities to integrate the use of renewable solar source to the current energy exploitation, the potential of rooftop solar photovoltaic system is around 9100 TWh that corresponds to 30% of electricity needed of cities, or almost 70% of the electricity demand for city inhabitants and consumers of commercial shops in 2050 in the 2DS. In the 2DS in 2050, it is forecasted that around 47% of global electricity generation will be covered by solar photovoltaic system with almost 2.400 Twh. The exploitation of rooftop solar photovoltaic system contributes to decrease the carbon dioxide ($CO_2$) emissions connected to electricity generation. Indeed in the 2DS, compared to 4DS, the reduction will be around 18 gigatonnes of carbo dioxide ($GtCO_2$) that correspond to a reduction of 9% [1].

More of the half of global solar photovoltaic systems, almost 60%, are installed on rooftop. This is because, most of the time roofs of buildings are not used and can become an important place where to produce energy. Indeed, it is important to exploit residential building rooftops for production of energy for buildings' inhabitants, and even rooftops of commercial and industrial buildings for the production of energy for the entire community. The challenge is that the smaller cities, where the largest rooftop photovoltaic system can take place easily, are the least prepared for implemented policies connected to renewable energies due to lack of skilled expertise. Regions and countries should try to fill this gap. The positive side of panels for solar energy is that they can be located close to the energy demand, reducing any possible losses. Moreover for instance, in hot climate peak loads connected to the request of energy to refresh the building spaces can be covered by the maximum output of photovoltaic panel around noon [1]. The surplus of energy produced by rooftop solar photovoltaic systems can be used for fuelling electrical vehicles. Buildings could be transformed in modern gas station that fuel electrical vehicles with electricity produced in the same place [5]. As already said, problems connected to urban form could be relevant due to shading from surrounding buildings or obstruction. Moreover, dense cities in some cases could be a problem because the high density often reduces area that are possible to be used for renewable energy production. The energy efficiency reachable also depends on the owners of the buildings. Indeed, it is always easier to install panel in single-family houses where the owner can decide autonomously, while in multi-family houses, where energy demand is higher and need to use renewable energies will be more consistent, the decision to install photovoltaic system is more complex due to interaction of multiple families. One innovative instruments promoted by cities are solar maps in which detailed information about each building is given. It is underlined the area of rooftop suitable for panels and the energy generation of electrical with photovoltaic panels and thermal energy with solar panels. Another possibility to produce energy will be locating photovoltaic system in the façade areas, allowing significantly the increment of energy produced even in high-rise buildings areas. National policies, such as government loans, should incentivise the uptake of photovoltaic solar systems [1].

Waste is another important source of energy. Already in the 19$^{th}$ century, waste was burnt into incinerators producing mechanical energy or electricity. Currently, waste-to-energy (WTE) are producing an amount of energy that is really limited. Indeed, in 2013 only 0,4% of electricity and 2% of district heating was covered by the energy recovered by municipal solid waste. In 2050, it is forecasted that electricity will be covered almost by 2% from WTE plants, while regarding heating generation, municipal solid waste in co-generation and heat plants can supply 27% of global district heating in cities. Taking into account waste management hierarchy, energy recovery towards waste-to-energy plants is the second to last preferable option. WTE plants have created in the decades debates related to air pollutants emitted. Governments should enforce WTE emissions with stricter standards informing population about the positive sides of this typology of energy production. It is also important to underline that in certain situations the alternative to WTE is landfilling. Landfills are not always controlled and managed in a proper way and in these cases methane emissions can contribute to global warming and can be risky for human health. For instance, in developing countries waste is usually thrown away in uncovered landfills with the risk to cause serious problems to environment and people. Moreover, municipal solid waste can also be burnt in co-generation plants, producing both electricity and heat, whit an energy recovery around 85% [1].

Wastewater treatment plants are another possible way to recover energy without using fossil fuels. Water will be always more requested due to the global increase of population. In 2050, global water demand, only for domestic use, could double compared with 2000. The energy potential reachable from this energy recovery is quite small, but every help is needed to achieve the result of sustainability. At least, this energy recovery could be useful to cover part of the energy required by wastewater treatment, providing cost savings to the operators of these plants that are usually public ones. In this way, in developing countries the goals of access to water, sanitation and energy will be always more sustainable [1].

Industrial excess heat (IEH) can be recovered and find several applications in the energy chain. First of all, IEH generation should be reduced as much as possible improving equipment insulation and monitoring and controlling processes. When level of optimisation is at the maximum from the economic point of view, the recover of IEH may start. This energy can be used directly on site, by District Heating and Cooling (DHC) network supplying energy to local surroundings of the industry or to generate electricity. Although recovering energy from low-temperature excess heat is possible, energy-intensive industrial sector is better to exploit excess heat from industrial processes. Indeed, to take advantage from low-temperature, large heat transfer surface areas are required that entail higher investments. However, energy-intensive industrial sector operates at more advisable temperature to recover energy. Indeed, heat demand between 100°C and 400°C is representing 48% of European energy-intensive sector and heat demand above 400°C is around 91% of industrial heat demand [1].

### 2.2.2. Supply of energy

An important topic to discuss is how to supply energy to end consumers. Indeed, if electricity and heat generation is fundamental to be implemented, the distribution of energy to citizens it is also critical. Indeed, heat can not be transported for long distances and the increasing number of distributed energy resources are generating more opportunities and challenges in the distribution grid. Distribution systems, with a wider number of renewable sources connected to urban grids and electrification due to heat and transport, are becoming always more autonomous with a proper balancing of energy generation. Therefore, they have to control and manage the interaction of new forms of energy [1].

District heating (DH), together with combined heat and power generation and renewable sources, has to be largely developed to reach objectives imposed by global and European Union targets and sustainable energy systems in which low environmental impact and renewable resources are the mainstream [10]. At the moment, only 11% of global space heating and water heating energy consumption is covered by district heating. District heating distribution is concentrated in some countries and regions. For instance, in Europe more than 6.000 district heating systems are present [1], with a well-developed framework in Northern European countries where cold climate is more rigid [10]. Furthermore, in north urban China more than 178.000 kilometres of district heating is counted covering almost 90% of floor area in that region, while in most of the other Chinese regions district cooling network is almost unknown [1]. DH is more efficient in densely populated areas in which the distribution has a wider role and can satisfy a larger number of citizens keeping the distribution profitable [10]. In DH is important to reduce use of fossil fuels and increasingly increment the use of renewable sources. This is only way to achieve a better result improvement the world current situation, because toady the production of energy is not economic, social and environmental sustainable [11]. Electricity and heat systems can be interconnected thanks to co-generation plants that allow the combined generation of heat and power [1]. Combined Heat and Power (CHP) plants are playing an important role in producing energy for DH, and both together are considered the most efficient way to use renewable energy sources. For instance, biomass CHP plants connected to DH is considered an efficient way to produce energy, and each renewable energy used will be well accepted to increase the sustainable sources. It is well known that renewable sources are non-controllable in nature. For this reason, thermal energy storage should be provided in distribution grid to provide the maximum affordability and exploitation of renewable energies [11]. Large hot water storage accumulators and electricity storage can be used to better control heat and electricity provision, especially during heat and electricity peak loads demand. Moreover, in case of surplus of electricity produced from renewable sources, it is possible to transform it from power-to-heat energy carrier [1].

In European Union, some pilot projects of DH combined with renewable energy have already been implemented [11]. For instance, in Meppel, a village in northeast Netherlands, a smart grid control system was developed to both manage electric and thermal energy. The energy is produced by district heating, biogas cogeneration and ground-source heat pumps. District heating supply to part of the buildings heat and hot water, while other consumers are supplied by electricity thanks to ground-source heat pumps. Heat for district heating and electricity for heat pumps are converted from biogas by a centrally-located combined heat-and-power engine [5]. Another example is the TU Delf Campus in which heating and cooling are provided by CHP, geothermal, thermal storage and surface water reducing of 10% the energy consumption and the production of $CO_2$ of 0,4 Mton per year. Therefore, a CHP-DH with renewable energy sources is seen as a solution to reach a 100% sustainable society. Manifold renewable energies can be taken into account with CHP-Dh systems such as solar thermal plants, biomass plants or wind power plants. This system is also usually integrated with other energy supplies and demands such as micro CHP plants or electrical vehicles. The most important achievable result is to satisfy the heat balance towards CHP-DH system with the use of renewable energies and thermal energy storage [11]. The use of thermal energy storage has to be implemented to balance the supply/demand off-set and to store energy to use it when the cost of production is higher and when peak loads are relevant. Thermal energy storage can be used in small scale domestic heating systems, and even in large scale District Heating and Cooling (DHC) systems. Indeed, storages are able to adjust the mismatch between time of production and time of demand [12].

Locating in the periphery of cities large photovoltaic solar thermal plants, and then supplying energy with DH, could be a solution to solve problems of space management. Indeed, as already said, in densely populated cities is not always easy to find suitable places where to locate these technologies given that shadings between buildings are really common. A solution could be the use of vertical surfaces of buildings [1].

## 2.3. Urban mobility

A Mobility framework can be considered sustainable when people can move easily and at the same time avoid negative environmental, social and economic impacts outside the mobility borders. "Sustainable transportation is about meeting or helping meet the mobility needs of the present without compromising the ability of future generations to meet their needs" (Brundtland Commission, formally the World Commission on Environment and Development (WCED), 1988) [13]. Transport is fundamental to global economy, job creations and to keep high life quality of citizens [14]. Indeed, sustainable mobility promotes business and social development satisfying the fundamental human need of moving. It has to be economic sustainable with the possibility to choose between different means of transport and it has to keep the GHG and acoustic emissions under defined levels, using renewable resources and minimizing the occupation of public lands [13].

Furthermore, transport and urban mobility have a big impact on the society. Everyday people move around cities to carry out different activities during their entire life causing negative and positive impacts inside and outside the mobility system. For instance, impacts generated inside the mobility framework are the ones that relapse into people that moves inside this system while impacts outside the mobility framework are air and acoustic pollution and the increment of real estate values around underground and railway stations [13].

Means of transport and urban mobility, together with buildings and industry, are the most evident cause of pollution and users of energy, but the chance to have a short-term benefit compared to buildings is higher. Indeed, rate of replacement of old cars with new increasingly more efficient ones, is more rapid than building refurbishment because, buildings have ten times longer life than vehicles. Moreover, the negative impact of means of transport is even bigger because of accidents and their consequences on healthcare and mortality rate [15]. Moving to always more populated cities, control the number of private vehicles will become fundamental and implement public transport system will be the right way to keep the city a comfortable place where to live. Design a well-planned and structured urban mobility framework is easier in a compact city because, the high density of people in a restricted area permit to provide an efficient public transport system. Indeed, promoting policies to develop compact cities is already a huge step that can be done to achieve a sustainable urban system [1]. At variance, a larger area with a low density of population will not be easily covered by public means of transports. Succeeding in achieving compact cities and a consequently higher share of travels will increase the frequency and the demand of movements and reduces trip distances with a huge benefit on public and shared means of transports, even reducing congestion and walking and cycling movements [14], [16]. Acting with urban policies for generating compact cities will be mostly possible in developing countries where the cities structure has still to be precisely defined and the citizens behaviour is still easily changeable [1].

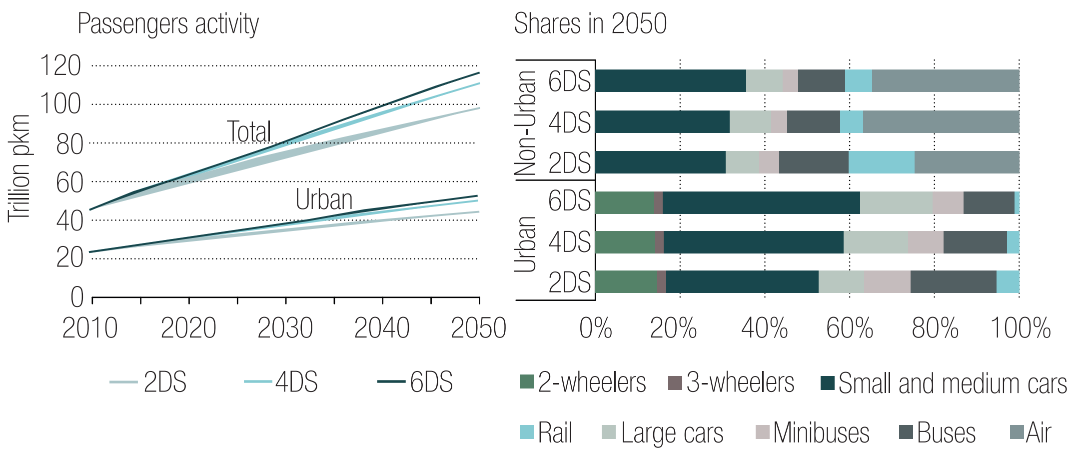
Reaching a sustainable urban mobility society will foresee the need to provide new technologies for vehicles and other means of transport and new infrastructures to develop an adequate network. These technologies and infrastructures have to be organized in a way in which the negative impacts on environment are reduced at the minimum required and the economic impact will be positive with the creation of new jobs and the improvement of accessibility. It is important to remember that infrastructures take many years to be planned and equipped, this is why we need to act now to determine the change in mobility network of 2050 is fundamental. Moreover, even an appropriated online system of information and data has to be developed to facilitate the integration and connection of the different means of transport [14].

### 2.3.1. Current situation

In 2015, 23% of $CO_2$ emissions was related to transport, with 93% oil products consumed and it is also known that half of the total passenger transport activity takes place inside urban areas. Cars, followed by aviation, are the main global urban energy demand for passenger transport, around 76%, and consequently the main GHG emitters in this sector.

Passenger activity will definitely rise in future, due to the increasing incomes of the growing global population, as the Figure 4 shows. To keep the quantity of travels low, as the below 2°C scenario expects, a series of policies

Figure 4. Passengers activity and means of transports changes in the next decades.

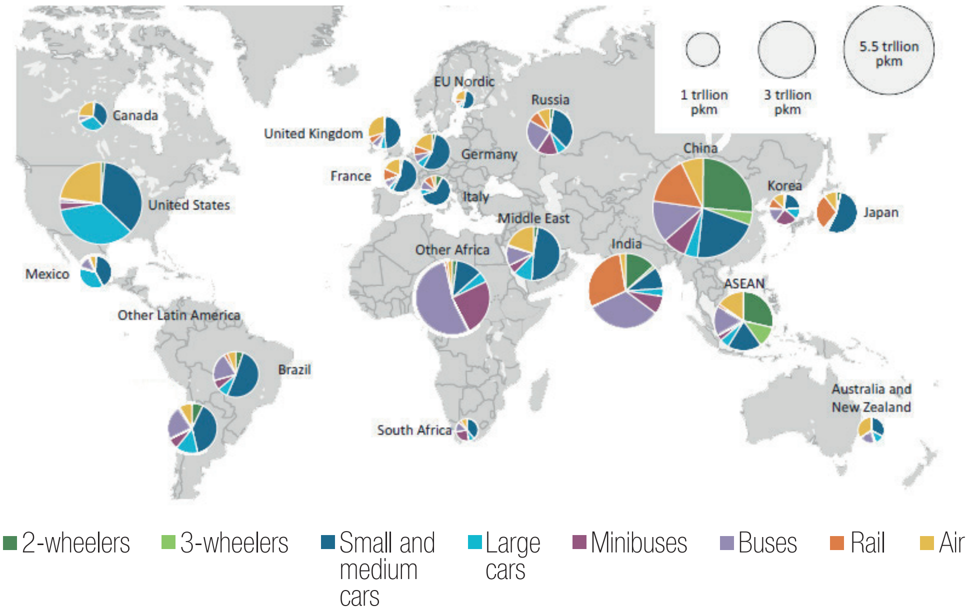



Source: IEA (International Energy Agency), Energy technology perspectives 2016. Towards sustainable urban energy system, Paris, 2016.

must be approved and implemented, such as higher fuel prices, higher vehicle taxes and the promotion of public transport, cycling or walking. Even if, the increment of kilometres travels every year is inevitable, shifting the number of kilometres travelled by people from one means of transport to another one is possible. The right path to chase a sustainable future is the 2DS, in which the total amount of kilometres travelled by private cars will decrease by 6% in 2050 and the presence of buses will increase.

In Figure 5, the widely modes of passenger transport activity can be analysed in the different regions of the world. It is easy to notice that in the developing countries, such as China, India and ASEAN (Association of Southeast Asian Nation), where the average incomes and consequently the car ownership levels are lower than in other world areas, such as Europe, America and Middle East, the 2-wheelers and buses are predominant and

Figure 5. Means of transports in different areas of the world.




Source: IEA (International Energy Agency), Energy technology perspectives 2016. Towards sustainable urban energy system, Paris, 2016.

that around 40% of China's stock of 2-wheelers is electric. The most serious problem is that the already developed countries have a society and an urban environment strongly dependent on cars.

Positive examples of working policies connected to car restrictions and public transport development are gaining ground in some cities of developed countries. Berlin and Paris, with their attention to an efficient development of the public transport, Amsterdam and Copenhagen, with the improvement and expansion of walking and riding infrastructures, London and Stockholm, with the new cordon pricing have to be only a starting point among the amount of future sustainable policies that has to be conducted in the different areas of the world. Especially in urban areas, the possibility to avoid/shift high GHG emissions is large. Human beings have a wide knowledge to implement the actual situation trying to leave a better planet to the future generations. Every investment done, to make the mobility always more sustainable, will be a new step towards a new success [1].

European Union and its members, signing up for [14], are trying to develop a Single European Transport Area going beyond the borders facilitating and integrating the multimodal national system. In this way the movements of citizens and freight should be easier and cheaper. The area in which the most significant efforts have to be made is the railway services that is still really connected to different countries. The three main actions foreseen by European Union are the improvement of the efficiency of vehicles' engines, the use of cleaner sources to produce energy and the better use of networks to make them safer through information and communication systems. Moreover, knowledge of citizens and promotion of more sustainable behaviour has to be spread in order to face these challenges [14].

### 2.3.2. Car dependence

Middle- and high-income countries in the world are mainly characterized by car dependence of their citizens. Indeed, after the economic development due to the end of Second World War, sales of private cars started growing, while cities and new infrastructures were reconstructed thinking about a new society that was characterized by the comforts that private cars dependence could give. Currently, most of the European Union cities have a structure that allows cars to be driven in every area of the city. Private cars dependence inside these cities is really rooted and trying to change the situation means modify the structure of the cities starting from roads and streets and make aware people of the necessity of this change.

An European statistic shows that six out of ten regions with the highest numbers of cars are located in Norther Italy [17], and among European Union members the number of private cars has increased in the last five years. The countries with the highest numbers of cars per inhabitant are Luxembourg and Malta, followed by Italy and Finland, while Poland, followed by Estonia and Latvia register the highest rate of vehicles older than 20 years. Moreover, another important distinction between countries is the numbers of petrol, diesel or alternatively engine powered cars sales. These data are quite different, depending on the country considered, because of the different fuel taxations present in each one. Almost in two thirds of European countries for which data are available, registrations of new vehicle powered by diesel engine is higher than the petrol ones. Moreover, from 2013 to 2015, in several countries the number of alternatively engine powered cars increased thanks to the government incentives and the advantages that these types of vehicles receive [18].

In the 20-20-20 strategy European Union has also provided some regulation for vehicles. Indeed, by 2020, 20% of fossil fuels used in transport sector should be substituted by alternatively sources and 10% of these new sources should be biofuels, while the rest should be covered by natural gas and hydrogen. These new sources will be renewable and moreover, they will produce lower quantity of air pollutants and GHG emissions. The world is now trying to change its route from a 'petroeconomy' to a 'bioeconomy', even if a debate over the real degree of carbon neutrality of biofuels is taking place [19]. Indeed, biofuels, such as biodiesel and bioethanol, are produced through biological processes and derived from plants or agricultural and industrial wastes. The problem is that the soil emissions caused by fertilizers can have more negative impacts than benefits. This is why currently European Union has put under discussion the idea of the target of 10% of biofuels [13].

Methane, or natural gas, could play an important role thanks to its cheap cost, but it is not penetrating so much the market because of the lack of supply infrastructures. Another alternative could be electricity power. Powered electrical engine vehicles sustainability depends on the way in which electricity is produced. Currently the diffusion of electrical vehicles is spreading slowly due to problems connected to batteries, their cost and their autonomy of use. Indeed, these cars are now only suitable for short-distances [13], and their diffusion is mostly taking place in cities where car-sharing is active and recharge power stations are present. Another interesting solution could be hybridisation. These vehicles are gaining market shares and thanks to their lower emissions of local pollutants are becoming one of the favourite option for car manufacturers. Eventually last option could be hydrogen, but its sustainability depends on which sources is used to produce it, and there are several security issues.

As we said before, one of the most dramatic problem of our society is car dependence. For this reason, trying to persuade citizens not to use private cars and to promote efficiently new policies is quite hard. Measures that can be taken and that are already active in some cities and countries can be at national or local level and they try to rationalize the use of cars or to promote and expand the use of public means of transports. These policies moreover, are supposed to reduce social costs such as time lost in congested traffic and the health costs of air pollutants and greenhouses gases emissions. National push measures to reduce use of private vehicles are usually aim at increasing costs. First of all, fuel economy regulation can change, and fuel taxes, that includes the costs of GHG emissions, can increase. European Union is also trying to improve the fuel economy of trucks. While the most efficient policies are the ones that expect higher taxations on vehicles, depending on their efficiency. Thanks to these policies, in a 2DS, is forecasted to avoid of shift from private cars to public transport 38% of the total urban passenger transport [1].

Local level policies, even defined travel demand management (TDM) [1], are categorized in three groups: pricing, regulatory instruments and support for public transport and non-motorised mobility [20]. Road pricing is a quite diffused policy that is already applied in cities such as London and Milan and provides congestion charging, cordon pricing and tolls on specific areas of the considered city. It is useful to reduce the presence of cars in really congested areas and makes convenient to travel with any other means of transport. To be more accepted by citizens, the money gained by road pricing and congestion charging have to be used to develop and improve public means of transports. Moreover, the payment of the fee is usually proportional to the salary of every citizen. A positive example of the good result of road pricing is the city of London in which the introduction of this toll has determined a reduction of 37% of kilometres driven by cars, a decrease of 13% of accidents and of 15% of the levels of pollution and a consequent increase of 30% of use of the public means of transport [13]. Another category of policies are the regulatory instruments that provide restrictions at different level. Some examples are access restriction to certain areas of the cities in defined times of the day, such as ZTL areas, parking reductions in already really densely populated cities or the limitation of access to vehicles with low tailpipe emission. In some developing countries, such as China, limitation on vehicle registration caps has been applied trying to reduce the number of cars in the most populated cities where problems connected to pollution are really serious. Moreover, trying to promote policies that permit to develop infrastructures to improve and better exploit public means of transports will permit to expand their use. Infrastructures connected to cycle and walk or to use alternatively fuels for private vehicles will be a great chance to change the future [1]. Other possible interventions could be to reduce the construction and the design of new large roads where cars can drive comfortably and increment services such as car-sharing or taxi-sharing. Indeed, increasing the number of people that will move with the same car indicates less traffic congestions, less pollution and even individual benefits connected to less costs for fuel and maintenance of private vehicles [13]. Eventually, it is important to say that not all policies can be applied to every typology of cities. For instance, with sprawling cities the primary need is to incentivize densification of inhabitants, polycentric development of public urban transport and restriction on parking in certain areas. While in high-density population cities in developing countries, develop infrastructures that promote sustainable way of moves from one side to another of the city will be the best solution [1]. Moreover, it will be fundamental that every measures taken to achieve a more sustainable mobility framework will show to the citizens and global population an economic return and benefits for the local government and the entire society [21].

Streets, roads, squares and their features characterize the framework of the city and are the place in which the majority of the social actions take place. Indeed, they are part of the urban landscape, and social place where citizens share part of their daily lives [22]. One of the most innovating idea, that is already having success in some European communities, is the car-free housing. Car-free housing concept involves people that share the desire to live in a sustainable way and following ecological values. This is mostly a way to promote healthier way of life thanks to less pollution and a more active population that have to cycle or walk to move from one place to another one [23]. Car-free hosing policy is quite a fascinating project, but really hard to realize involving large numbers of people. A more feasible project is the one of 30 km/h zones, that are areas of cities in which the maximum velocity allowed is 30 km/h and in this way the traffic of residential areas is reduced, and the security and liveability is guaranteed. It is also proven that with cars that drive at this velocity, the rate of mortality in accidents is incredibly lower. To be sure that this measure will be efficient is not sufficient to use traffic signs but first of all, citizens of the area have to become awareness of the real benefits of this project and the framework of the existing roads have to change in a way in which high speeds are not allowed. [22].

### 2.3.3. Rail, public transport, ride and walk

The measures that can be taken on rail transport are mainly connected to the energy efficiency of trains. Indeed, material substitution to reduce weight, and improve aerodynamics will allow to achieve better performances of these means of transport. Moreover, already two-third of passenger rail transport activity is currently on electrical trains but, as already said, this will be a positive side only if the electricity is produced by renewable sources [1].

To shift a large number of transfers from private vehicles to public means of transport some incentives and promotion policies have to be developed. Indeed, the challenge is to convince people to leave their comfortable private cars to use public trains, subway or buses. The first step that has to be done is the improvement of the quality of means of transport. Moreover, their speed and frequency have to be increased to allow comfortable journeys and faster movements than usual. Coordinating the manifold means of transport (subway, buses, tramways etc.) of a city will be fundamental to guarantee faster and more comfortable movements from one part to another of the city than private cars and to reduce the waiting times at the stops. Another way to promote public transport will be the exploitation of an integrated ticket that will be valid in every movement done and for every means of transport taken [13]. To develop these measures, finding funding is fundamental. Investments and subsidies need to be found to cover the costs that are not paid by fares. The gap between the money earned by fares and what is necessary to develop new infrastructures and to improve public means of transports is indicated by the farebox recovery ratio. Farebox recovery ratio tend to be lower in low-density cities where private cars have the landslide majority, while are far higher in cities such as Hong Kong, Shanghai, Singapore, Tapei City and Tokyo in which the well-developed public transports allow to have a high share of trips. In these cases, urban public transport is self-sustaining and the money obtained by fares can be used to improve, expand and provide additional services [1].

Another way to attract people to use public means of transport is to invests in infrastructures and urban design that provide safer walk- and cycle-paths, to reach stop stations in a comfortable and safe way [1]. For instance, provide large and easily accessible bicycle paths, guarded parking for bicycles or dynamic ride sharing will be interesting for people that are using cars for short distances. Indeed, in European Union it is counted that 30% of journey of cars are less than three kilometres longer, and the 50% less than 5 kilometres. Currently, bike-sharing services are trying to penetrate the market shares thanks to their convenience. Moreover, a peculiar services of bike-sharing without stations is trying to be developed in some European cities due to the fact that in developing countries such as China, this innovation has achieved resounding success [13], [1].

### 2.3.4. New technologies and awareness raising projects

Information and Communication Technologies (ICTs), Intelligent Transport Systems (ITS), Automatic Identification and Data Capture (AIDC), Internet of Things (IoT), real time GIS and geo-localisation are the technologies of the future to develop, integrate and improve to have an effective travel demand management. These technologies could be useful to carry out manifold of functions such as: real-time timetables of public transports, information about congested area of the cities, speed and connectivity of intermodal urban public transport systems, location and time for carpooling users and location and availability of parking. Moreover, always thanks to innovative application on smartphones, services connected to bike-sharing, car-sharing and taxi-sharing are already available [1]. To implement all these policies, data available and accessible have to be used. In this way, new technologies will enable people to better use mobility services promoting the efficient use of means of transports [24]. Even if, these new ways to move are reducing the private vehicle use, it is not already clear and easy to forecast which will be the impacts of these services on energy use, emissions and travel behaviour [1]. Eventually, the use of high-accuracy maps can permit to electrical vehicles to be more energy efficient thanks to an appropriate management of their batteries and fuel energy [25].

The factors that influence the way of moving of human beings are manifold and most of the time difficult to manage and irrational. Indeed, private vehicles are always considered the faster one, regardless the traffic congestion and the typology of journey. It was demonstrated that human being feels the necessity to move at least around 60-70 minutes per day and that this data has always kept constant during the centuries [13]. For this reason, one of the largest dilemma of mobility is that if we accelerate the travel times, the desire of human being will consequently increase with a failure of ITS technologies that will be effective only on the short-period. The best way to achieve benefits from urban mobility system changes is to raise awareness of people thanks to promotional campaigns of different means of transport and real benefits that are possible to achieve thanks to them. Moreover, let monitoring data and results of new policies applied be known will be a huge step which will allow citizens to understand better the real benefits and negative impacts of their actions and behaviours [13].

## 2.4. Waste management

Waste is the result of an inadequate thinking [26] and use of resources in human activities. It is defined by the United Nations Environment Programme (UNEP), as "objects that the owner does not need, want or use them, and they should be recycled or disposed". It usually represents something that cause an enormous loss of resources from the material and energy point of view [27]. The main problems related to an incorrect waste management are an inadequate waste collection and disposal system that can caused the spread of diseases and hygienic problems in populated areas and the social costs of $CO_2$ emissions. Waste can be categorized towards different perspectives such as its origins, its materials, its applications and its safety. Indeed, hazardous wastes are the ones that have to be controlled with more attention. Moreover, the most demanding challenge that have to be faced is the Earth's limited resources [28]. Indeed, from 1980s-1990s sustainability started to be discussed, otherwise natural resources will not meet the needs of future generations [28] and if people in the entire world will start following current European lifestyles, it would take the resources of two and a half planet to support them [29].It is counted that almost 3 billion tonnes of waste are thrown away among European Union countries annually and that 100 million of it, is composed by hazardous waste [30]. European Union members and all the other developed countries are the first countries that have to change their behaviours in production and consumption trying to avoid and stop further worsening for the future generations. The most used practises in sustainable waste management are waste reduction, waste separation and waste recycling and it is proven that without community and citizens awareness these measures are not efficient as they could be with a conscious involvement [31].

In the last decades, Europe has enjoyed its high level of life quality reached, and currently it is facing the challenges to change its behaviours. Our lifestyle is leading us to an inefficient use of natural and energy resources that make us produce more waste than we can recycle as a useful resource. In the last years, more efficient and controlled products have entered the market and consumers awareness is taking this social change towards the right direction, even if more drastic measures and policies have to be taken to contrast the huge environmental problems that the earth is going to deal with. Measures, both at individual and industry level, have to be taken to improve the life cycle of products from the extraction of raw materials, to production, distribution, use and disposal. European Union Commission is trying to build and strength policies and measures to better control and define these different phases of each single product and to help consumers to raise awareness connected to these topics and choices [29]. Waste management indeed, should be considered as composed by different stages that are generation, collection and disposal systems. The challenge will be to act as these operations are interconnected one to each other's. Furthermore, it is fundamental to understand which are the connections between these processes and transport systems, land use, urban development, population growth and health issues [26].

Thinking about a sustainable society in the long-term, taking into consideration the idea to use and promote objects that cause the least environmental impacts is fundamental. Indeed, every product we buy and use in everyday life has negative impacts on the environment because energy has to be consumed to produce and use it, and when the product is obsolete waste is created. Remove objects from the trade that use an excessive amount of energy or water or hazardous materials to be produced is the first step that can be done. For this reason, the designing phase of each product is considered crucial and is trying to be regulated by minimum requirements that allows to have more sustainable products. The most common problem is that people can not understand how it is possible that their actions can influence so much big problems such as increase of planet temperature, climate changes and pollution. The European Union is trying to raise the awareness among producers and industries promoting friendlier environment regulatory and exploiting the potential of information and communication technologies (ICT). For instance, success has been reached by EU energy label that certifies and shows to consumers the energy-efficiency of kitchen, electrical appliances and light bulbs. The number of products imported in European Union countries is significantly increasing, mainly from developing countries in which environmental issues are not always taking into account. Growing our awareness will allow to change the current situation, even trying to promote international agreements that will permit to improve behaviours in all over the world [29].

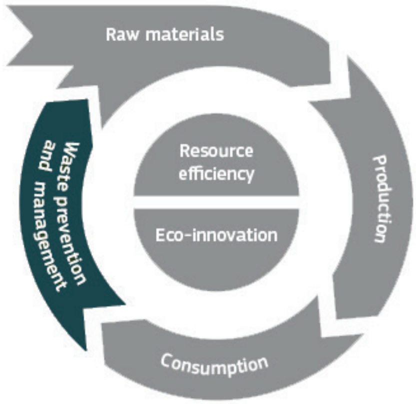
### 2.4.1. Current and future situation

Analysing Eurostat data for European Union members, and Italian data from ISPRA, the Italian association for the environmental protection and research, is possible to better understand the current situation connected to waste management and if and how this sector is trying to consider its possibility to succeed in sustainable goals. First of all, it is important to say that in the past waste management was strictly connected to hygienic topics, while right now the main goals of waste management are volume reduction, environmental protection, resource conservation and elimination of hazardous materials [32]. In 2014, considering all the 28 European Union members, around 240,8 million of tonnes of urban waste were produced. It is also important to notice that in the same year it was possible to confirm the decrease of production that was already characterizing the previous years [33]. Indeed, as it is counted in [34], between 2006 and 2008, total annual of waste generation decreased with 10%. The significant difference is between old countries members and new countries members of European Union. Indeed, the 15 older members produce 516 kg of urban waste per habitant every year, while, in the new countries members, this data is around 315 kg per person [33]. The activity that produces the highest amount of waste is the construction sector with the 34,7% of the total amount of waste, followed by mining quarrying and manufacturing. Another relevant issue of waste management is hazardous waste. Indeed, if they are not treated in a safely way, they can cause elevated risk to human health and to the environment, and it is counted that almost 3,8% of the total amount of European waste is constituted by hazardous waste [27], [34]. Furthermore, the nature of waste is changing, mostly because of the increasing production of high-tech products, and for this reason it contains a wide mix of materials including plastics, precious metals and hazardous materials. Hazardous materials are the major problem because they contain heavy metals and toxins that make waste difficult to treat, despite special processes are provided. This is why regulations about some types of chemicals product have already been applied and are restricting and banning some products. Another huge problem is the illegal waste shipment of these products abroad where it could be managed in unsafe conditions. European Union is trying hard to help its countries to control and monitor this illegal business [35]. Eventually, another fast growing waste stream in the European Union countries is the electrical and electronic equipment waste (WEEE), that is also containing hazardous material, as heavy metals, difficult to treat and dangerous for the human health and valuable raw materials, such as gold, silver and platinum. New regulations from European Union have to be developed in order to promote a more effective and enforceable way of recycling these types of products trying to better use resources that before were lost to landfill [35].

Trying to clarify the typology of treatment to which waste is disposed we count that the 47,4% of the total amount produced by European Union members is sent to landfill, the 36,2% is sent to recovery operations such as recycling, 10,2% is backfilled and the remain amount is sent to incinerators, with energy recovery (4,7%) or without (1,5%) [27], [34]. Concerning Italian data, in 2015, the national production of urban waste is almost 29,5 million of tones that is characterized by 43,3% of organic waste [33]. Moreover, it is important to underline that 34% of municipal solid waste was sent to landfill in 2014, compared to the some countries such as Germany, Belgium, Sweden, Denmark, Netherland and Austria whose share is below 4% [36].

As already said before, with the increasingly growing of world population combined with the highest income of the developing countries, total consumption and amount of waste are going to increase drastically. These increments will cause negative impacts on health and environment due to the emissions to air, soil and water and even greenhouse gases from waste disposal. Even if, waste management is becoming always more sophisticated with the increment of the amount of rigorous rules connected to landfilling and incinerators, and the raising of awareness of separation and recycling waste techniques, the pressure on waste infrastructures and ecosystem is becoming always more urgent due to the increasing world population [30]. Indeed, it is forecasted that without the application of any sustainable policies or measures, from 2008 to 2020 waste generation is expected to increase by 7%.

Figure 6. Circular waste management.




Source: EC (European Commission), Waste prevention and management, 2017. Available at: http://ec.europa.eu/environment/green-growth/waste-prevention-and-management/index_en.htm, last access: November 2017.

Full implementation of European Union legislation will allow to increase prevention and recycling, and reducing significantly the GHG emissions helping to achieve the targets imposed by 2020 [34]. Indeed, this will be a great opportunity to improve resource efficiency of Europe and reaching a more sustainable and circular economy [37].

The long-term goal of European Union is to develop a recycling society, avoiding waste and minimising the extraction of additional raw materials.

The main aims will be the promotion of waste policy targets in all European Union countries, the reduction of the amount of waste generated, the limitation of landfilling and incineration for non-recyclable materials and the radical increase of recycling, recovering and re-using of each products [27], [35]. Furthermore, European Union, in its legislation, includes targets that European Union countries have to reach by 2020. First of all, the re-use and recycling of waste materials have to be increased of a minimum of 50% by weight, including paper, metal, plastic and glass from households and the re-use and recycling of 70% by weight of construction materials [35], [38].

### 2.4.2. Waste hierarchy and key actions

The European Union Waste Framework Directive has defined a waste hierarchy to clarify which are the options that have to be applied when we are talking about the treatment of waste [30], [35], [37]. According to this hierarchy, the two best options that can be chosen for waste treatment are the prevention in the production of waste and the re-use of products, while

Figure 7. Waste hierarchy.


Source: EU (Europenan Commission), Being wise with waste: the EU's approach to waste management, 2010. Available at: http://ec.europa.eu/environment/waste/pdf/WASTE BROCHURE.pdf, last access: November 2017.

the other options are the recycling (including composting) that is still a good solution to waste management and other typologies of energy recovery and then, as last resort, the disposal through landfill [37].

Starting from the most efficient way to manage waste, it is possible to say that prevent the production of objects allow not to think about how to dispose them. Even thought waste prevention is a challenging way of thinking for a consumer society, it has to become a common policy boost to the right way to manage waste [35]. Waste prevention includes a series of policies that allow to reduce negative impacts on environment and human health from the extraction of raw materials to the use of the products. The measures that can be applied are the reduction of materials used for the realisation of the different products and the rise of efficiency in their use reaching a sustainable consumption. Strict avoidance of waste is then characterized a limitation of unnecessary consumption and the designing of products that are the cause of less waste. Applying a qualitative prevention will be also possible reducing the use of hazardous materials. Indeed, to create a working-well plan to prevent waste it is even important to involve productive industries and sectors, designers, service providers, and public and private consumers [30]. One of the key action provided to waste prevention is eco-design, which is focused on sustainable aspects during the designing and production phases of the concerned products. These eco-friendly products should be made with recycled secondary raw materials, without using any typologies of hazardous materials, consuming the less energy as possible during the production phase and being recyclable after the use phase [35]. Moreover, European Union has introduced in 1992 its EU eco-label, a flower logo, that helps people to identify products that are environment-friendly. Nowadays, 26 product groups are covered by this logo and include textiles, paints, papers, detergents and other products. These products had to meet strict criteria to be part of the EU eco-label, but the idea is to simplify the bureaucracy in order to expand always more the products covered by this label [29].

Waste prevention of European Union includes three different key actions: informational, promotional and regulatory strategies. The informational objective is to promote waste prevention techniques and campaigns to raise awareness of citizens. Promotional strategies include the provision of financial and logistical support for research, development, voluntary agreements and clean consumption. While regulatory strategies try to expand limits on waste generation such as pay as you throw scheme, extended producer responsibility policies and eco-design requirements [30]. Furthermore, in [30] European Union identifies which are the different steps to succeed in a waste prevention programme. First of all, the starting point of this process is to evaluate the available data on the current situation of waste management prevention, such as quantities of collected and hazardous waste per person, use of eco-label products and citizens covered by pay-as-you-throw. Then, before elaborating a well-structured plan, it is important to set the priorities of the planning on which stakeholders, waste stream and phase of lifecycle have to be focused. Eventually, a planning with a consequent implementation of monitoring phase is required. Indeed, even in this sector it is fundamental to remember that what is not measured and counted, it is not managed and controlled [30].

Waste prevention can also be described by the point of view of typology of the waste. For instance, if we talk about biodegradable waste it is important to raise the awareness of citizens on the huge quantities of usable food discarded every year considering both the economical losses and the environmental impact on collecting and treating this waste. Related to paper waste, it is fundamental to avoid junk mail that are useless and produce huge amount of waste. Helping the expansion of second-hand market of electrical and electronic equipment and the reduction of packaging will also allow to achieve a better system for waste prevention [30].

Successful waste prevention strategies are already operative in some European countries. For instance, in Vienna a waste prevention program is focused on spending public money to buy green products and services, defined as green public procurement to sensitize small firms to use re-used products, promoting the repair of goods [35]. Green procurement can lead to save money for public authorities and even for the whole society promoting the market of green products and technologies, mainly in sectors such as transport and construction [29]. Moreover, citizens can buy and sell objects through an online flea market preventing tonnes of waste annually, implementing local repair and service centres. Re-used centres are also expanding their actions in Belgium where it is possible to extend the useful life of discarded clothes, appliances, kitchenware, furniture, books and bicycles. Connected to waste food, it is possible to mention two important and successful initiatives that are already operative in Italy and Portugal. The first one, called eco-point initiative, requires to dry food sold in bulk through dispensers in Italian supermarkets. This operation allows to reduce materials used to packaging and permits to customers to buy the right amount of food that they desire. Furthermore, consumers save money of shoppers and packaging. It is counted that 30 eco-points in Italy and Switzerland prevent the use of almost 1 million packages per year. Meanwhile the second initiative in Portugal, called Menu Dose Certa or Right-sized Menu, promotes a balanced diet trying to raise the awareness of food waste creating portions that generate less food waste. In 2001, reduce food waste by 48,5 kilos per year per restaurant was possible. Another policy in France, called 'Stop-Pub', promotes the reduction of junk mail using post-box sticker that expressed the desire to not receive that typology of unaddressed mail [35].

The second step of the waste hierarchy is the re-use, which consists in the repeated use of components or products such as, refrigerators, ink cartridges and computer printers. For instance, in the Netherlands a European Union programme allows to achieve a large scale of re-use of second-hand car components. Indeed, a huge amount of materials such as plastics, metals, rubbers and glass are still present in damaged cars [35].

Recycling is the third step of the waste hierarchy. Re-use is the repeatedly using of materials, while recycling consists in using materials to make new products [26]. Recycling is fundamental because it reduces the amount of waste that are sent to landfill and the extraction of raw materials. Taking into account that Europe is an importer of scares raw materials for foreign countries, recycling will allow to provide independence in the use and consumption of raw materials. Moreover, it is proven that to create recycled products is necessary less energy than to realize new products. European Union rules are increasingly setting targets for recycled material in order to gain from the recycling process the highest number of products that can be used again, maximizing the value of materials. Extending producer responsibility is becoming fundamental to make responsible producers of the entire life of their products, even considering the financial part, from the extraction of the raw material, to the production, the packaging and the moment in which it becomes a waste. In this way, producers are incentivized to generate products that are possible to be re-use or recycled in order not to lose too much money [35].

The second to last step in the waste hierarchy is energy recovery. Indeed, waste can be used as fuel in certain industrial processes to produce electricity, steam and heating for buildings. Even though energy recovery through incinerators is not always the best choice to manage used materials, several restrictions and legislation are trying to set limits in order to minimize the environmental costs and maximise the benefits. It is fundamental that hazardous materials and those that are difficult to be burn or which release pollutants at high temperatures, are completely destroyed before the incineration. Indeed, incineration plants need to work under certain specific conditions, to minimize pollutants that can be emitted [35]. Instead, opinions are really divergent concerning waste-to-energy plants. Indeed, some studies, such as [36], [39], [32] declares that incinerator combined with heat and power is considered the best solution from the economic, environmental and energy point of view. Waste-to-energy plant is a process that recover energy in form of heat, electricity or transport fuel. The last generation plants have the capacity to destroy organic hazardous components, recovering energy and saving landfill space [36]. An innovative application of waste-to-energy plants is their connection with District Heating and Cooling (DHC) systems. For instance, in Copenhagen three waste-to-energy plant are installed providing 30% of total district heat to regions that surrounds the city, while in Amsterdam two waste-to-energy plant are warming 12.000 households and providing 75% of total electrical consumption of the city [39].

The last option listed in the waste hierarchy is the landfill. Landfill is the first way in which waste was treated and also the less appropriate to a sustainable way of thinking. The most critical problem of landfill is the release into the air of methane that is a greenhouse gases 25 times more pollutant than carbon dioxide. It can contaminate soil and water causing public health and environmental problems. Moreover, landfill should be the last choice in the waste treatment because it is counted that materials that is buried every year could have a commercial value of around €5.25 billion. The new Landfill Directive imposed by European Union is leading to positive results. Indeed, the reduction of 35% of biodegradable waste and 25% of municipal waste landfilled, compared to 1995 levels, was reached in 2016. Even if landfill remain the more used technique of waste disposal in the majority of European Union countries, these new results achieved are allowing to reduce significantly the emissions of methane gas in soil and water [35].

As it said before, product's life should be circular starting from the extraction of raw materials, going through the production, supply, use and finishing with the waste treatment. Moreover, to achieve environmental improvements and economic gains life, the cycle perspective is the right direction [40]. A life cycle approach and way of thinking should be used in order to identify possible improvements of goods and products in the environmental impacts. Indeed, it will generate change in the generation and design of products and management of waste [30]. The aim is to analyse every stage of a product's life identifying in which of them improvements can be made, not shifting negative impacts form one stage to another [35]. Most companies are moving towards this new perspective becoming responsible of their products from the raw material extraction to the waste treatment [40].

Eventually, globalization and the exchanges of European Union countries with the rest of the world is increasing, accelerating the import of raw material semi-manufactured materials and the export of waste that can be transformed into secondary raw materials. For this reason, rules to prevent illegal waste exports and ensuring that waste is treated in high standard facilities in third countries in fundamental. In this field and others, European Union waste legislation is playing an important role and for this reason it will be fundamental to implement and enforce the already existing rules [34].

## 2.5. Other possible measures

It is essential to underline that all the measures described above have to be applied at the entire district scale and to be expanded to the entire urban system to achieve the transformation of cities into more sustainable systems. The real need is to act on each field described and in all the others that consume energy and produce non-sustainable behaviours. In the last paragraph of this chapter, other possible measures are described connected to public street lighting and furthermore, an innovative system of carbon capture and storage is illustrated.

### 2.5.1. Public street lighting

Public street lighting is one of the field that influences the consumption of energy inside urban systems and that can contribute to the reduction of energy wasting and pollutants emissions. The 19% of global energy consumption is related to lighting. Furthermore, considering outdoor lighting, 40% of total energy consumption is due to public lighting. The positive side is that the chances to drastically reduce this consumption are high [41]. Indeed, European Commission has declared, after several studies, that investing in new more efficient lighting system will decrease the consumption of energy between 30% and 50% [42].

Currently, high-pressure sodium lamps are the most diffuse ones in urban systems. When new measures are applied, the only requirement that has to be met by public street lighting is the production of enough light for street users and, in case of the reduction of lighting levels, the non-compromising of users productivity, safety and satisfaction [42]. In [42] three features that have to be adressed by sustainable lighting technology are listed: the energy saving obtained by high energy efficiency, the long lifetime of the products used and the recyclability of them. Nowadays, LED lamps, which stands for light emitting diode, are indicated as the most performing ones as they transfer directly electrical energy into light, in contrast with the traditional lamps used. These typologies of lamps are offering high quality illumination and reduce drastically the energy consumption and the emission of pollutants [41], [42].

Another measure that can be applied together with the substitution of lamps currently in use with LED ones is the smart control of public street lighting. Indeed, a new generation of lamps is starting to be integrated with smart sensors and controls which allow to regulate street light in accordance with the presence of people and vehicles in the streets. Moreover, they will also manage the lamps maintenance knowing the exact lifetime of each lamp, its location and when it is necessary to replace it [41], [42].

### 2.5.2. Carbon capture and storage

In the last decades, carbon dioxide ($CO_2$) capture and storage has been categorized as one of the most important technology to decrease $CO_2$ and to achieve targets imposed by international agreements and by European Union. The World Energy Council has included this innovative technology in the useful policies to reach positive sustainable results in 2050. Even European Union has provided the use of carbon capture and storage, including this strategy among the long-term strategy of “A Roadmap for moving to a competitive low carbon economy in 2050” [43]. Indeed, carbon capture and storage policy has to be exploited to carry out the ambitious aim to keep well below 2°C the climate change forecasted in the Paris Agreement. The capture and storage of $CO_2$ remains until now, the only technology able to decrease significantly the emissions from fossil fuels used in power generation and industrial processes [44].

Carbon dioxide capture and storage is a process that includes several steps. First of all, $CO_2$ has to be separated from industrial and energy related sources applying them to large point sources. Then $CO_2$ have to be compressed and transported either in geological formations in the oceans, in mineral carbonates to be stored, or in industrial processes to be used. Eventually, the isolation from the atmosphere in long-term isolation areas is provided. To transport these emissions pipelines or ships are used. Pipelines are preferred to transport large amounts of $CO_2$ for distances around 1.000 kilometres. While for smaller amounts of $CO_2$, almost few million tonnes per year, and longer overseas distances ships are economically, more adapt to meet this objective [9]. Transport exploiting pipelines is quite diffused and already used, especially in North America. Even in European countries and Australia the interest towards developing these pipelines is increasing to distribute emissions from inland to regional hubs in the future. At variance, shipping transformation has not been yet developed, even if shipping will allow more flexible transportation solutions [44]. Taking into account all these processes, and considering the life cycle assessment approach, the overall efficiency of this technology radically decreases. On the other hand, considering the technology without including the transportation, a reduction of 90-95% of carbon dioxide emissions can be achieved [43]. Other problems connected to this innovative technology are the unexpected leakage of wide amount of $CO_2$ due to damages to containment structure or gradual leakage in the atmosphere for long period. It is certain that consequences in the long-term are still unknown. Sleipner project on Norway was the first one to have permanent and dedicate $CO_2$ storage with monitoring technologies. Currently, 15 large-scale projects are expanding all over the world. Thanks to research and development capture, transport and storage technologies are enhancing a developing increasingly better technic. Moreover, with the scale-up of these techniques, the investments costs will significantly decrease in the next years [44].

Concerning benefits achieved with the implementation of this technology, the results will be excellent. Indeed, it is forecasted that in 2DS by 2050 carbon dioxide capture and storage system will reduce $CO_2$ emissions of 94 gigatonnes. From the power sector will be captured almost 56% of the emissions, around 80% from coal-fired power generation, 31% from industrial processes and 14% from fuel transformation. Carbon capture and storage is considered fundamental in deep emissions reductions for some industrial processes, such as the production of chemicals iron, steel and cement [44].

## 2.6. Bibliography

[1] IEA (International Energy Agency), Energy Technology Perspectives 2016 – Towards Sustainable Urban Energy Systems, Paris, 2016.

[2] S. Maier, Smart energy systems for smart city districts: case study Reininghaus District, Energy Sustainability and Society 6 (2016).

[3] C. Delmastro, G. Mutani, and S. P. Corgnati, A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale, Energy Policy, 99 (2016) 42–56.

[4] D. Exner, V. D'Alonzo, G. Paoletti, R. Pascual, and R. Pernetti, Building-Stock Analysis for the Definition of an Energy Renovation Scenario on the Urban Scale, in Smart and Sustainable Planning for Cities and Regions, 2017, pp. 33–54.

[5] M. De Groote and M. Fabbri, Smart buildings in a decarbonised energy system - 10 principles to deliver real benefits for Europe's citizens, 2016. Available at: http://bpie.eu/wp-content/uploads/2016/11/BPIE-10-principles-final.pdf, last access: November 2017.

[6] A. Kylili and P. A. Fokaides, European smart cities: The role of zero energy buildings, Sustainable Cities and Society 15 (2015) 86–95.

[7] Covenant of Mayors, How to develop a Sustainable Energy Action Plan (SEAP) - Guidebook, 2010. Available at: http://www.eumayors.eu/IMG/pdf/seap_guidelines_en.pdf, last access: November 2017.

[8] EC (European Commission), Strategic Energy Technology Plan, 2017. Available at: https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan, last access: December 2017.

[9] Intergovernmental Panel on Climate Change, Carbon Dioxide Capture and Storage, 2005. Available at: https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf, last access: December 2017.

[10] S. Amiri and G. Weinberger, Increased cogeneration of renewable electricity through energy cooperation in a Swedish district heating system - A case study, Renewable Energy 116 (2018) 866–877.

[11] H. Wang, W. Yin, E. Abdollahi, R. Lahdelma, and W. Jiao, Modelling and optimization of CHP based district heating system with renewable energy production and energy storage, Applied Energy 159 (2015) 401–421.

[12] P. D. Thomsen and P. M. Overbye, Energy storage for district energy systems, in Advanced District Heating and Cooling (DHC) Systems, 2016, pp. 146–166.

[13] L. Staricco, Le politiche per la mobilità. Costi e benefici della mobilità, lecture notes from the course 'Politiche e progetti urbanistici', Politecnico di Torino, AY 2014-2015.

[14] EC (European Commission), Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, 2011. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN, last access: November 2017.

[15] K. Steemers, Energy and the city: Density, buildings and transport, Energy and Buildings 35 (2003) 3–14.

[16] J. Macedo, F. Rodrigues, F. Tavares, Urban sustainability mobility assessment: indicators proposal, Energy Procedia 134 (2017) 731–740.

[17] Eurostat Statictics Explained, Stock of vehicles at regional level, 2017. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Stock_of_vehicles_at_regional_level, last access: November 2017.

[18] Eurostat Statictics Explained, Passenger cars in the EU, 2017. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_cars_in_the_EU, last access: November 2017.

[19] J. A. Mathews, Carbon-negative biofuels, Energy Policy 36 (2008) 940–945.

[20] D. A. Hensher and S. M. Puckett, Congestion and variable user charging as an effective travel demand management instrument, Transportation Research Part A: Policy and Practice 41 (2007) 615–626.

[21] P. Goodwin, Peak Travel, Peak Car and the Future of Mobility: Evidence, Unresolved Issues, Policy Implications, and a Research Agenda, 2012.

[22] L. Staricco, "Multifunzionalità e conflittualità nelle zone 30," TeMA 4 (2011) 59–68.

[23] J. A. Kushner, Car-Free housing developments: toward sustainable smart growth and urban regeneration through car-free zoning, car-free redevelopment, pedestrian improvement districts, and new urbanism, Journal of Environmental Law and Policy 23 (2005).

[24] S. Schatzinger and C. Y. R. Lim, Taxi of the Future: Big Data Analysis as a Framework for Future Urban Fleets in Smart Cities," in Smart and Sustainable Planning for Cities and Regions, 2017, pp. 83–98.

[25] D. Karbowski, V. Sokolov, and A. Rousseau, Vehicle energy management

optimisation through digital maps and connectivity, 2015.

[26] J. K. Seadon, Sustainable waste management systems, Journal of Cleaner Production 18 (2010) 1639–1651.

[27] Eurostat Statictics Explained, Waste statistics, 2017. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics, last access: November 2017.

[28] M. . Edalatpour, S. M. . Mirzapour Al-e-hashem, B. Karimi, and B. Bahli, Investigation on a novel sustainable model for waste management in megacities: A case study in tehran municipality, Sustainable Cities and Society 36 (2018) 286–301.

[29] EC (European Commission), Environment fact sheet: Sustainable consumption and production - a challenge for us all, 2008. Available at: http://ec.europa.eu/environment/archives/eussd/pdf/brochure.pdf, last access: November 2017.

[30] European Commission Directorate-General Environment, Preparing a Waste Prevention Programme - Guidance document, 2012. Available at: http://ec.europa.eu/environment/waste/prevention/pdf/Waste prevention guidelines.pdf, last access: November 2017.

[31] A. S. Permana, S. Towolioe, N. A. Aziz, and C. S. Ho, Sustainable solid waste management practises and perceived cleanliness in a low income city, Habitat International 49 (2015) 197–205.

[32] P. H. Brunner and H. Rechberger, Waste to energy - key element for sustainable waste management, Waste Management 37 (2015) 3–12.

[33] ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), Rapporto Rifiuti Urbani - Edizione 2016, 2016. Available at:

http://admin.isprambiente.gov.it/files/pubblicazioni/rapporti/RapportoRifiutiUrbani_Ed.2016n.252_Vers.Estratto.pdf, last access: November 2017.

[34] EU (European Commission), Report from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions on the Thematic Strategy on the Prevention and Recycling of Waste, 2010. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0013&from=EN, last access: November 2017.

[35] EU (Europenan Commission), Being wise with waste: the EU's approach to waste management, 2010. Available at: http://ec.europa.eu/environment/waste/pdf/WASTE BROCHURE.pdf, last access: November 2017.

[36] F. Cucchiella, I. D'Adamo, and M. Gastaldi, Sustainable waste management: Waste to energy plant as an alternative to landfill, Energy Conversion and Management 131 (2017) 18–31.

[37] EU (European Commission), Waste prevention and management, 2017. Available at: http://ec.europa.eu/environment/green-growth/waste-prevention-and-management/index_en.htm, last access: November 2017.

[38] EU (European Commission), Waste Framework Directive, 2016. Available at: http://ec.europa.eu/environment/waste/framework/targets.htm, last access: November 2017.

[39] G. Ham and D. Lee, Consideration of high-efficient Waste-to-Energy with district energy for sustainable solid waste management in Korea,

Energy Procedia 116 (2017) 518–526.

[40] EU (European Commission), Making sustainable consumption and production a reality - A guide for business and policy makers to Life Cycle Thinking and Assessment, 2010. Available at: http://ec.europa.eu/environment/pubs/pdf/sustainable.pdf, last access: November 2017.

[41] G. Shahzad, A. Waheed Ahmad, and C. Lee, Energy-efficient intelligent street lighting system using traffic-adaptive control, IEEE Sensors Journal 16 (2016) 5397–5405.

[42] A. Gil-de-Castro, A. Moreno-Munoz, A. Larsson, and J. J. G. De La Rosa, LED street lighting: A power quality comparison among street light technologies, Lighting Research & Technology 45 (2013) 710–728.

[43] H. Lund and B. V. Mathiesen, The role of Carbon Capture and Storage in a future sustainable energy system, Energy 44 (2012) 469–476.

[44] IEA (International Energy Agency), 20 Years of Carbon Capture and Storage - Accelerating Future Deployment, Paris, 2016.

# CHAPTER 3
# Cost-benefit analysis and co-benefits

# 3. Cost-benefit analysis and co-benefits

After having described some of the policies and measures that can be applied to achieve a sustanaible district, we introduce the cost-benefit analysis (CBA) process and the concept of co-benefits. Indeed, it is interesting to understand which benefits can be reached with a more sustainable way of life and perspective, and how these benefits can be translated in an economic return for the entire society. The two words benefit and co-benfit are usually used to indicate any additional positive impact that is generated by policies, programs or projects that have as main goal the production of positive results. The concept of co-benefit differs from benefit since it started to be used around 1990s in relation with environmental, social and economic aspects. The most common and effective tool to evaluate the co-benefits is the cost-benefit analysis. [1].

## 3.1. Cost-benefit analysis

CBA is an analytical tool to evaluate an investment implemented to improve the social welfare and to appraise the economic advantages and disadvantages by assessing its costs and benefits [2]. This type of analysis allows to decide the best choice among different policies and measures. Morevoer, Through the translation in monetary terms of benefits and the quantification of non-market goods, one of the main purpose of CBA is to demonstrate the convenience of a specific intervention rather than possible alternatives. These interventions try to allocate public resources in a more efficient way proving the social benefits that can be achieved [2]. This economic evaluation is sometimes called social cost-benefit analysis because its aim is to appraise costs and benefits for the entire society [1]. Indeed, it is mainly applied to evaluate transformation of infrastructure and wide renovation projects where large public investments are forecasted [3], [4]. The CBA belongs to a single criterion method that provides a monetary approach. The drawbacks of the CBA is the handling of intangible impacts and some scholars suggest to the joint use of CBA with other evaluation tools, see for more details [4].

In the Table 1, the main points connected to this methodology are summarized. This analysis should be applied before the choice between different options in order to evaluate in a proper way the best option. Moreover, it can also be provided after the realization of a specific project to monitor data and to evaluate which are the real consequences and benefits of the applied policy. In this way, it will be easy to determine which measures can be taken as a positive example for future initiative and to which type of cities they can be applied. CBA is usually applied to large scale project and tries to quantify and measure effects. Its main objective is to choose the most efficient way to achieve results avoiding the waste of resources.

Table 1. Cost-benefit analysis features.

| | Cost-benefit analysis |
|---|---|
| When | Primarily ex ante and possibly ex post |
| Where | Primarily large scale |
| What | Quantifiable and measurable effects |
| Why | Efficiency |
| How many | Single criterion and result |
| Ranking | Output (support to decision makers) |

Source: P. Beria, I. Maltese, and I. Mariotti, Multicriteria versus Cost Benefit Analysis: a comparative perspective in the assessment of sustainable mobility, European Transport Research Review 4 (2012) 137–152.

The results that are obtained, can be expressed in a single aggregate measure, the monetary one [4]. In [4], the strengths and weakness of CBA are enumerated. It is significant to underline that the easiness of communication and the fact that this analysis uses a common language that can be use worldwide is essential. Indeed, communicate in monetary terms the results of an appraisal is the best way to make understand citizens and the entire community which are the real benefits of a certain project. While, concerning the weakness of CBA the most difficult problem to face is the need of many data that are hardly available and the impossible assessment of 'soft' effects such as beauty, personal beliefs and attitudes [4]. Table 2 summarizes the strong and the weak points of the CBA.

Table 2. Cost-benefit strenghts and weaknesses

| | Cost-benefit analysis |
|---|---|
| Strenghts | Rigour and rationality |
| | Largely formalised |
| | Transparency |
| | It is a 'common language', known and used worldwide |
| | Easy communication of the results |
| | Indipendent from judgements |
| | Potentially partecipative |
| Weaknesses | Difficult technique, expensive |
| | Need of many data, sometimes hardly available |
| | Pratically impossible to assess 'soft' effects (beauty, personal belief, atttudes) |
| | Equity is not a goal directly assessed, but left to decision maker |

Source: P. Beria, I. Maltese, and I. Mariotti, Multicriteria versus Cost Benefit Analysis: a comparative perspective in the assessment of sustainable mobility, European Transport Research Review 4 (2012) 137–152.

CBA appraises the economic return that the entire society has from the policies described and give to public investors a reason to invest in these policies. Indeed, to achieve wide social changes, it is fundamental to involve as much as possible the entire community, providing policies at a large scale. As a matter of fact, promoting measures only for buildings is important as the changes can also start from small realities, but expanding projects to an urban scale will be more effective. For this reason, a well-defined cost-benefit analysis can motivate public institutions to better understand the importance of investing in certain policies, that can be really efficient to achieve a more sustainable urban system.

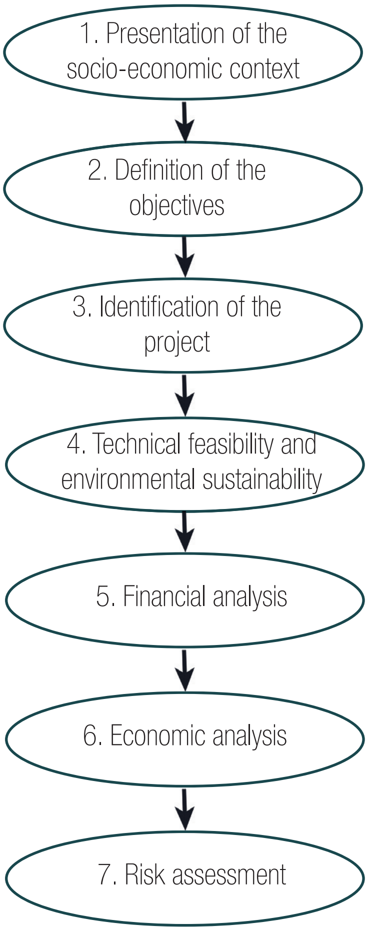
Targets and objectives, imposed by European Union, to achieve by 2020 and 2050 can be quantify through CBA [2]. The main fields in which these targets have been set are employment, innovation, education, climate change and social inclusion. Moreover, in the Europe 2020 agenda, seven flagship initiatives are representing these areas: innovation, digital economy, employment, youth, industrial policy, poverty and resource efficiency. Concerning priorities, European Union has foreseen to reach smart, sustainable and inclusive growth. To understand better why CBA contribution could be fundamental we discuss some examples. Innovation objective can be assessed by the technological progress that can be reached by using specific smart technologies and calculating the economic returns created by license deals. Climate change can be estimated by assessing costs and benefits of climate change adaptation and mitigation measures. Indeed, it is possible to easily estimate the economic value of greenhouse gas emissions in the atmosphere and the opportunity cost of the energy supply savings. While concerning rate of employment, the improvement effect can be calculated by applying the Shadow Wage Conversion Factor to labour cost [2].

CBA judges economic advantages and disadvantages of an investment decision thanks to the evaluation of its costs and benefits. General principles that refer to this economic analysis can be enumerated. First of all, the opportunity cost of a good or a service is defined and included in this analysis when a decision between different alternatives has to be taken. It represents an alternative given up and its exploitation loss from the economic point of view. Moreover, it has to be underlined that the cost-benefit analysis is connected to a microeconomic approach. In fact, it receives inputs in monetary costs and gives outputs that represents benefits. The sum of all the costs is representing the total cost that is related to the projects, while the sum of the benefits represents the total benefit that the community can deduce. Costs are considered as negative impacts on the society and of the investment chosen, while benefits are the positive ones. Both have to be translated first into monetary terms, as money is the unit measure of this analysis. Secondly they should be discounted and eventually a net total benefit can be calculated [2]. In the quantification of costs and benefits, both direct costs and non-market goods and services have to be monetised. The first ones, such as time or environmental costs, can be estimated by monetary terms thanks to the willingness to pay or by deriving prices from substitute markets. While the non-market goods can be assessed by substracting taxes from the opportunity cost and by evaluating the direct effect on the market. When all the relevant positive and negative impacts have been quantified, future costs and benefits can be discounted to carry them into the present days thanks to a social discount rate. Indeed, CBA is based on monetisation and inter-temporal discount [3], [4]. Eventually, this type of analysis has a long-term perspective, including objectives that can be evaluated from a minimum of 10 to a maximum of 30 years or more. For this reason, it is also important to set a proper time horizon, depending on the specific project, forecasting future costs and benefits and adopting suitable discount rates to present values of costs and benefits [2].

### 3.1.1. Cost-benefit analysis steps

In order to achieve a cost-benefit analysis some fundamental steps, as it is shown in Figure 1, are included in the appraisal.

Figure 1. Cost-benefit analysis steps.




Given the large amount of data needed, the analysis is quite complex. For this reason in [2], the European Commission tries to outline which are the main phases of the analysis in order to better clarify this type of economic evaluation. We remind that with CBA the public institutions could be incentivized to start investment in certain policies as positive impacts on society are shown.

Indeed, following these steps the socio-economic return is found out and the promotion of public large projects can be widely expanded.

The first step of the analysis consists in the description of the social, economic, political and institutional context in which the project will take place. This phase has to be developed from the project design and appraisal stage. To ensure an adequate project performance and an easier development of the investment, it is important to generate a favourable context as much as possible. In this first step, it is also considered fundamental to analyse deeply the demand. Indeed, forecasting future trends about users, benefits and costs will allow to provide a more suitable project. The other features, that can also be well-traced in this part, are the existing economic policies and developed plans that are already present on the territory. Moreover, the capacity of the institutions to improve the current situation has to be increment together with the perception and the involvement of the local population [2].

The definition of the objectives is obviously essential for the positive outcome of the project. The clearer the objectives are, the easier the identification of the better projects will be. In fact, describing the aims of each policy, their negative and positive effects can be better analysed and identified. Furthermore, the identification of the objectives of the project allow to justify the project's relevance. Proving that a project contributes to reach the EU policy goals and national or regional long-term development plans will be essential to the promotion of a certain project. The third phase of CBA is the identification and the definition of the project that can be realized to achieve goals that have been set. When a project is well-defined some analytical issues are developed, implemented and identified [2]. In the article 100 of Regulation (EU) No 1303/2013 a project is defined as 'a series of works, activities or services intended in itself to accomplish an indivisible task of a precise economic or technical nature which has clearly identified goals' [2]. First of all, the activities and the physical elements that will be involved to provide a service or a good with defined objectives have to be clearly defined. Furthermore, to specify project activities, the location, the typology of infrastructure and intervention and the services provided have to be enumerated. After that, the body responsible for the fulfilment of these activities, such as the project promoter or the beneficiary, is defined together with its technical, financial and institutional capacities. Eventually, the final beneficiaries and all relevant stakeholders are properly described together with the impact area of the project. In this way the boundaries are set and depending on the size and the scope of the investment, local, regional or national borders are identified. After having set boundaries, it will be easy to analyse the project's final beneficiaries, such as the entire community of the defined area. Moreover, large scale projects do not only involve the producer and direct consumers of the service, but they also have influence on partners, suppliers, competitors and public administrations [2].

The fourth step of a CBA requires to ensure the technical feasibility and environmental sustainability of a certain project. These data have to be listed to report as much information as possible. It is essential to find detailed information concerning demand, different options, environment, climate change and technical design considerations, cost estimates and implementation schedule. As already said, the demand analysis is a fundamental requirement to evaluate an investment. Indeed, the current demand can be easily analysed, while the future demand can be forecasted thanks to assumptions and economical models. Then, different options can be compared to choose the adequate one. A strategic option analysis is recommended to list alternative strategies and choosing the suitable one. The best solution is also chosen thanks to a comparison of the possible different technological solutions. During the promotion and the choice of the project, the different options should underline their contribution in achieving resource efficiency and climate change targets for 2020 and 2050, as specified in [2].

The next step is to carry out the financial analysis. This analysis allows to understand if the project is financially sustainable and if the investment, required to realize the project, is profitable for the stakeholders. Moreover, cash flows that will characterize the calculation of the socio-economic costs and benefits will be outlined. First of all, the total amount of the investment costs has to be computed in this step of CBA. They are constituted by initial investments, replacement costs and the residual value of the fixed investments. Initial costs include all the fixed and non-fixed assets. For instance, the first ones are land, plant, equipment and machinery, while the non-fixed assets are the project management, the technical assistance, the construction supervision and the publicity. The replacement cost counts the need to replace short-life machinery and equipment during the period in which the project has been considered. While, the residual value of the fixed investments is representing the remaining value of the fixed assets and their remaining potential service thanks to the fact that their economic lifetime is not yet wholly exhausted. In case the time horizon decided for the project will be equal to the economic lifetime of the assets, there will be no residual value of the fixed assets [2].

After having considered the total amount of the investments, the operating costs and revenues are taken into account. Operating costs represent all the money spent to operate new services to maintain them updated. Generally speaking, the costs are categorized in fixed and variable costs. The first ones do not vary in relation with the amount of goods or services provided, while the variable costs change with the increment and the reduction of the volume of production. Costs are usually forecasted on the historic unit costs [2]. In [2], the authors propose instances for the costs included in operation and maintenance (O&M). Some examples are: labour costs for the employer, materials needed for maintenance and repair of assets, consumption of raw materials, fuel, energy and other process consumables, services purchased from third parties, rent of buildings or sheds, rental of machinery, general management and administration, insurance cost, quality control, waste disposal costs, and emission charges. On the other hand, the revenues are defined in the Article 61 (Operations generating net revenue after completion) of EU Regulation 1303/2013 as the 'cash in-flows directly paid by users for the goods or services provided by the operation, such as charges borne directly by users for the use of infrastructure, sale or rent of land or buildings, or payments for services' [2]. As it is possible to understand from this definition, revenues can easily be estimated by the quantities of goods and services that is forecasted to provide and by their prices. Eventually, sources of financing have to be identified to invest in these large public projects. From this perspective, even though national, regional and local public institutions together with European Union have to play a key role, the involvement of private contributions and investors may still be essential in order to achieve a new sustainable society.

Surely, any policy, measure and project realized has to be financial sustainable and, in other words, revenues (cash in-flows) have to be higher than costs (cash out-flows). The difference between cash in-flows and cash out-flows will allow to evaluate the project showing the deficit and the surplus of every year [2].

After having analysed the total cash in-flows and cash out-flows and showed the positive incomes and the expenditures connected to each possible measures and policies. The next step involves an economic analysis. This part of CBA has the main function to contribute in the appraisal of the social welfare improvement due to the chosen project. In this, we introduce the concept of shadow price. The shadow price corresponds to the social value and the cost opportunity of a good or a service provided. In this case, market prices are not taken into account because they are considered distorted. One of the first step needed is the fiscal correction, as taxes and subsidies do not represent real costs or benefits for the society. After that, conversion from market to shadow prices has to be carried out and the evaluation of market, non-market impacts and the correction for externalities is conducted. Assuming that costs and benefits will occur at different times, it is important to discount them in order to have the possibility to compare them. The discount rate gives the possibility to compare benefits and costs and to calculate economic performance indicators such as [2]:

- Economic Net Present Value (ENPV) which is the difference between the discounted total social benefits and costs;
- Economic Rate of Return (ERR) which is the rate that produces a zero value for the ENPV;
- Benefit/cost ratio (B/C ratio) which is the ratio between discounted economic benefits and costs.

The thoughest part of this analysis is the determination and monetization of the benefits of policies and projects during the economic evaluation. Indeed, in certain cases, the difficulties in monetize benefits is the cause of the impossibility to take into consideration certain fields during the entire process of the cost-benefit analysis. Moreover, another drawback is the need of large amount of data that is hardly available. Eventually, some benefits can be evaluated towards a monetary value, while others are considered to be non-market impacts as they do not have a market value.

Direct benefits are usually estimated through the willingness-to-pay (WTP). This evalutation approach quantifies an outcome, that is seen as desirable, expressing the maximum amount that people would be willing to pay for it. Two techniques exist to evaluate WTP, and the choice between them depends on the nature and availability of the data researched [2]. The first one is the revealed preference approach, in which for instance hedonics prices method is used. On the other hand, the stated preference approach is characterized by the use of survey directed to the users of the benefit [5]. In case WTP method is not applicable, the avoided cost for users to achieve a result with other means can be evaluated [2]. Concerning the non-market impacts, willingness-to-pay and other methods should be used to quantify them. Sometimes it is really difficult to do it and, in these cases at least, define them in physical terms is fundamental. In this way, considerations regarding all fields can be assumed.

The last step is the risk assessment in which adversity and difficulties of projects are considered. This step is composed by different phases: sensitivity analysis, qualitative risk analysis, probabilistic risk analysis and risk prevention and mitigation. In the first phase the possible difficulties and critical fields of the project are found out and analysed. For every variable is evaluated the effect that it has on the Net Present Value. Then, thanks to a qualitative risk analysis, understanding which events could be potentially adverse during the design phases will become easier. For instance, delays on construction phases could be considered as one of these critical events. Lastly, with the probabilistic risk analysis, a distribution of the probability of each risk will be determined and with all these steps the issues concerning projects could be controlled and mitigated [2].

After having analysed in detail which are the steps of a cost-benefit analysis, it is useful to describe which are the benefits on a society and on its environment when policies and measures to achieve sustainable urban system are applied.

## 3.2. Co-benefits

Regarding projects whose aim is the achievement of a sustainable urban system, the main goal is the improvement of energy efficiency which is more convenient than reducing energy consumption. Indeed, even though the two issues are related, in [6] the authors proved that increasing energy efficiency achieves more benefits on the entire public system. Some of the co-benefits of sustainable policies and measures can be monetized in a direct way. Examples are: the reduction of energy or fuels, throughout their savings or in more complicate ways the improvements of health and wellbeing of the entire society. Furthermore, there are some impacts, positive or negative ones, that sometimes fall on third parties. For instance, if a project has the purpose to relocate some functions that generate traffic congestion in a different area of a city, there will also be the reduction of risk of accidents in that area [7].

However, benefits and co-benefits produced by urban projects are manifold and it is not always easy to consider all of them and to monetize them. Co-benefits can be categorized with several techniques that are all valid and useful. In fact, it is easier to subdivide them into sectors in order to not lose track of some benefits that can be obtained with the analysed policy or measure. Thus, positive impacts can be subdivided considering the types of beneficiaries, the nature of the impact, the feature of its impact and according to a temporal scale [6]. Here we analyse how co-benefits are categorized in various bibliographic sources. Starting from [2], benefits generated by an investment project are described by following five sectors on which policies can be applied: transport, environment, energy, broadband and research, development and innovation.

Table 3. Co-benefits classification.

| | Co-benefits |
|---|---|
| Transport | Travel time savings |

| | |
|---|---|
| Transport | Vehicle operating costs savings<br>Operating costs of carriers<br>Accidents savings<br>Variation in noise emissions<br>Variation in air pollution and GHG emissions |
| Environment | Ecosystem and biodiversity preservation<br>Increase availability of drinking water supply and/or sewer services<br>Health and environmental hazards (variation in contamination of air, water and soils<br>Increase recreational value<br>Increase in property value<br>Variation in GHG emissions |
| Energy | Variation in air pollution and GHG emissions<br>Improved energy efficiecy<br>Increase and diversification of energy supply to meet increasing demand<br>Increase of security and reliability of energy supply<br>Reduction of energy costs for substituion of the energy source |
| Broadband | Increased take-up of digital services for households and businesses<br>Improved quality of digital service for households and businesses<br>Improved provision of digital services for public administrations |
| Research, development and innovation | Establishment of more numerous or more long-lived sart-ups and spin-offs<br>Development of new/improved products and processes<br>Knowledge spillovers to non-user businesses<br>Human and social capital development<br>Reduction of environmental and health risk<br>Value of scientific publications and cultural effects |

Source: European Commission. Directorate-General for Regional and Urban policy, Guide to cost-benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014-2020, 2015.

At variance, in [6] positive impacts connected to improvement of energy efficiency are categorized considering the types of beneficiaries. Thus, we have four different categories: individual, sectoral, national and international. The first one group the benefits that can be considered in a more efficient way at the personal and household level even if they have consequences on a larger scale. The second one is referring to impacts on specific sectors such as transport, industry and so on. Then, the national one is related to the effects that fall on the entire territory. And finally, the international one refers to benefits which involve several countires. For instance, energy efficiency has effects that fall outside the border of a single country.

Table 4. Co-benefits classification

| | Co-benefits |
|---|---|
| International | GHG emissions |
| | Moderated energy prices |
| | Natural resource management |
| | Development goals |
| National | Job creation |
| | Reduced energy-related public expenditures |
| | Energy security |
| | Macroeconomic effects |
| Sectoral | Industrial productivity and competitiveness |
| | Energy provider and infrastructure benefits |
| | Increased asset values |
| Individual | Health and wellbeing |
| | Poverty alleviation (energy access and energy affordability) |
| | Increased disposable income |

Source: L. Ryan and N. Campbell, Spreading the net: the multiple benefits of energy efficiency improvements, Internaional Energy Agency, Paris, 2012.

Another typology of classification is illustrated in [1] in which co-benefits are divided into the seven components of the ideal smart city: smart natural environment, smart activities, smart community, smart governance, smart economy, smart built environment and smart mobility.

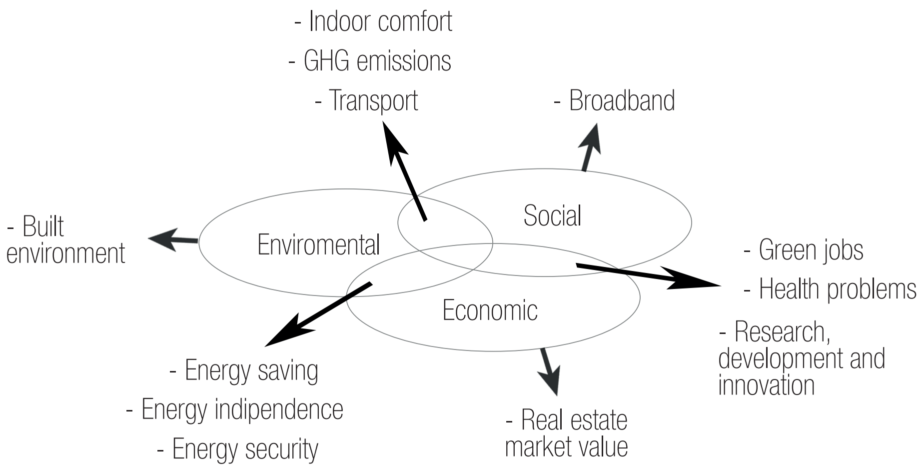
Table 5. Co-benefits classification

| | Co-benefits |
|---|---|
| Smart natural environment | Local air quality improved |
| | Better environmental resources management |
| Smart services | Health and well-being increased |
| Smart community | Tackling fuel poverty |
| | Users awareness on energy related issues increased |
| | Enhancement of neighbourhood identity |
| Smart governance | Innovation in processes and decision making |
| | Territorial attractiveness increased |
| | Institutional relationship and networks created |
| Smart economy | Positive changes to local taxes revenue |
| | Softer loans conditions |
| | Stimulation of local job's market |
| | Local energy supply chain development |
| | Energy services establishment |
| | Innovation in technology development and adoption |
| | Professional skills development |
| Smart build environment | Increased assets value |
| | Building life cycle costs reduction |
| | Resilience of energy infrastructures increased |

Source: A. Biesllo, G. Grilli, J. Balest, G. Stellin, and M. Ciolli, Co-benefits of Smart and Sustainable Energy District Projects: An overview of Economic Assessment Methodologies, in Smart and Sustainable Planning for Cities and Regions, 2017, pp. 127–164.

Lastly, as already discussed in the initial paper, co-benefits can be categorized dividing them according to the field upon which they have positive impacts. It is possible to notice from the Figure 2 that most of the co-benefits have an impact on more than one sector. In fact, the environmental, economic and social aspects are most of the time connected among them and for this reason categorizing them can be quite challenging.

Figure 2. Co-benefits classification




After this analysis, it is possible to claim that benefits and co-benefits are manifold and well interconnected among them. Moreover, every project, on which the cost-benefit analysis is applied, has its related positive impacts and a different way to monetize them. In the following paragraphs some of these benefits will be described considering their importance inside every project, describing their influences on other fields and the consequent generation of other positive or negative impacts. Moreover, as cost-benefit analysis provides the comparison of costs and benefits, both of them must be converted in monetary values. For this reason, when possible, techniques and methods to monetize these benefits are also described.

### 3.2.1. Energy saving

Reduction of energy consumption is related to the increment of energy efficiency. As a matter of fact, energy saving is possible thanks to policies and measures that provide the improvement of current energy performances of every buildings considering all their functions [8]. It is well known that improvement of efficiency and energy saving is the result of two different aspects. Indeed, energy can be wasted due to a bad technological performance or because of non-technical reasons such as individual behaviours [6]. Concerning the technological aspect, it is important to invest in projects that provide the achievement of an improvement in the buildings envelope as underlined in [2]. For urban systems, mostly in European Union, in order to have an effective reduction of costs related to energy consumption it is fundamental to act on the wide already existing building stock [9]. As already described in the second chapter, both for private and public buildings, retrofit already exisitng buildings is essential. This step may involve new insulations of the facades and roofs, with the replacement of old windows with more performing ones and with the installation of new technical systems for heating, cooling and hot water systems [2]. Furthermore, we emphasise that the improvement of energy efficiency due to the energy performance improvements listed, is related to the increment of indoor comfort. Another aspect, that has to be pointed out, is the importance to substitute the use of fossil fuels with renewable sources. The second ones can be exploited indefinitely without an end, and they do not have no an influence on the costs and they do not produce GHG emissions. Nevertheless the most challenging issue connected to renewable energies is the not correspondence between the peak of energy production and the peak of energy demand. Indeed, if we consider the production connected to solar power in residential buildings, the peak of energy production is during the daylight, while the energy demand is smaller in the central hours of the day. At variance, during the evening hours, the peak of energy demand takes place while the energy production through solar power is at minimun. For this reason, one of the challenge of the next years is to develop energy batteries and storages that can exploit renewable sources as much as possible in order to overcome the cases in which, peaks of energy demand and peaks of energy production do not match. Moreover, we remark that each policy and measure to retrofit building stocks give the possibility to society to take advantage from the creation of new green jobs. In fact, the additional jobs created to these new initial investments allow to stimulate the current stagnation of job market. Moreover, it will avoid the increment of unemployment benefit payments as the authors claim in [9].

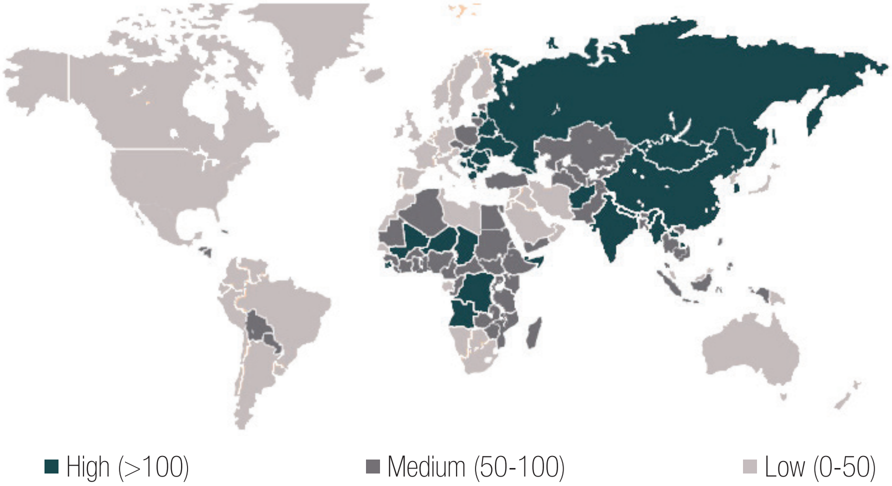
On the other hand, as long as individual behaviours are concerned, the improvement of organisation and energy management plays a key role [6]. Indeed, although our buildings have features that permits to achieve high level of energy performances, that is not possible if occupants of these buildings do not behave properly. Raising awareness of citizens and diffuse information concerning the right rules to adopt in the use and exploitation of energy will increase the energy performances of both private and public buildings. Furthermore, the improvement of energy efficiency and its consequent energy saving will allow to increase the indoor comfort and to reduce the emissions of pollutants in the air. As a matter of fact, the reduction of energy use is strictly connected to the co-benefits obtained by the decrease of production of emissions. Explaining to citizens the relation between population behaviour and the air quality should be fruitful in the endless fight against pollution issues. Talking about the reduction of energy use, it is relevant to point out the need to reduce the use of fossil fuels in every fields, even the ones that are not strictly connected to buildings. Clearly, for instance, fossil fuels are also exploited for means of transports. Even in this sector, the exploitation of alternatives fuels should be enhanced overcoming the use of fossil fuels.

Considering the benefit of the reduction of energy and fuel use, the monetization is given by the decrease of costs connected to the use of energy and fuel. Being aware of the reduction of costs will be a huge incentive for households to improve energy performances of their buildings and to adapt their behaviours following a more sustainable way of life.

### 3.2.2. Air pollution

Nowadays, one of the most challenging issue for the environment protection is the emission of pollutants. GHG, which stands for greenhouse gases, and particulates matter are causing huge damage to earth, its natural environment and human being. In the last decades, air pollution has been drastically increasing drastically due to the emissions produced by an uncontrolled use of fossil fuels. Since these emissions are produced by different fields, they should be radically cut by all the countries in all the sectors. Example of sources of these emissions are the buildings, the fuels of means of transport and power and industrial plants [10]. For instance, when we consider building sector, decrease of air pollutants is possible thanks to the reduction of heat dispersion and the consequent amount of energy consumption [2]. As it is shown in Figure 3, human being deaths due to air pollution are still high, especially in the developing countries of the eastern area of the world. Furthermore, in 2012, according to the World Health Organization (WHO), household air pollution has caused 4.3 million deaths worldwide. Moreover, in the same year, 3.7 million deaths were counted in relation with ambient air pollution. The vast majority of these deaths, the 88 %, were counted in urban areas in low- and middle-income countries, and 70% of them were occurred in the Western Pacific and Southeast Asian Regions [10].

Figure 3. Death per 100.000 people per year due to air pollution




Source: IEA (International Energy Agency), Energy technology perspectives 2016. Towards sustainable urban energy system, Paris, 2016.

Every project analysed towards a cost-benefit analysis has to include information concerning the reduction or the increment of GHG emissions and particulate matters. The benefit of air pollution reduction is related to benefit for human being health, as already described, and to the impacts on ecosystems and biodiversity. Respiratory and cardiovascular diseases are caused by particulates such as $PM_{10}$ and $PM_{2,5}$, while $CO_2$ emissions are mostly responsible for global warmer and related damages to environment. Moreover, acidic substances are causing negative impacts on crop, on biodiversity and on buildings materials of facades through corrosive processes.

The $CO_2$ emissions are usually monetized obtaining the kilograms of carbon dioxide for each energy carrier used [11]. Indeed, each energy carrier has a correspondent value that expresses the quantity of $CO_2$ emitted in relation with the energy consumed in $kgCO_2/kWh$ [12]. The computations needed to obtain the total quantity of $CO_2$ emitted is described in the UNI/TS 11300-4 [13]:

$M_{del,i}\ CO_2 = Q_{del,i}\ k_{em,i}$ [kgCO2]

| | |
|---|---|
| $M_{del,i}\ CO_2$ | $CO_2$ production of the energy carrier [kgCO2] |
| $Q_{del,i}$ | quantity of energy consumed for the specific energy carrier [kWh] |
| $k_{em,i}$ | $CO_2$ emission factor for the specific energy carrier [kgCO2/kWh] |

In the cases in which a quantity of electricity is exported, the reduction of $CO_2$ emissions produced is considered:

$M_{ex}\ CO_2 = Q_{ex,el}\ k_{ex,el}$ [kgCO2],

and it is subtracted to the quantity previously calculated:

$M_{net}\ CO_2 = Q_{del,i}\ k_{em,I} - Q_{ex,el}\ k_{ex,el}$ [kgCO2].

After having obtained the total quantity of $CO_2$ produced, this value has to be monetized to be part of the cost-benefit analysis processes. In the European regulation n. 244/2012 [14] the prices per ton of $CO_2$ emissions produced are expressed and they range from a value of 20 € per ton until 2025, to a value of 35 € per ton until 2030 and eventually to 50 € after 2050.

### 3.2.3. Increment of indoor comfort

Nowadays, mostly in developed countries, people spend most of their time inside buildings. For this reason, the control of indoor air and the high quality indoor comfort are increasingly required [15]. Indeed, we underline that, when we talk about indoor comfort we take into consideration its acoustics, lighting and thermal environment comfort and its indoor air quality [16]. This topic is relevant when benefits are considered, as outside air is bound to enter in closed spaces and to worsen its quality. However, many studies are focusing on outdoor air pollution and its consequent on human being health and well-being, while on the other hand indoor air is not always taken into consideration. Nevertheless, it is relevant to point out that it is easier to monitor indoor spaces of public buildings compared to the ones of residential buildings. Indeed, residential indoor air spaces are controlled by their inhabitants that act taking into consideration their comfort with respect to that specific moment. At variance, offices and public buildings are easily monitored since their indoor air quality is guaranteed by designed and controlled precise rules and by technical installations [15].

Low indoor climate quality has huge influences on the well-being of the occupants of buildings and on the productivity inside spaces dedicated to educational and working functions. Moreover, considering buildings owners and the whole society, negative consequences due to poor indoor climate have more impact than costs related to energy consumption for the same building. Furthermore, occupants that are not felling comfortable, they are usually taking actions that imply issues for energy consumption [16]. In [16], the authors underline that the achievement of high performance and cost optimal solutions related to energy consumption, sometimes implies a worse indoor thermal comfort. Indeed, to pursue the ideal thermal indoor comfort together with a good cost optimal solution for energy efficiency, the initial investment costs have to be increased.

Concerning related benefits to indoor comfort, for instance, when indoor air quality in offices is considered, productivity increment and sick leave reduction is related to a better air quality space. Lastly, it is important to consider air indoor quality when we consider benefits since quality of life can be influenced by it. Starting from the design of buildings, the attention should be also payed on these issues.

### 3.2.4. Green jobs

First of all, it is relevant to define which is the meaning of green jobs as it has not an universally accepted definition. Generally speaking, this concept indicates the preservation of the natural environment and the exploitation of renewable resources. Indeed, nowadays, the term 'green job' can be referred to the ability of these jobs to meet social poverty, to its potential to exploit renewable energy resources and to improve environmental protection and quality [17]. Green jobs are increasingly more discussed due to the need of urban systems to move towards low-carbon societies. Since transforming fossil fuels energy-based economies into low-carbon ones is a huge challenge, investments have to be fruitful to develop benefits for the future generations. It is high time for the European Union and other developed countries to accelerate this transformation which also depends on the capacity of the economy to react in a proper way and on the ability of citizens to adapt their behaviours to a developing sustainable environment and society [17].

In literature, the effects of green projects on jobs are three: direct, indirect and induced. Direct employment effect is given by investment projects that are developed in environmental and energy fields, such as jobs given by construction and installation sectors, manufacturing, project management of new plants and connected to the use of new renewable energy sources. Indirect employment effect is related to services and materials that are needed to develop these investments and to the great chance that they are giving to suppliers to expand their trade. Lastly, the induced employment effects are given by the additional spending capacity obtained by direct and indirect jobs. For instance, the introduction of new job places will increment the general welfare of citizens and for this reason the demand of other good and services can increase. However, we should also consider the job-destruction effect due to the jobs places lost during this transformation of the society. That is why, it is important to take into account the net employment effect that is considering both the employment effects and the unemployment effects.

The challenges of these green jobs will involve as many workers as possible. Even if variables to take into consideration are manifold, studies that try to estimate the rate of new employments in these fields are increasing, we refer the interested reader to [17] and references therein.

Considering the importance of reaching a positive net rate of employment, governments should start to think about the introduction of investments project for green growth [6]. To monetize the benefits coming from the creation of new green jobs, there are different sources of literature that estimate the number of jobs places obtained for each million of euro invested in new projects. This number has to be multiplied for the shadow wage that measures the opportunity cost of labour. The shadow wage is determined by [8]:

$$SW = W \ (1-t) \ (1-u)$$

W represents the average construction gross annual salary

t income tax rate

u unemployment rate of the area or country considered

Moreover, knowing the number of new job places introduced in the market of employment, it is also possible to estimate the money saved by governments to pay subsidies for unemployment.

### 3.2.5. Real estate market value

The improvement of energy performance of buildings and their efficiency influences the market value of sales and rents of real estate. Many studies are already trying to estimate, regarding the residential sector, the increase in the real estate market value after having achieved more efficient energy performances. As claimed in [16], the improvement of energy performance is strictly related to the willingness to pay more for a more energy efficient building. In the last years, European Union is paying always more attention on these topics as it has set short- and long-term targets for its progressive reduction of dependence on fossil fuels use [18]. Moreover, with the Energy Performance Building Directive [19], European Union member States have to adopt the Energy Performance Certificates (EPCs) to increase the awareness of consumers on energy performances of buildings [18], [20]. This instrument has the main aim to compare building energy performances during the purchasing and renting decision processes and to make consumers' decisions more aware. Furthermore, it has an impact on the value of the properties and make aware the investor and the owner on the positive and negative energy features of the considered building. Unfortunately, nowadays, these comparisons are not possible between different European Union member States since each of them has different rules on this topic [20].

In most of the cases, the real estate value increases with the increment of the energy performance that is indicated on the EPCs. In one article of 2012 published in the Italian financial newspaper 'Il sole 24 ore', the influence of the energy classes of dwellings pointed out in the Italian EPCs in the variation of prices are indicated. If we consider similar properties, one with a G class and the other with a C class, then the price ranges vary from 4% in Florence to a maximum of 15% in Milan. On the other hand, when the analysis is extended to the market of new buildings, the same article indicates a price range of 21.6% between a class G and a class A [18]. Sometimes mismatches between predicted and real performances of buildings are revealed. That is due to different mix of issues during the design and planning phase, too advanced monitoring and control systems and inappropriate behaviour of occupants of the building [18].

In [16], three procedures to quantify and monetize the increment of real estate market value due to improvement of its energy performances are enumerated . The first one, the hedonic pricing method, consists in the evaluations of dwellings attributes and their prices [18]. Indeed, through this method, a correspondent price to each building features is given comparing buildings among them. The second one is a method based on the direct comparison of transactional prices on similar properties. At last, the third one is the willingness to pay method.

### 3.2.6. Health and wellbeing

The transformation of the current fossil fuel-based society to a low carbon one will drastically influence the human being health and the entire social wellbeing. As already said in the previous chapter and in the paragraph concerning the benefits of the reduction of $CO_2$ emissions, deaths connected to the production of $CO_2$ and $PM_{10}$ emissions are increasing and will grow up in the future if efforts will not be made [10]. That is why policies that will reduce the emissions produced will allow to improve the current situation of human being society. Moreover, even measures taken on urban mobility are considered fundamental to increase the savings related to public healthcare system. Indeed, the reduction of accidents in the streets will allow to decrease the amount of money spent by sanitary system. For instance, in [21], zone 30 examples are described, and the related benefits on accidents reduction and money saved by public healthcare system are underlined.

Even though benefits on human being health related to the development of sustainable policies are vast, it is still quite hard to monetise them. Indeed, while it is almost always possible to evaluate the money spent for hospitalization, medical examinations and medicines related to a precise health issue, it is still quite hard to estimate the quantity of the reduction of patient related to a specific health issue as human being health is connected to manifold aspects.

### 3.2.7. Light pollution

Urban settlement is characterized by the presence of artificial lighting. Indeed, the economic development and the urban and population growth has lead to a society which is always more dependent on artificial lights for different uses such as public street lighting and architectural, domestic and vehicle lighting. For these reasons, and for security, suburbanization and convenience reasons, artificial lighting is permanently switched on during the whole hours of darkness or during some of them [22], [23]. As street lighting during night time is likely going to grow due to the increment of urban areas and the necessity to keep them safe, the consequences of this policy have to be investigated, analysed and improved to forecast negative impacts.

Artificial light has a remarkable influence on biological systems from cell to ecosystem and on human beings, even where light pollution has low levels during night-time. Indeed, short pulses of light during night have a negative impact on photosynthesis, photoperiodism and circadian clocks of some species [22]. Furthermore, negative impacts are also relevant on health human beings, including diseases as obesity and breast cancer. The first impact on human health is due to the disrupting of endogenous circadian clock and the suppression of the production of melatonin [24], [25]. The first one is responsible for the regulation of the behavioural and psychological responses to meet environmental challenges [25], while the second one is generating issues in the regular process of sleeping. Both syndromes of circadian and melatonin disruption can induce to an increment of cancer risk and to the generation of heart disease, diabetes and obesity [24]. These are the reasons why light pollution should be reduced and increase the benefits that will be generated on ecosystems and human being's health. So far, methods to monetize these health benefits have not been found yet, even though the economic benefit on society are clear and examples are the money saved by public healthcare system thanks to the reduction of light pollution and its consequent decrease of human being diseases. Since hospitalization, medical examinations and medicines have an high impact on economy of the sanitary system, the reduction of health problems will generate economic benefits on the whole society.

## 3.3. Bibliography

[1] A. Biesllo, G. Grilli, J. Balest, G. Stellin, and M. Ciolli, Co-benefits of Smart and Sustainable Energy District Projects: An overview of Economic Assessment Methodologies, in Smart and Sustainable Planning for Cities and Regions, 2017, pp. 127–164.

[2] European Commission. Directorate-General for Regional and Urban policy, Guide to cost-benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014-2020, 2015.

[3] P. Beria, I. Maltese, and I. Mariotti, Multicriteria versus Cost Benefit Analysis: a comparative perspective in the assessment of sustainable mobility, European Transport Research Review 4 (2012) 137–152.

[4] P. Beria, I. Maltese, and I. Mariotti, Comparing cost benefit and multi-criteria analysis: the evaluation of neighbourhoods' sustainable mobility, 2016.

[5] Y. Zhou, T. Nurmagambetov, M. McCord, and W.-H. Hsu, Economic valuation of selected illnesses in environmental public health tracking, Biomedical and Environmental Sciences, 2017.

[6] L. Ryan and N. Campbell, Spreading the net: the multiple benefits of energy efficiency improvements, Internaional Energy Agency, Paris, 2012.

[7] European Commission. Directorate General Regional policy, Guide to Cost-Benefit Analysis of investment projects, Brussels, 2008.

[8] C. Becchio, S. P. Corgnati, F. Dell'Anna and M.C. Bottero, Cost benefit analysis and smart grid projects, NEWDIST (2016) 278-287.

[9] A. Joyce, S. Naess-Schmidt, and M. Bo Hansen, Monetising the

multiple benfits of energy efficient renovations of buildings in the EU, 2013.

[10] IEA (International Energy Agency), Energy Technology Perspectives 2016 – Towards Sustainable Urban Energy Systems, Paris, 2016.

[11] G. Heefner and N. Campbell, Evaluating the co-benefits of low-income energy-efficiency programmes, Paris, 2011.

[12] F. Dell'Anna, Evaluating co-benefits of nZED projects: methodological approach and experimentation in the city of Turin, master thesis in Architettura Costruzione Città, Politecnico di Torino, AY 2015.

[13] UNI/TS 11300-4:2012 Prestazioni energetiche degli edifici. Parte 4: Utilizzo di energie rinnovabili e di altri metodi di generazione per la climatizzazione invernale e per la produzione di acqua calda sanitaria.

[14] European Commission (EC), Commission delegated regulation (UE) no 244/2012 of 16 January 2012 (..), 2012. Available at: https://publications.europa.eu/en/publication-detail/-/publication/61c1bce1-e229-4225-91e4-069c6bed5570/language-it, last access: May 2018.

[15] C. K. Chau, W. K. Hui, and M. S. Tse, Valuing the health benefits of improving indoor air quality in residences, Science of the Total Environment 394 (2008) 25–38.

[16] C. Becchio, S. P. Corgnati, L. Orlietti, and G. Spigliantini, Proposal for a modified cost-optimal approach by introducing benefits evaluation, Energy Procedia 82 (2015) 445–451.

[17] Z. Natalia, Green jobs - a co-benefit of EU climate policies: myths and realities, 2011.

[18] S. Copiello and P. Bonifaci, Price premium for buildings energy efficiency: empirical findings from a hedonic model, Valori e valutazioni. Teorie ed esperienze 14 (2015).

[19] European Parliament, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Official Journal of the European Union, 2010.

[20] R. P. Pascuas, G. Paoletti, and Ro. Lollini, Impact and reliability of EPCs in the real estate market, Energy Procedia 140 (2017) 102–114.

[21] L. Staricco, Multifunzionalità e conflittualità nelle zone 30, TeMA 4 (2011) 59–68.

[22] K. J. Gaston, J. Bennie, T. W. Davies, and J. Hopkins, The ecological impacts of nighttime light pollution: a mechanistic appraisal, Biological Reviews 88 (2013) 912–927.

[23] K. W. Riege, Light pollution, Science 179 (1973) 1285–1291.

[24] Y. Cho, S.-H. Ryu, B. Ri Lee, K. Hee Kin, E. Lee, and J. Choi, Effects on artificial light at night on human health: A literature review of observational and experimental studies applied to exposure assessmen, Biological Rhythm Research 32 (2015) 1294–1310.

[25] A. E. Zubidat and A. Haim, Artificial light-at-night - a novel lifestyle risk factor for metabolic disorder and cancer morbidity, Journal of Basic and Clinical Physiology and Pharmacology 28 (2017) 295–313.

# CHAPTER 4
# Aims, instruments and methodology

# 4. Aims, instruments and methodology

In this chapter, we define which are the main goals, the tools and the methodology of the reference project that we are going to develop. After having defined the environmental problems that are having implications for the entire planet, and the targets imposed from international agreements and European Union to improve the current situation, we have described possible ways to achieve a more sustainable urba system. Moreover, we underline the importance of focusing more on the whole urban system than on the only building sector. Under this perspective, the analysis and study of nearly zero energy districts and smart sustainable cities has been assertive to understand the importance of the involvement of the different sectors that interact in an urban system to achieve a sustainability from the economic, social and environmental point of view. Then, policies and measures that can be taken to obtain a nearly-zero energy district have been described, dividing them in four different category that have been identified as: buildings retrofit with renewable resources exploitation, mobility, waste management and street public lighting. Then, we analyse the cost-benefit analysis process and its steps have been analysed in order to understand better how this type of economic assessment works and which benefits can be reached thanks to new sustainable policies and measures. Thanks to cost-benefit analysis process, the co-benefits, can be monetized. In this way, the positive impacts of a nearly-zero energy district could become tangible. Nowadays, energy retrofit of buildings are developing quite fast and always more people are taking into consideration these policies thanks to the raising awareness of the economic benefit that is possible to achieve with more efficient buildings and policies. For this reason, it is fundamental to underline the economic and social benefits that a more sustainable perspective can give to a society.

In this framework, the driving idea of this thesis is not to examine an already existing district and to apply new policies and measures, but to design a reference district for the city of Turin. The reference district case study will be composed, considering the entire city of Turin, by an ideal average number of citizens, of buildings and so on. The main aim is then, to create a district characterized by the main features of Turin, that could represent the entire city and to apply on it different scenarios characterized by various policies on different fields. Then, after a comparison of energy consumptions and emissions produced, we can evaluate the different scenarios. Moreover, with the cost-benefit analysis we can better analyse the economic sustainability of the project and through its economic performance indicators it is possible to estimate which is the social-economic convenience of each scenario and to choose the most efficient one. The future ambitious idea behind this reference district is to start an analysis that can generate a representative sustainable district for the city of Turin. Indeed, the most performing scenario identified by this analysis could be suitable to be reproduced in other areas of the city covering at the end the entire surface of Turin.

Since improvement of energy performance at building level has already been discussed extensively, it is time to deepen the possible measures for sustainable development of cities. Models that suggest policies for the retrofit of existing and new buildings have already been analysed, studied and promoted. At variance, models for urban areas, in which more sectors can be included, have still to be well-developed. In the next decades, developing prototypes to implement sustainable policies and measures, will be an outstanding opportunity to improve the current situation.

To sum up, tha main steps of the project carried out in this thesis work are here enumerated. Firstly, the creation of the reference district with its main features are addressed. Then, thanks to the previous bibliographic analysis conducted, the possible policies for every category of intervention identified are discussed. Afterwards we apply different measures on the sectors under consideration and five final scenarios were extrapolated. Lastly, thanks to the cost-benefit analysis process, we could estimate the economic convenience of each scenario and choose the most convenience one.

In this chapter, we choose to better analyse and define the tools used to implement the goals of the thesis. Then, we deeply explain the methodology used to create this reference project.

## 4.1. Instruments

Two important tools were studied and used during the steps of the definition and study of the reference district. The first one, Tabula, was fundamental to determine the energy performance of buildings in the current state, while the second one, MasterClima, was used to estimate the energy performance of buildings after the different retrofits. Here we are going to describe how the two tools work and their features.

### 4.1.1. Tabula

The project Tabula (Typology Approach for BUiLding stock energy Assessment) was conducted between 2009 and 2012 and supported by the European program Intelligent Energy Europe. The aim of this project was to create a well-defined framework of the European typologies of residential buildings. Thirteen European countries were involved and the Italian project was carried out by the Polytechnic of Turin. For each country, a classification scheme, grouping buildings, has been developed and its main goal was to create residential buildings prototypes characterised by typical energetic features. Every building type can be exploited by each country to inform citizens about the building performance of the national building stock, underlining the potential environmental benefits and economic savings in case of buildings retrofit. Indeed, in Tabula two levels of buildings retrofit were also analysed. The first one is characterized by the typical policies applied in the country, while the second one also entails the application of the most innovative technologies available [2].

The residential building typologies are published in the typologies of residential building Webtool [3]. For each country, a matrix, with the photography of the building model, organized according to the period of construction and the dimension of the building has been developed. In the Italian webtool this classification has been develop according to the average climatic area. In fact, the climate zone E was the one chosen since 52% of the Italian village are part of this climatic zone. Some data are referred to Italy, while some others to the Piedmont region because 74% of the village in this region are categorized in the climatic zone E [2].

The building types identified are 32, given by the union of 4 different dimension and geometry, called buildings categories (apartment blocks, multi-family houses, terraced-houses and single-family houses) and 8 building-age classes characterized by different construction periods. As already said, the Italian matrix reports the feature of the climatic zone E, the average one in Italy, and represents 4.250 Italian municipality on the total amount of 8.100. The columns represent the building categories, while in the rows the building-age classes are enumerated. The geometrical and technological characteristics of 14 out of 32 typologies buildings, apartment blocks and multi-family houses before 2005, were obtained by real reference buildings. While the others have the features of the average of a building stock that can be associated to these categories. The energy performance of these buildings and of their two levels of buildings retrofit were defined, in terms of annual consumption of primary energy for heating and domestic hot water, thanks to the calculation procedure described in the UNI/TS 1330-1 and UNI/TS 1300-2. The calculation has been carried out with the climate features of the city of Turin available in [2].

Concerning construction systems, to each building of the matrix a construction system with a specific value of transmittance was associated. It was the same with the transparent component of the building envelope. Moreover, even the typology of power and electrical supply system is identified for each building. Starting from this data, that analyses the current situation of the Italian building stocks, two retrofit scenarios are developed. The first one is a standard building retrofit that includes the most frequent retrofit policies and measures that are usually taken in Italy. While the second one, is an advanced building retrofit that provides the application of the most innovative technologies available for the retrofit building sector.

#### 4.1.2. MasterClima

Another tool, that we used during the definition of the reference district, is MasterClima. This software was used in the consumption building analysis of the district. Indeed, the first step was to choose which buildings have to be submitted to retrofit and then reproduce the current situation of these buildings in MasterClima using the features expressed in Tabula. The main aim was to create an energy model for each typology of building in MasterClima in order to have models of buildings that can faithfully represent the consumptions of the reference buildings present in Tabula. In this way, it was then possible to apply the energy retrofits decided on these buildings.

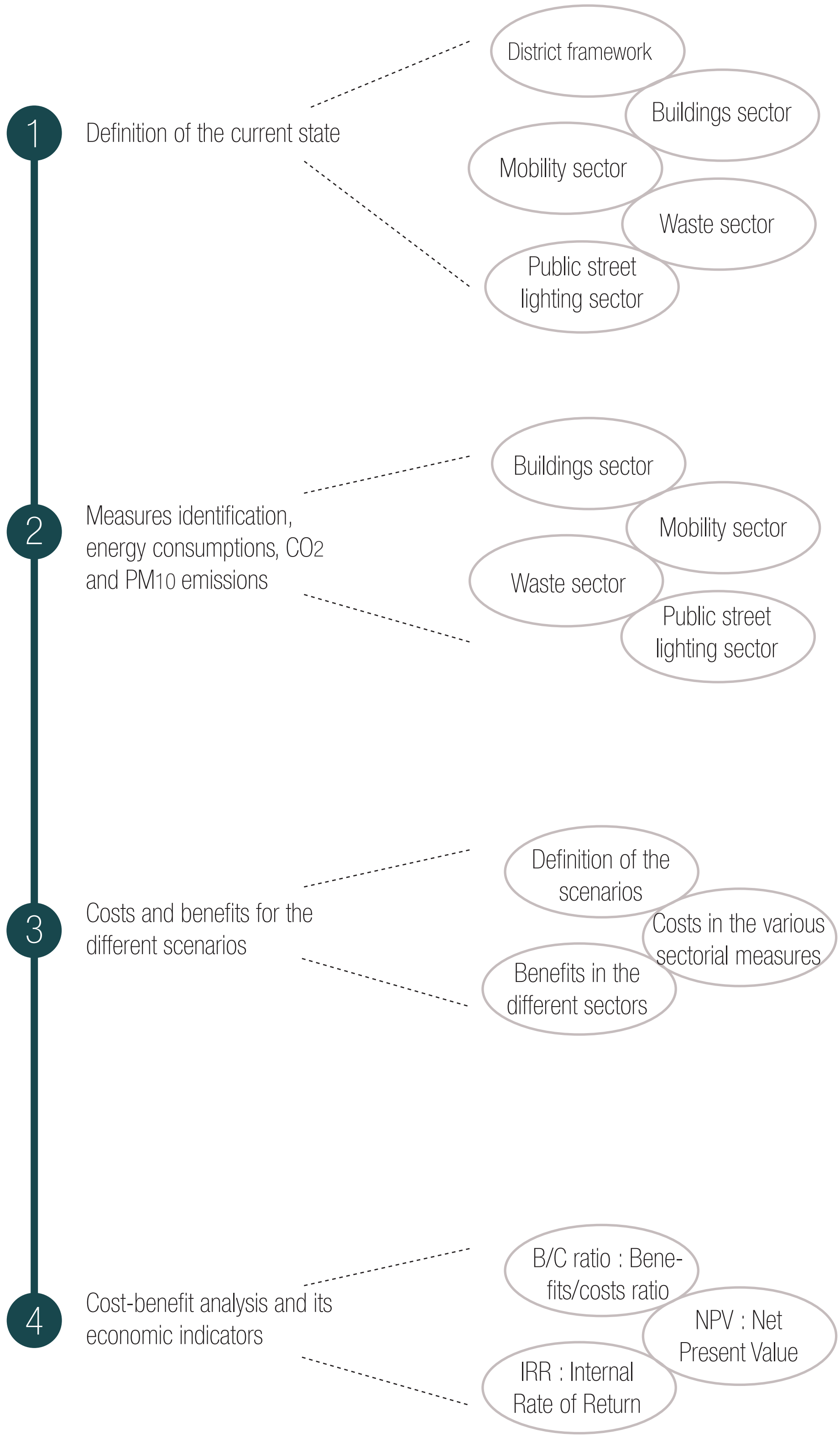
MasterClima (MC) is a software produced by Aermec that has the main function to draw up the energy performance certificate of buildings. In [4], some interesting details concerning this software are given. Its last version, the one used in the analysis of the thesis case study, is updated to the technical regulation UNI/TS 11300-2014 and to the 'DM 26 giugno 2015', in which the new way to determine the energy efficiency class and the new minimum requirements concerning the buildings performance are defined [5]. The interface of the software is quite easy and the different drop-down menu characterized the main sectors which have to be analyse in the production process of energy performance certificates. First of all, the main climate data have to be inserted to characterize the area in which the buildings analysed are located. Moreover, in the first main drop-down menu the different components, which characterizes the building can be inserted. In the second one, the various components are interconnected and surface areas of each of them have to be determined. Furthermore, ventilation, domestic hot water and internal heat gain data can be defined towards the current regulations or inserted manually after having calculated them. The third drop-down menu concerns the heat and domestic hot water system, while the fourth one shows the results coming out from this analysis. The results of this software are quite detailed and allows to characterize all the data concerning the power system of buildings and even the CO2 emissions produced by them. In the last drop-down menu the energy performance certificate is shown, which is already filled in with the data obtained by the software. Eventually, the menu on the right of the interface shows the main final data obtained by the software about building analysed.

After having recreated the current state of the buildings of the district, MasterClima allows the different retrofits. Indeed, we created a copy of the current state file of each building for each type of retrofits and simply changing the interested data it was possible to recalculate the values concerning the energy consumption of buildings. In this way, it was easy to compare data from the current state with the ones in which the retrofits were applied. As the comparison of energy and CO2 could be easily achieved, it was then possible to determine the costs of each retrofits applied.

## 4.2. Methodology

In the following paragraphs, we decided to illustrate which is the methodology used and the main steps followed to define this reference project, its improvement policies and its cost-benefit analysis. Here below, in Figure 1, we list the main steps of the methodology followed to develop this project. The first fundamental step was the definition of the reference district of the city of Turin. Firstly, it was decided a district and street framework that could be representative for the entire city, and then we determined four fields to analyse and on which apply new policies and measures. The four sectors selected were: buildings, mobility, waste and public street lighting. We estimated for the current state the total consumption of energy and fuel and the total emissions produced by all the fields considered. Afterwards, various measures for each sector were identified and according to them, the energy consumptions and the CO2 and PM10 emissions produced were estimated comparing these results with the ones obtained in the analysis of the current state. After that, five scenarios composed by the application of a retrofit measure for each sector were formed and we estimated for each of them costs and benefits. The last step we took, after having obtained all the costs and benefits for each scenario, was the estimation of three economic indicators of performance through the cost-benefit analysis.

Figure 1. Main steps of the methodology



### 4.2.1. Definition of the current state

Before starting the description of the methodology used to achieve the goals set, we underline some decisions that were taken during the definition of the entire district and the following calculations. First of all, for every field taken into consideration, as for example the number of inhabitants, the average data concerning the city of Turin were searched. Then, if Turin data were not available, we sought the province of Turin data, and the following steps were the regional and the national information available. In this way, it was possible to reproduce as closely as possible the current situation of the city of Turin. Moreover, we remark that all the consumptions and emissions are referred to an entire year. Indeed, even if at the beginning, the calculations regarding transport, waste management and public illumation were estimated per day, afterwards they were reffered to an entire year. The main reason of this choice was the necessity to consider the consumptions and emissions of buildings annualy. Since buildings are the most influencing sector on the entire district, and mostly because they need a major effort in the calculation procedure, we decided to rescale to an entire year the data obtained from other sectors. Besides, it is interesting to evaluate the total energy balance on the entire district annualy as it gives a more complete view to analyse the consumptions and the emissions produced. The last relevant reason why the data are referred to an entire year is the cost-benefit analysis. Indeed, the cost-benefit analysis is considered on a timeframe of thirty years and for this reason, we estimate the cash flow for every year of this period.

Another important hypothesis concerns the building sector. The consumption data extrapolated from the creation of the energy model of each building typology do not consider that in reality most of the buildings are joined one to each other. Indeed, Tabula building typologies are considered as isolated buildings. As we used these buildings models to get consumption data of different categories and class-ages of buildings, we could not consider the existence of neighbouring buildings. We are aware about the fact that in this way consumption results are larger than they should be, but it was not possible to consider bordering neighbouring buildings because there are no other tools that provide detailed information as Tabula does. Moreover, as buildings location was chosen arbitrarily in the district, it was decided to not hypothize the presence of jointed facades in the calculation of consumption.

To create a reference project that can be duplicated and reproduced in Turin, an initial analysis of the entire city was carried out on different fields. For instance, concerning the largest sector considered, the building one, thanks to the investigation of the distribution residential building stocks, its diversity and its population density, it was possible to distribute more realistically the different typologies of buildings and how to identify the reference case study features. In the next paragraph, we are going to describe how we defined the street framework of the district and which are its main features concerning inhabitants, buildings and functions.

#### 4.2.1.1. District framework

First of all, we had to identify an area of the city with a reasonable dimension, a street framework, an average building density and an heterogeneity of building stocks that could represent an average of the city of Turin. The identification of this area was primarily connected to the need of defining streets and city blocks of our reference district. The chosen area is located in the south of City Park Pellerina and it is extended among Giacomo Medici Street, Lecce Street and Monte Grappa Street. The size of this area was determined in order to have a number of buildings that allows to analyse the diversity between them and to have a space that permits to evaluate its energy consumption, $CO_2$ and PM10 emissions and costs at the district level. Furthermore, this area dimension has to give the possibility of charatecterize the main features of the mobility, waste and public street lighting sectors. The area selected corresponds almost to a surface of 13 average census sections dimension. The average of the census sections dimension was obtained by the data available in [6]. The dimension and the street framework of the selected area were kept for our reference district, while the buildings in the area were not considered. In fact, in our designed reference district, it was chosen to reproduce the features of Turin building stocks distributing the different typologies of buildings that characterize the city inside the district. In this way, the reference case study can represent the entire city and its building diversity.

To determine the number of inhabitants of our reference district, the population density of the area previously selected was determined thanks to 'Geoportale di Torino' [7]. We summed up the areas of the different census sections and their number of inhabitants, obtaining the population density. As the surface of the area selected and the one of our reference case study are the same, we can assume that the number of inhabitants are the same.

#### 4.2.1.2. Buidings sector

After having determined the number of inhabitants, we obtain the total area covered by buildings. Indeed, in the General Urban Development Plan of Turin, 34 $m^2$ of dwelling floor space per inhabitants are required. We then distribute the total dwelling floor space between the typologies of buildings. To do this, we needed three information: the subdivision in different typologies of the buildings, the percentage of distribution of them and their gross floor area. The first information is obtained by the subdivision og the buidings in 32 typologies carried out by Tabula since the same categories and age-classes of buildings were used. The second information, the one concerning the percentage of distribution of buildings, was extrapolated by the previous analysis carried out concerning the city of Turin. Indeed, we had already analysed which was the percentage of distribution of the typologies of the buildings in the city. Lastly, data concerning the average gross floor area of Turin buildings were obtained by the information available in [5], [8] and [9]. Indeed, in [5] values of GFA for each building-age classes and buildings categories were available for the average of the city of Turin [5], while in [9], [8] the same data were available for Turin section 3. After having analysed the material, it was assertive to consider the data available from the city of Turin. Indeed, the data of Turin can represent a perfect average to create a reference project that can be reproduced in the entire city. At variance, data from section 3 are more detailed due to the smaller dimension of the area, but they represent only a certain sector of the city with certain precise features. For instance, moreover, Turin section 3 has the highest population density compared to the other sections of the city, with a small surface area and a high number of inhabitants. With this three information, we estimate the total square meters for each building typology and the consequent number of buildings subdivided in the 32 building types identified by Tabula.

Furthermore, taking into account the number of buildings and inhabitants, it was fundamental to diversify the function of the buildings. Indeed, to design a realistic district a mix of functions is needed. We decided to introduce in the district a school (nursery and primary school), some offices and some shops at the ground floor of the residential buildings. Even in this case, the total area dedicated to shops and offices was obtained by the average that characterize the city of Turin. This data were taken form [8]. Concerning the school dimension, [10] was consulted.

To sum up, in this first part, concerning the main feature of the district, we defined of our reference district:

- The surface area.
- The total gross floor area of residential buildings for the entire district area.
- The number of population.
- The total groos floor area of the other functions (not residential ones).
- The total cover surface of the district area.
- The number of buildings subdivided in the building typologies.

Next, we could move our attention on the other useful information needed to define the residential and non-residential fileds.

Firstly, we could extrapolate the area of each floor for each typology of building dividing the total gross floor area of each building by the number of floors indicatated by Tabula for each building tyopology. Secondly, we identified for each type of function the thermal and electrical consumptions. Total thermal consumptions were estimated obtaining the consumption in $kWh/m^2$ for each function and each typology of residential buildings, and multiplying them for the total area of the buildings. On the other hand, the total electrical consumptions in the residendial buildings were calculated obtaining the consumption in kWh per occupants of each building, while the non-residential electrical consumptions were estimated multiplying the consumption in $kWh/m^2$ for the total square meters for each function. Regarding the residential buildings, the data of thermal consumption were already enumerated in Tabula. Indeed, in Tabula brochure the residential thermal consumption is estimated for each building of the matrix constituted by the building-age classes and building categories. It is important to pay attention that in Tabula the primary energy need of heating and domestic hot water also includes the electrical primary energy need of electrical auxiliaries. For this reason, to estimate separately the thermal and electrical consumption, we had to separate the consumption of the two typologies of primary energy. Since we know the electrical consumption of the auxiliaries, thanks to the information available in Tabula, after having transformed it in primary energy, it was possible to substract it to both the heating and domestic hot water obtaining the primary energy need excluding the electrical need.

We had to create energy models of buildings in two cases: of the ones on which we decided to apply retrofits and of the ones that we decided to connect to district heating. Indeed, it was necessary to reproduce faithfully these buildings features in order to obtain energy models with the same consumption data given by Tabula. In the first case, to have in the next phases the possibility to apply retrofit measures on the envelope and the technical systems. While, in the second case, to estimate the consumptions of the buildings conncted to the district heating. The program chosen for the creation of energy models was MasterClima.

Another relevant design choice involved the fuel used for each building typology. We decided to keep the same fuels and technical systems that are suggested for each category building and age-class building in Tabula, nevertheless we made some changes to remain faithful to Turin situation. Gas oil has been selected for a small percentage of residential buildings, while the other buildings were divided between natural gas and connection to distric heating. The number of buildings connected to district heating were decided following the data concerning the total volume of the buildings connected to district heating in Turin, available in [11]. All residential buildings consumptions were calculated dividing them between final buildings consumption and primary energy need for each energy carrier. Then, the electric and thermal consumption of non-residential buildings were also estimated, considering the average consumption of these types of functions.

These first steps were fundamental to achieve a complete definition of the main features and consumptions of the buildings of the reference district. Hence, the consumptions of the total amount of buildings that characterize the district were estimated. Furthermore, thanks to the conversion factor in primary energy, we manage to divide the primary energy calculated, in renewable and non-renewable one. Eventually, the total CO2 emissions of the buildings sector were obtained by the data extrapolated by MasterClima, as it is possible to estimate them multiplying the emission factor of CO2 of every energy carrier for its energy consumption. Furthermore, we also considered the emissions of the particulate matter PM10, estimating its production for all the energy consumption of the sector.

**4.2.1.3. Mobility sector**

As long as mobility is concerned, we decided to focus our attention on cars, considered as private vehicles, and on buses as public means of transports, since they are the most diffused ones. Firstly, the number of cars owned by inhabitants of the district were obtained rescaling them to the number of cars per inhabitants in Turin. Then, we needed to better specify the typology of fuels used for each private vehicles and to subdivide them into Euro categories. These lasts are showing the progression of the acceptable limits of the exhaust emissions of the vehicles in European Union members. Thanks to sustainable mobility plan of Turin [12], which provides the number of cars of the city, divided according to the typology of fuel and the Euro category, we distributed cars in the district according to the same proportion. Afterwards, to better define the current state of the reference project, we estimated the consumption of fuels of cars, their costs and their $CO_2$ and PM10 emissions. Moreover, analysing the Turin area previously selected to define the street framework of our reference district, we noticed the presence of four different lines of buses. Since street framework was defined by this area, we decided to design the same numbers of bus lines in our reference district. After having drawn these lines on the district plan, we determine the kilometres travelled by each line. Furthermore, we hypothesized the average frequency of buses in the different lines and consequently it was possible to estimate the kilometres travelled per day by buses in the entire district, their consumption and their emissions. Even the number of passengers was estimated considering the average of passengers per kilometres on Turin buses. To obtained all the data described, we exploited the information available in [12].

#### 4.2.1.4. Waste sector

Concerning waste management, we decided to evaluate the kilometres travelled by rubbish trucks in the district. Indeed, as rubbish has to be collected every day in the entire district, they have a negative impact on the total fuel consumption and above all on the public expenditure and $CO_2$ and PM10 emissions. Even in this case, the kilometres travelled per day by rubbish trucks were calculated estimating the kilometres of the streets of our district. Then, we calculated the consumption of fuel and $CO_2$ and particules matters emissions connected to a small rubbish truck.

#### 4.2.1.5.Street lighting sector

The last sector considered was the public street lighting. After having located street lights approximately every 50 meters, we selected the most frequent typology of lamps. Information regarding the city of Turin were found in [13]. With the subdivisions in different lamps, we estimated the electrical consumption for each of them and their $CO_2$ emissions.

### 4.2.2. Measures identification

After having defined the current situation of the district, calculating its consumption, $CO_2$ and PM10 emissions for each energy carrier and sector, we started thinking about different ways to renovate the area reaching the desired reduction of consumptions and emissions. For each sector we identified more than one intervention. For buildings sector, four different measures have been established, while for the other three sectors two interventions were analysed. Energy savings, $CO_2$ and PM10 emissions reduction were taken into consideration for all the measures described, comparing them with the current state of our reference district.

#### 4.2.2.1. Buildings sector

Since buildings sector has a huge influence on the district, we decided to provide four different measures for this sector. As already said, the first step was to recreate the energy models of the current state of buildings thanks to MasterClima. The main data of the buildings were extrapolated by Tabula [2], [3] and inserted in MasterClima. The main goal was to obtain approximately the same result for energy need and primary energy need both for heating and domestic hot water as the ones expressed in the reference buildings of Tabula. After that, the files of the current state of the buildings were copied and the data connected to the retrofit that had to be applied were changed. We decided to exclude from the retrofit measures all the categories of buildings built before 1945 and after 2005. Indeed, it is possible to consider buildings before 1945 protected for their historical-artistical value and the ones built after 2005 with features that already respect the current Italian regulations on buildings energy efficiency. For these two reasons, we will only consider all the categories of buildings constructed between 1945 and 2005. We opted for apply renovations firstly on buildings envelope. Indeed, all the buildings were submitted to envelope efficiency improvement while, according to the four different measures, every building had different interventions connected to the technical installation. The three options foreseen were the improvement of efficiency of the boilers powered by natural gas, the extension of district heating and the installation of heat pumps jointed with photovoltaic panels systems. From now on we will call the four meausures applied on buildings: Carbon Base, Carbon Advanced, Electric Base, Electric Advanced.

First of all, all the buildings in all the four measures, that were submitted to a change of the technical system, will also be submitted to the efficiency of the envelope. Concerning the envelope retrofit, we followed the requirements provided by the new rules imposed in the last years concerning the improvement of the building performances [1]. The commitments already existing buildings are:

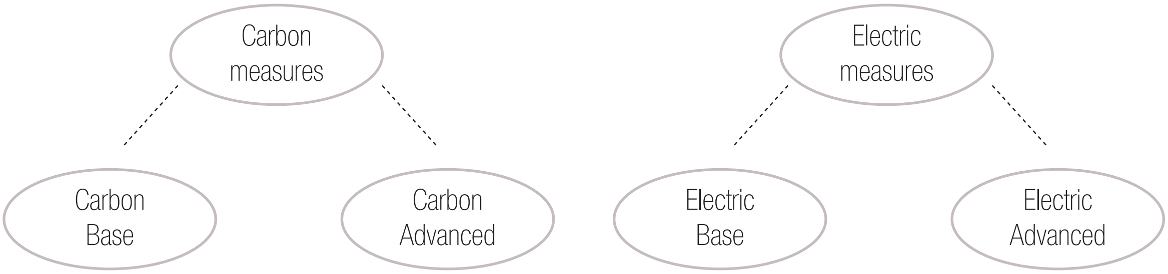
- vertical elements towards the outside and non-heated area with a thermal transmittance of U=0,26 W/mK;
- horizontal elements and roofs towards the outside and non-heated area with a thermal transmittance of U=0,22 W/mK;
- horizontal elements (pavement) towards the outside, non-heated area and a ground with a thermal transmittance of U=0,26 W/

mK;

- windows that satisfy the thermal transmittance of U= 1,40 W/ mK.

Concerning the retrofit of the technical systems, the idea was to extend the existing district heating area in each of the four measures, as in Turin, buildings connected to district heating are increasing year by year, and to provide in the two carbon scenarios the substitution of old boilers with the more efficient condensing ones. Meanwhile in the electric scenario we foreseen the substitution of old boilers with heat pumps and photovoltaic panels systems. The further subdivision between 'base' and 'advanced' is given by the quantity of interventions on buildings installation, excluding the district heating connection. The quantity of technical installations renovated in base measures reflects the real quantity of Turin buildings that are requiring renovations nowadays [14], while in the advanced measures all the installations buildings are renovated. We remember that the interventions are carried out on buildings built between 1945 and 2005.

Figure 2. Subdivision of carbon and electric measures.




As previously said, for each typology of building and retrofit a new file in MasterClima was created. In this way, it was possible to evaluate how the performance of these buildings improves comparing the data of the current state with the ones obtained after the retrofits. The data compared were the ones connected to the energy used and the emission of CO2 and PM10.

#### 4.2.2.2. Mobility sector

After having evaluated the savings on each single typology of building, we moved on the transport mobility of our reference district. We decided to evaluate two possible measure that could be applied to the district:

- the complete replacement of old buses with electrical ones;
- the complete replacement of old buses with electrical ones + the increment of the number of buses.

In the first measure, we supposed to replace all the buses that cross the district every day with electrical ones. The need of electricity for buses to travel all around the district was estimated. Consequently, it was possible to evaluate the CO2 emissions, comparing both energy consumption and CO2 emissions with the current state situation.

Regarding the second measure, it was decided to maintain the electrical buses provided in the first measure and to increase the frequency of buses for each line that cross the district. In this way, the number of buses were increased and consequently the journeys of cars could be considered reduced. It was supposed to increase of 20% the rides of buses, calculating the extra fuel consumed, its cost and the extra CO2 and PM10 emissions produced. On the other side, it was also estimated the reduction of number of cars, of the fuel consumed and the consequent CO2 and PM10 emissions decrease.

#### 4.2.2.3. Waste sector

Concerning waste sector, we decided to reduce the frequency of collection of rubbish in the district. Indeed, the idea was to remove the current waste containers and to install, in the entire district, bigger waste containers partly landfilled in which a larger amount of rubbish can be stored. The two measures decided for this sector were:

- collection of waste twice a week;
- collection of waste once a week.

In the current state of our reference district the collection is foreseen once a day. In both cases, the reduction of fossil fuels used, CO2 emissions and PM10 were estimated.

#### 4.2.2.4. Street lighting sector

After having defined in the current situation the different types of lamps present in the district and the actual consumption of public street lighting, the two level of interventions applied were:

- the substitution of 50% of current lamps with LED ones;
- the total substitution of current lamps with LED ones.

As usual, we evaluated the consumption savings and CO2 and PM10 emissions reductions with respect to the current state.

### 4.2.3. Costs and benefits for the different scenarios

The third phase to define our reference district is characterized by the definition of retrofits scenarios that involve all the sectors considered. All the costs and benefits have to be estimated in order to apply a cost-benefit analysis on these scenarios. In the following paragraphs we are going to clarify how the scenarios are composed and which were the costs and the benefits considered.

#### 4.2.3.1. Scenarios definition

We are now going to define the retrofit scenarios for the entire reference district. Indeed, since the retrofit measures involved more than one field, we had to create scenarios in which we indicated one typology of retrofit for each field. To better clarify, in each retrofit scenario, every sector involved in our reference district (building, mobility, waste and public street lighting sector) has to be characterized by the application of one of the policy before described. In this way, we are going to generate different scenarios that represent different possible solutions to achieve a more sustainable district considering all the different fields. Moreover, the final aim of this thesis is to compare different retrofit scenarios through the economic indicators of the cost-benfit analysis, finding the best environmental, social and economic sustainable solution for the entire district. The best scenario will be characterized by the most performing measures on each sector and will allow to have a positive final cash-flow. This scenario will be the one that allows to have more social benefits than costs.

Since the measures applied on all the sectors are twelve, the number of the scenarios generated will be large if we are going to assume all the combinations among them. Since it is quite challenging to evaluate all the possible scenarios and to compare them with a cost-benefit analysis, we decided to assume six retrofit scenarios choosing in the most convenient way the combinations among the various retrofit measures of the different sectors taken into consideration.

#### 4.2.3.2. Costs

As already described in the previous chapter, in order to carry out a cost-benefit analysis, it is required to consider the costs and the benefits of each specific project. For this reason, in this paragraph and in the next one, we are going to explain which costs and benefits we considered for each scenario.

Concerning costs, we firstly estimate the initial investmet cost that will allow to develop the project planned. Then, we evaluate the running costs that are composed by all the costs which premit to maintane and to make the project work during the years. For instance, we are going to include in this category the maintenance costs and the costs of energy and fuels. Moreover, in the running costs are also included the social costs connected to the production of emissions. After that, we take into account the replacement costs and the residual value at the end of the lifetime of the investment. The first one considers the need to replace certain devices or items during the entire lifetime of the investment because either they do not work more or they become obsolete. Regarding residual value, it is defined as the value that is still attributable to an investment at the end of its lifetime. Indeed, the lifetime of the investment is the period of time chosen to evalutate the total investment and on which the investment can have impact, while the economic life starts with the realization of the project and ends with the exhaustion of the functionality of the project realized. To estimate the residual value at the end of the lifetime of the investment we will use the calculation illustrated in [15]. It allows to determine the depreciation to apply on the initial investment cost of the project.

$$D = \frac{(A+20)^2}{140} - 2,86$$

where D is depreciation and A is the ratio between the lifetime of the investment and its economic life.

#### 4.2.3.3. Benefits

As long as the benefits are concerned, the methodology applied is to evaluate the economic value of some benefits considering the entire district and to monetize other benefits regarding only one of the specific sectors analysed. Indeed, we decided to monetize the savings for the avoided $CO_2$ and $PM_{10}$ emissions considering all the sectors that influence the scenarios toghether. While, the other benefits analysed are more specific for each sector. To estimate the monetary value of the emissions avoided of $CO_2$ and $PM_{10}$, we follow the values available in [16] and [17]. Furthermore, for each sector we take into consideration the costs avoided for the maintenance of technical devices, if the new ones require less maintenance than the older ones.

Regarding the buildings sector, we consider the costs avoided thanks to the savings of energy. Indeed, with the improvement of buildings energy performances, the reduction of energy bills are drastic and we can consider as a significant benefit the savings obtained thanks to the reduction of the different energy sources consumptions.

Moreover, the retrofit on buildings assumed in the various groups of measures will foresee large initial investment costs. On one hand, these are negative for costs, while on the other hand they have a positive side as they generate new green jobs. Indeed, among the benefits connected to buildings sector, we also considered the creation of new jobs that increases the employment rate and the savings obtained thanks to the reduction of unemployment subsidies. Lastly, we took into account the increments of the real estate market values of the building stock due to the improvement of its energy performance.

Concerning mobility and waste sectors, we estimate the costs avoided for the reduction of fuel use. Moreover, we also consider the gains from the increment of tickets bought for the use of buses. Regarding public street lighting sector, we monetize the costs avoided thanks to the reduction of energy consumption.

In order to make everything clearer, to monetize benefits, we always consider the difference between the results obtained in the current state analysis and the ones obtained in each analysed scenario. This difference is then considered as a cost avoided for the society and it obviously represents a benefit.

### 4.2.4. Economic indicators of CBA

Before describing the methodology applied to carry out the cost-benefit analysis, we underline that this typology of economic analysis has the aim to select projects that gives the best benefits, compared to the costs, to the entire society. It is relevant to define this point as all the values are estimated considering costs and benefits for a whole community. After having defined the total costs and benefits for all the scenarios, we can move forward with the creation of the matrix of the cost-benefit analysis for each of them. Indeed, we are going to insert in the columns the time frame of the lifetime of the investment while in the rows, all the costs and benefits in the specific period of the investment [15] . With the definition of the costs and benefits in a specific period, we can determine the cash flows and the economic indicators in every moment of the investment to allow the comparison among the different scenarios. The economic indicators evaluated were the ones already enumerated in the third chapter:

- Economic Net Present Value (ENPV): the difference between the discounted total social benefits and costs, $ENPV = \sum_{t=0}^{n} Ft \times (1+i)^{-1}$;
- Economic Rate of Return (ERR): the rate that produces a zero value for the ENPV, $\sum_{t=0}^{n} Ft \times (1+i)^{-1} = 0$ ;
- Benefit/cost ratio (B/C ratio): the ratio between discounted economic benefits and costs; $B/C = \frac{\frac{\sum_{t=0}^{n} Bt}{(1+s)^t}}{\frac{\sum_{t=0}^{n} Ct}{(1+s)^t}}$ .

In our analysis we compare these three economic indicators obtained for each scenario, to decide which will be the best one to allow a social and economic sustainable investment.

## 4.3. Bibliography

[1] V. Corrado, I. Ballarini, S. P. Corgnati, Building Typology Brochure - Italy. Fascicolo sulla Tipologia Edilizia Italiana, 2014. Available at: http://www.building-typology.eu/downloads/public/docs/brochure/IT_TABULA_TypologyBrochure_POLITO.pdf, last access: May 2018.

[2] TABULA webtool. Available at: http://webtool.building-typology.eu/#bm, last access: May 2018.

[3] MC 11300 (MasterClima 11300). Available at: http://www.masterclima.info/page/Software.aspx, last access: March 2018.

[4] G. Vergerio, La questione energetico-ambientale-economica nell'edilizia residenziale: Sviluppo di una metodologia di valutazione semplificata per interventi a scala urbana, Polytechnic of Turin, 2017.

[5] Città di Torino, Sezioni di censimento, 2017. Available at: http://aperto.comune.torino.it/?q=node/113, last access: December 2017.

[6] Città di Torino, Geoportale del Comune di Torino. Available at: http://www.comune.torino.it/visualizzatore/, last access: December 2017.

[7] G. Mutani, C. Delmastro, M. Gargiulo, and S. P. Corgnati, Characterization of building energy consumption at the urban scale, Energy Procedia 101 (2016) 384–391.

[8] C. Delmastro, G. Mutani, and S. P. Corgnati, A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale Energy Policy 99 (2016) 42–56.

[9] DM 18/12/1975 - Norme tecniche aggiornate relative all'edilizia scolastica, ivi compresi gli indici di funzionalità didattica, edilizia

ed urbanistica, da osservarsi nella esecuzione di opere di edilizia scolastica. Available at: http://www.edscuola.it/archivio/norme/decreti/dm181275.html, last access: January 2018.

[10] Città di Torino, InformAmbiente. Available at: www.comune.torino.it/ambiente/energia/fonti_rinn/integrazione-edificio-impianto.shtml, last access: Febraury 2018.

[11] Città di Torino, Piano urbano della mobilità sostenibile. Sistema della mobilità in città. BANCA DATI - Scenario di riferimento, 2008. Available at: http://www.comune.torino.it/geoportale/pums/cms/http://www.comune.torino.it/geoportale/pums/cms/images/files/introduzione/PUMS_ALL2_SISTEMA_MOBILITA_IN_CITTA_tabelle.pdf, last access: November 2017.

[12] Gianpaolo Roscio, Illuminazione pubblica.L'eseperienza di Torino, intervento al convegno "Illuminazione pubblica. Un'opportunità rilevante di risparmio economico ed efficienza energetica", 11 Dicembre 2014.

[13] DM 26/6/2015 - Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici, Allegato I, Criteri generali e requisiti delle prestazioni energetiche degli edifici. Available at: http://www.sviluppoeconomico.gov.it/index.php/it/normativa/decreti-interministeriali/2032966-decreto-interministeriale-26-giugno-2015-applicazione-delle-metodologie-di-calcolo-delle-prestazioni-energetiche-e-definizione-delle-prescrizioni-e-dei-requisiti-minimi-degli-edifici, last access: Febraury 2018.

[14] ENEA (Agenzia Nazionale Efficienza Energetica), Rapporto Annuale

2017. Le detrazioni fiscali del 65% per la riqualificazione energetica del patrimonio edilizio esistente, 2017. Available at: www.anit.it/wp-content/uploads/2017/08/Detrazioni-65-2017.pdf, last access: Febraury 2018.

[15] Ri. Roscelli, Manuale di estimo. Valutazioni economiche ed esercizio della professione, Novara, 2014.

[16] Commission delegated regulation (UE) n.244/2012 of 16 January 2012. Available at: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex:32012R0244, last access: June 2018.

[17] U. Schirpke, R. Scolozzi, and C. De Marco, Modello dimostrativo di valutazione qualitativa e quantitativa dei servizi ecosistemici nei siti pilota. Parte 1: metodi di valutazione, EURAC, Bolzano 2014.

# CHAPTER 5
# Reference district in Turin

# 5. Reference district in Turin

In this chapter we are going to better describe how we defined the reference district for the city of Turin, which were the retrofit measures applied and how the analysis of the costs and the benefits influences the various scenarios. As already said, the aim of the first part of the thesis was to analyse with a theoretical approach the different measures and policies that can be applied in the development of a more sustainable society, to understand the approach of a cost-benefit analysis and which are the main features of the co-benefits involved in urban projects. While, in the second part we have defined the methodology to design a reference district and we introduced the retrofit measures and the cost-benefit analysis.

The idea to take into consideration an area with the average dimension of a district was connected to the willingness of reproducing and analysing the main features of an urban system. Indeed, in our reference district we are going to involve different urban fields so that we consider a wider analysis compared to the only buildings sector. Moreover, we are going to outline a district, which can be identified as a reference one in the city of Turin, as its features will represent the entire city. After the definition of the current state, we are going to define different ways to achieve a more sustainable district and to compare the results obtained with the application of these policies with the ones obtained by the current state. In fact, the aim is to apply to the city of Turin different retrofit scenarios that represent possible solutions for a sustainable development, to define their energy consumptions, their emissions and their costs and benefits. After having compared all the energy consumptions data extrapolated by the manifold measures applied and their consequent production of $CO_2$ and $PM_{10}$ emissions, we will create various possible scenarios composed by one measure applied on each of the four fields. In the last step, we will then evaluate the costs and benefits connected to these scenarios, in order to carry out the cost-benefit analysis.

## 5.1. Definition of the current state

The first step was the definition of the features of our reference district that could become representative for the entire city of Turin. Indeed, first of all, we had to define the current state characteristics of the district to compare them with the results obtained after the retrofits provided in the different sectors. Our reference district had to be characterized by the average main features of the city of Turin as the idea was to develop a district that represents, not only the framework of the entire city, but an average of the energy consumptions and $CO_2$ and $PM_{10}$ emissions typical of an area of the city with the same dimension. In the next paragraphs, starting from the district framework definition, we are going to define the main features of each of the sectors considered: buildings sector, mobility sector, waste sector and public street lighting sector. The main goal of this first part was the definition of the energy consumptions considering the different energy carriers and their $CO_2$ and $PM_{10}$ emissions, analysed separately and together the different sectors.

### 5.1.1 District framework definition

First, we started from the definition of the district and its street framework. It was necessary to do it in order to locate, draw and better understand the spatiality of the district. For instance, knowing the dimension and drawing the building blocks of the district allowed checking the correct quantity of buildings in the district. Moreover, after having characterized the streets structure it was easier to evaluate the presence, the features and the paths of the public means of transports. To draw the district framework, we had to identify an area of Turin to take inspiration from the structure form. This is why, we decided to select an area of the city with a dimension, a heterogeneity of building stocks and a density population that could be representative for our study, and that could be an average for the city of Turin. Therefore before choosing this area, we analysed the building stock of Turin, the distribution of the different typologies of buildings in the city, its population density and how it varies in the entire city of Turin. After this study, the chosen area is the one located in the south of City Park Pellerina among Giacomo Medici Street, Lecce Street and Monte Grappa Street.

The area chosen has a surface of 13 average census sections. Indeed, this dimension was considered proper to develop a project that can involve different fields and can recreate a small urban system with all its main features. The average of the census sections dimension was obtained by the data available in [1]. The surface of our reference district will be the same of the one of the selected area in Turin:

**Area → 0,438 km²**

Then, we gathered information about the number of inhabitants of the selected area in order to define the population of our reference district with the same number of inhabitants. Thanks to Turin Geoportal [2], this data was estimated summing up the number of inhabitants for each census section inside the interested area.

**Population → 8.975 inhabitants**

The number of inhabitants was a fundamental data in order to estimate useful information concerning buildings, mobility and waste. The first sector we are going to describe is the buildings one.

### 5.1.2. Buildings sector

Starting from the number of inhabitants, we could obtain the total area covered by residential buildings by multiplying the number of inhabitants for the square meters required for each person. Indeed, 34 $m^2$ per inhabitants are provided in the Regulatory Plan of the city of Turin [3].

**Surface covered by residential buildings ⟶ 305.143,80 $m^2$**

Since the idea was to design a reference district as plausible as possible, a mix of functions had to be provided. The non-residential functions were selected among the most prevalent ones installed in urban systems. We decided to include some small commercial activities, offices and one school. Again, to determine the total surface used for each function, we followed the Turin average. Since in Turin the area covered by offices and small commercial activities is respectively approximately 2% compared to the sum of the buildings surface covered by residential functions and these other two [4], we assigned the same percentage to the reference project. Concerning the school complex, the typology of school for the district were chosen using the Istat Data of Piedmont Region [5], comparing them to our reference district. The two typologies of school selected were the nursey school and the primary school as respectively they are provided every 2.657 inhabitants and 3.220 inhabitants. While high schools are expected for larger areas with a major number of inhabitants. For these reasons, for our reference district we decided to provide a school complex composed by a nursery school and a primary school. To determine the dimension of this school complex, the rules of the Ministerial Decree of 18th december 1975 [6] was followed. We estimated a dimension of 8.660 $m^2$, as 22 $m^2$ and 25 $m^2$ per pupil are planned for nursery and primary school [6].

**Surface covered by offices → 6.838 m²**

**Surface covered by small commercial activities → 5.272 m²**

**Surface covered by school complex → 8.660 m²**

To sum up, the total covered area of the district is:

**Total cover surface → 325.931,80 m²**

Having defined the total covered area of the district was important to distribute the total surface among the different typologies that characterize the building stock. As already described in the previous chapter, Tabula [7] was used to define the building stock of our reference district. Tabula pinpoints 32 different typologies of buildings that represent the Italian building stock and analyses each of them defining their dimensional features. The challenge at this point was to distribute the total buildings surface previously calculated, among the different typologies of buildings. First of all, we underlined that the areas of small commercial activities and offices were inserted in the same buildings in which the residential function is located, while the school complex was located in a separated building. For this reason in the following distribution the school complex is not included. Moreover, it is important to remember that the 32 typologies of buildings are divided into 4 building categories and 8 building age-classes characterized by different periods of construction. The four building categories are apartment blocks (AB), multi-family houses (MFH), terraced-houses (TH) and single-family houses (SFH), while the eight building age-classes are: before 1900, 1901-1920, 1921-1945, 1946-1960, 1961-1975, 1976-1990, 1991-2005 and after 2005. Before using Tabula data, we analysed the information about the building stock of Turin available in [4] and [8], regarding the number of buildings and their surfaces. Indeed, these articles are focused on Turin city and the quantity of its number of buildings and their surfaces. We then had to compare the information in [4] and [8] with the one available in [7], as in [4] and [8] the typologies of buildings are 40 (the same 4 categories of Tabula and 10 building age-classes), while in [7] there are respectively 4 and 8 classes. This difference is given by the fact that in [4] and [8] the analysis of the Turin building stock is adapted to the building age-classes used for the census, while the subdivision in [7] represents specific building system techniques that most of the time correspond to important laws and rules [9]. As already done in [9], the surface of Turin buildings divided in 10 building age-classes were redistributed in the 32 buildings age-classes of Tabula. The correspondence is illustrated in Table 1.

Table 1. Correspondence between the two buildings age-classes subdivision.

| Turin data | Tabula |
| --- | --- |
| -1900 | -1900 |
| 1901 - 1918 | 1901 - 1920 |
| 1919 - 1945 | 1921 - 1945 |
| 1946 - 1960 | 1946 - 1960 |
| 1961 - 1970 | 1961 - 1975 |
| 1971 - 1980 | |
| 1981 - 1990 | 1976 - 1990 |
| 1991 - 2000 | 1991-2005 |
| 2001 - 2005 | |
| 2006- | 2006- |

G. Vergerio, La questione energetico-ambientale-economica nell'edilizia residenziale: Sviluppo di una metodologia di valutazione semplificata per interventi a scala urbana, Polytechinic of Turin, 2017.

After this redistribution, we could extrapolate the average area for each building typology of Turin considering the subdivision in 32 typologies of

Tabula. Moreover Tabula web tool and brochure [7], [10] is used to define the energy models and building consumptions of each building typology in kWh/m² with the aim to multiply this value for the total square meters of each building typologies of Turin given by [9].

The percentage of distribution of the total covered surface by buildings among different buildings typologies was acquired by the data present in [9]. The total covered area considered was 317.253,80 m², as school complex was treated separated by other buildings. Thus, the total number of buildings of the district are:

**Number of buildings → 283 + 1 school complex**

Moreover, from Tabula we could extrapolate the number of floors for each typology.

Afterwards, we draw the district buildings. We kept the street framework of the Turin area selected at the beginning and in that urban pattern we located the buildings. Furthermore, the division between higher and lower buildings was maintained as we arranged the single-family houses and terraced-houses in the northern area of the district, and the apartment block and multi-family houses in the southern part. The school complex of our reference district was placed in the same location where the school actually is in the area selected. Small commercial activities and offices were spread in the entire district to provide all the area with the same quantity of services. On one hand, shops are located at the ground floor of buildings, while on the other hand offices are at the first floors of the buildings.

In Figure 1, both residential and non-residential functions are shown. The buildings are also illustrated in their subdivision among the different four categories: apartment blocks, multi-family houses, terraced-houses and single-family houses.

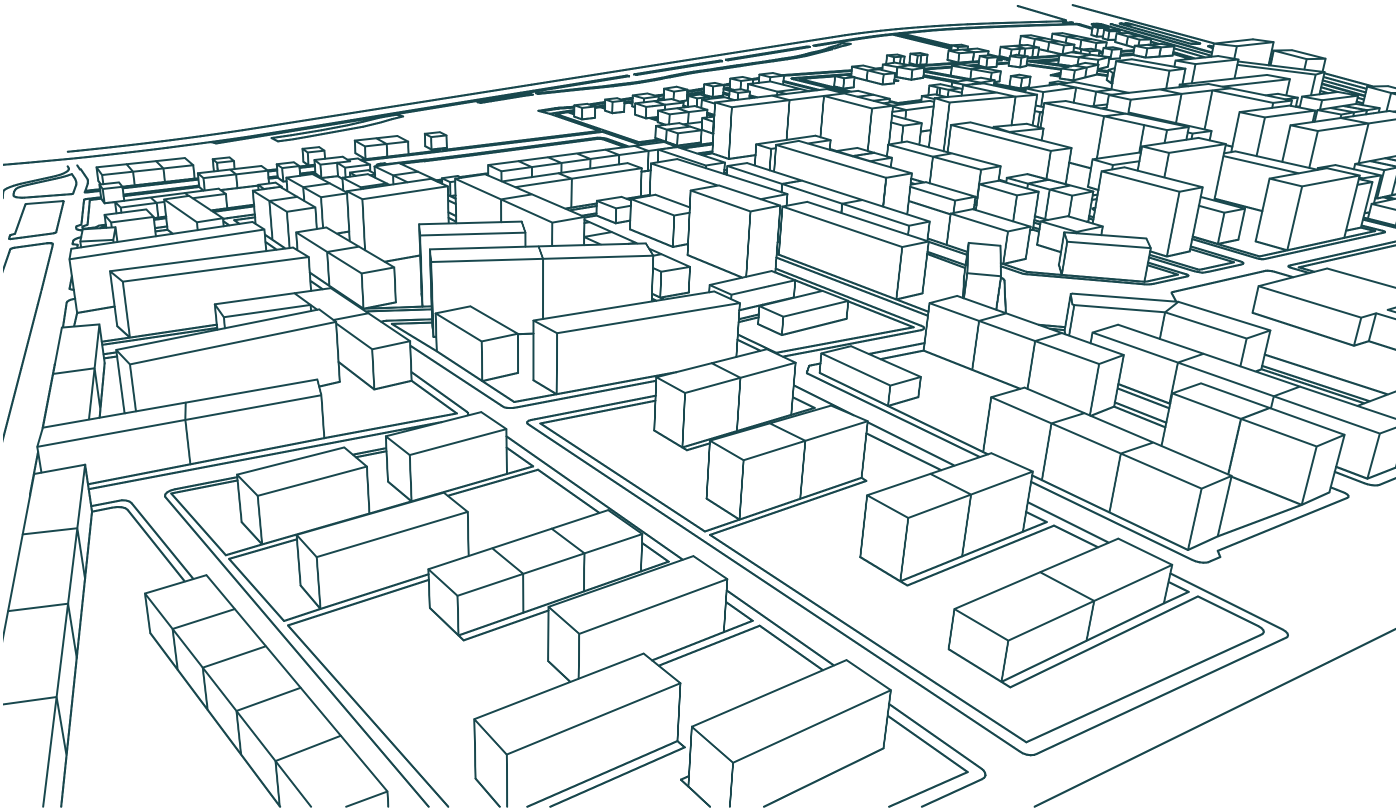
Figure 1. Buildings typologies and non-residential functions, scale 1 : 7.500.


In Figure 2, the various building age-classes are shown and also in this case all the functions are illustrated. Concerning the non-residential functions, we decided to allocate one small commercial activity in each building age-classes for the building category of apartment blocks and multi-family houses.

After having drawn and determined the location of buildings, we outlined

Figure 2. Buildings age-classes and non-residential functions, scale 1 : 7.500.


the main characteristics for each field in the current state of the reference project. In buildings sector, the largest challenge was to estimate the consumption for each energy source, both for heating and hot water, for each building function. We started from the definition of the residential buildings as they are the most numerous ones. The first step was to define the type of fuel used for each typology of building and to decide where to locate the district heating network to connect buildings. In Tabula [7], the type of fuel and the typologies of boilers are illustrated for all the 32 types of building. We decided to follow as faithfully as possible Tabula information, but since in this tool district heating is not considered, we had to make some changes. Indeed, Turin is one the cities with the largest number of buildings connected to district heating in Europe and for this reason it is fundamental to include this technology inside our case study. From [11], we found out that currently the 40% of the total volume of residential buildings in Turin is connected to district heating and the same percentage was reported in our district. Thus, we placed the district heating network in an area such that 40% of the total volume of residential buildings were connected. At variance, the rest of buildings use gas oil or natural gas. As gas oil boilers are almost not used anymore, we decided to keep them in only one typology of building, covering the 4% of the buildings, both for heating and domestic hot water. The rest of the buildings consequently use natural gas as energy carrier. Moreover, some typologies of buildings use electricity to produce domestic hot water as they have individual water heaters for each apartment.



In the following map, Figure 3, the subdivision between gas oil, natural gas boilers and district heating connected buildings is shown. We have to specify that the energy source here defined are referred to heating system. Indeed, some buildings are using the same energy source or district heating also for domestich hot water, while others are using electricity. In this map this distinction is not pointed out. Moreover, concerning offices and small commercial activities they are using the same energy source of the building in which they are located, while the quantity of consumption will be differentiated from the residential function.

Figure 3. Main energy source and district heating area, scale 1 : 7.500.

Afterwards, the next goal was to estimate the consumption for each typology of buildings and then for the non-residential function. In Tabula the energy need Qnd and primary energy need QP for both heating and domestic hot water are enumerated. This data are provided in $kWh/m^2y$ and can be after multiplied for our residential square meters to obtain the total energy consumptions for each building typology. We had to reproduce the energy models in MasterClima in two cases:

- For all the category of buildings that are built between 1945 and 2005. Moreover, among these buildings are also included the ones that are really connected to the district heating in the current state. These models are necessary to apply the energy efficiency improvement provided for each measure in the next steps.
- For all the categories of buildings, built before 1945 and after 2006, that are connected to the district heating in our district current state, as Tabula does not provide this type of technical system.

All the geometrical information, dimensions and characteristics for every construction element, and technical installation data regarding buildings were extrapolated from [7] and [10]. The procedure to create the energy models with MasterClima was learnt by the detailed description reported in [9]. With that method we could obtain the energy models needed. Concerning the other buildings typologies, we could use the values of primary energy need in $kWh/m^2y$ provided by Tabula.

To check the accuracy of energy models generated, we compared Tabula data concerning energy need Qnd and primary energy need QP for both heating and domestic hot water with the ones obtained in the energy model created with MasterClima. Energy need Qnd can be directly compared, while we have to clarify some points about the comparison of primary energy need QP. First of all, the conversion factor in primary energy need are different in Tabula and MasterClima, as the first tool use the conversion factor used in 2011, while MasterClima uses the ones that are illustrated in the Ministerial Decree 26th June 2015 [12]. Moreover, to be compared they had both to be reported net of electricity primary energy. As already explained, the generation of these energy models and the comparison between the final results in Tabula and the ones obtained in MasterClima is needed to evaluate the precision of the models created. The objective was to use them later, to apply retrofit interventions, adding insulations to envelope and changing technical installations, with respect to the the current state and to estimate the improvement of the energy performances due to these retrofits. In the following charts this comparison is illustrated for the buildings built between 1946 and 2005.

**1946-1960 AB**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 157 | 146,5 |
| Energy need QW,nd [kWh/m²] | 17,9 | 19,1 |
| Primary energy need QH,nd [kWh/m²] | 234 | 222,4 |
| Primary energy need QW,nd [kWh/m²] | 61,3 | 65,6 |

**1961-1975 AB**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 134 | 128,6 |
| Energy need QW,nd [kWh/m²] | 18,2 | 19,3 |
| Primary energy need QH,nd [kWh/m²] | 226,8 | 219,1 |
| Primary energy need QW,nd [kWh/m²] | 49,5 | 53 |

**1976-1990 AB**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 67,6 | 66,9 |
| Energy need QW,nd [kWh/m²] | 17,4 | 18,2 |
| Primary energy need QH,nd [kWh/m²] | 94,5 | 92,8 |
| Primary energy need QW,nd [kWh/m²] | 23,4 | 24,9 |

**1991-2005 AB**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 62,9 | 55,6 |
| Energy need QW,nd [kWh/m²] | 17,1 | 17,8 |
| Primary energy need QH,nd [kWh/m²] | 77,7 | 68,2 |
| Primary energy need QW,nd [kWh/m²] | 23,9 | 25,3 |

**1946-1960 MFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 170 | 173,9 |
| Energy need QW,nd [kWh/m²] | 17,7 | 18,6 |
| Primary energy need QH,nd [kWh/m²] | 240,6 | 264,8 |
| Primary energy need QW,nd [kWh/m²] | 60,3 | 97 |

**1961-1975 MFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 153 | 157,7 |
| Energy need QW,nd [kWh/m²] | 16,9 | 17,7 |
| Primary energy need QH,nd [kWh/m²] | 200,2 | 207,4 |
| Primary energy need QW,nd [kWh/m²] | 26,2 | 27,8 |

**1976-1990 MFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 105 | 96,8 |
| Energy need QW,nd [kWh/m²] | 16,6 | 17,3 |
| Primary energy need QH,nd [kWh/m²] | 132,3 | 128,4 |
| Primary energy need QW,nd [kWh/m²] | 23,3 | 24,6 |

**1991-2005 MFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 70,3 | 68 |
| Energy need QW,nd [kWh/m²] | 17,9 | 19 |
| Primary energy need QH,nd [kWh/m²] | 104,3 | 101 |
| Primary energy need QW,nd [kWh/m²] | 24 | 26 |

**1946-1960 TH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 173 | 171,8 |
| Energy need QW,nd [kWh/m²] | 15,8 | 16,2 |
| Primary energy need QH,nd [kWh/m²] | 258,8 | 257,4 |
| Primary energy need QW,nd [kWh/m²] | 46,6 | 37,2 |

**1961-1975 TH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 241 | 232,6 |
| Energy need QW,nd [kWh/m²] | 16,6 | 17,1 |
| Primary energy need QH,nd [kWh/m²] | 341,7 | 330,6 |
| Primary energy need QW,nd [kWh/m²] | 36,9 | 36,8 |

**1976-1990 TH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 113 | 116,6 |
| Energy need QW,nd [kWh/m²] | 15,3 | 15,7 |
| Primary energy need QH,nd [kWh/m²] | 158,9 | 160,9 |
| Primary energy need QW,nd [kWh/m²] | 51,4 | 52,9 |

**1991-2005 TH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 85,1 | 92,4 |
| Energy need QW,nd [kWh/m²] | 15,8 | 16,2 |
| Primary energy need QH,nd [kWh/m²] | 125,5 | 135,3 |
| Primary energy need QW,nd [kWh/m²] | 31,1 | 32,4 |

**1946-1960 SFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 257 | 264,4 |
| Energy need QW,nd [kWh/m²] | 14,4 | 15 |
| Primary energy need QH,nd [kWh/m²] | 388 | 406,1 |
| Primary energy need QW,nd [kWh/m²] | 42,5 | 48,3 |

**1961-1975 SFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 344 | 339,4 |
| Energy need QW,nd [kWh/m²] | 14,6 | 15,1 |
| Primary energy need QH,nd [kWh/m²] | 486,8 | 484,3 |
| Primary energy need QW,nd [kWh/m²] | 34,3 | 36 |

**1976-1990 SFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 136 | 143 |
| Energy need QW,nd [kWh/m²] | 13,8 | 14,5 |
| Primary energy need QH,nd [kWh/m²] | 222,3 | 234,6 |
| Primary energy need QW,nd [kWh/m²] | 32,4 | 34,3 |

**1991-2005 SFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 92,3 | 99,2 |
| Energy need QW,nd [kWh/m²] | 14,2 | 14,8 |
| Primary energy need QH,nd [kWh/m²] | 120,9 | 131,7 |
| Primary energy need QW,nd [kWh/m²] | 19,1 | 20,3 |

The comparison has been successful as results are similar one from each other. We can also underline that there are some reasons why the results are a bit different one to each other. First of all, the legislation of reference was modified in 2014, after the development of Tabula project, and moreover the variables that are behind this calculation are so numerous that the various approximations applied in the realizations of the models have not helped the results to be utterly equal.

For buildings categories built between 1946 and 2005, connected to distrct heating, we calculated their consumptions after having generated their energy models with MasterClima. Indeed, in this case the energy need, that depends from the features of the envelope, remains exactly the same while we have to change the technical installation to the models already created. Thus, we copy the file already used for these buildings typologies and substitute the old boilers with a substation for the district heating. In Table 2, detailed information about technical data installation to insert in MasterClima are illustrated. Some data are extracted from UNI-TS 11300-2 2014 which is the current relevant legislation for the determination of the primary energy need and performance systems for heating and domestic hot water. At variance, other data were taken from Tabula brochure [7]. In the cases in which only the reference table is indicated, we had to consult for each building these charts as these values depend from different features that change in the different typologies of buildings. On the other hand, the value connected to the circulation pumps are always the same for every building typology.

Table 2. Techincal data installations.

| Heating | | Domestic hot water | |
|---|---|---|---|
| $\eta_e$ --- > | chart 17 UNI-TS 11300-2 2014 | $\eta_e$ --- > | 1 |
| $\eta_d$ --- > | chart 23 UNI-TS 11300-2 2014 | $\eta_d$ --- > | chart 12 Tabula |
| Qaux --- > | 1,6. Circulation pump for centralized installation - chart 11 Tabula | Qaux --- > | 2. Centralized hot water production with circulation pump - chart 16 Tabula |

where:

$\eta_e$ Emission performance [-]

$\eta_d$ Distribution performance [-]

Qaux Power of electric auxiliaries of the system [kWh/m²]

The next step was to give the right size to the substation of the district heating for each apartment block and multi-family house connected to the district heating network. To obtain this value of power we needed to calculate the design thermal load following the legislation UNI EN ISO 12831:2006 [13]:

$$\Phi_{HL} = \Sigma\Phi_T + \Sigma\Phi_V + \Sigma\Phi_{RH} \quad [W]$$

$\Phi_{HL}$ Design thermal load [W]

$\Sigma\Phi_T$ Total heat losses for transmission for heated spaces [W]

$\Sigma\Phi_V$ Total heat losses for ventilation for heated spaces [W]

$\Sigma\Phi_{RH}$ Time to recover of the boiler [W]

Where:

$\Phi_T = H_{tr}\ \Delta\theta_{project}$ $H_{tr} = \Sigma U_i \times A_i \times e_i + \Sigma U_i \times A_i \times b_i$

$\Phi_V = H_V\ \Delta\theta_{project}$ $H_V = V \times \rho \times c_p = V \times 0{,}34$

$\Phi_{RH} = S_U \times f_{RH}$ $S_U$ useful floor area for each building,

$f_{RH}$ from the chart NA.11b of the legislation.

For all the energy models $\Delta\theta_{project}$ is 28°C and $f_{RH}$ is 11W/m².

This calculation needs to estimate the power of the generator to cover all the heat looses for transmission and ventilation in the worst weather conditions and to take into account the intermittence problems of the generator. Htr is given by the thermal transmittance values of each envelope components multiplied by its area and exposure coefficient "e". In the HV calculation the value 0,34 is given by the product between air density and its thermal capacity, which it is given by the net heated volume and hourly air exchange.

Looking back at the definition of energy consumptions of buildings, we underlined that we had also to create energy models for all the categories of buildings built before 1945 and after 2005 that were connected to the district heating in the initial state of the district. Indeed, in these cases we had to create a model in which the features of the envelope were taken from TabulaWebTool [10], while the technical installation is not the same. Indeed, the building is connected to a substation of the district heating network. To size the substation of each building, the same calculation previously described for the design thermal load had to be applied. In the following charts we are going to indicate in which buildings this procedure was applied and we demonstrate the accuracy of the models created comparing, as already done in the energy models of buildings built between 1946 and 2005, results obtained with Tabula and the ones obtained with the energy models realized with MasterClima. For these models, the data compared is only the energy need Qnd both for heating and domestic hot water. Indeed, primary energy need QP obtained by the models of MasterClima can not be compared with the one of Tabula as the first one provides the use of district heating, while the second one uses the technical installation expected by the building typologies of Tabula. Energy need Qnd can be compared as it only involves features concerning the different components of the envelope that are the same in Tabula and in MasterClima models.

**1901-1920 AB**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 194 | 196,4 |
| Energy need QW,nd [kWh/m²] | 18,1 | 19,3 |

**1921-1945 AB**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 162 | 166,6 |
| Energy need QW,nd [kWh/m²] | 18,1 | 19 |

**-1900 MFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 250 | 240,1 |
| Energy need QW,nd [kWh/m²] | 16,1 | 16,2 |

**1901-1920 MFH**

| | Tabula | MasterClima |
|---|---|---|
| Energy need QH,nd [kWh/m²] | 199 | 207 |
| Energy need QW,nd [kWh/m²] | 17,9 | 18,4 |

The last point to underline is that in apartment buildings, in which the domestic hot waters was produced individually by water heaters, this typology of system was kept. Indeed, it was evaluated too complex and expensive to remove water heaters in each flats and to centralize the technical system. In these cases, heating system was connected to district heating while domestic hot water was kept separated for each flat with the use of water heaters.

The definition of buildings sector was quite articulated as many models had to be create and the data to extrapolate from them needed to be analysed. The data taken into account for each model were: the energy need Qnd, the primary energy need QP and the final consumption Qdel for each energy source. All these data were present both for heating and domestic hot water. Moreover, primary energy need QP was divided between renewable primary energy $Q_{P,ren}$ need and non-renewable primary energy need $Q_{P,nren}$. All these data extracted by MasterClima, for the buildings for which the models were created, and by Tabula for the other typologies of buildings for which it was not necessary to create a energy model, were expressed in kWh/m²y. After that, we evaluated the total consumption of this sector in the entire district. Indeed, the results obtained in kWh/m²y were multiplied for the area of all the buildings of each building typologies.

Another important data that was obtained for each building typologies is the quantity of $CO_2$ emissions expressed in kg$CO_2$/m²y. From MasterClima energy models these data can be directly obtained. At variance for the buildings for which a energy model was not needed, $CO_2$ emissions were obtained through calculations. The procedure to obtain $CO_2$ emissions was applied to the data before acquired, by multipling the final consumption of each energy source by an emission $CO_2$ factor. Here the emission $CO_2$ factors used are enumerated:

- Natural gas: 0,1969 kg/kWh

- District heating : 0,3088 kg/kWh
- Electricity : 0,4332 kg/kWh
- Gas oil : 0,2642 kg/kWh

Also in this case, the values obtained $kgCO_2/m^2y$ can be multiplied for the total area of each building typology to determine the total emissions of the entire district for the buildings sector.

We remark that our district also includes non-residential functions and that even for them consumptions have to be estimated. As non-residential functions, except for school, were located inside apartment blocks and multi-family houses residential buildings, energy for heating and hot water are produced with natural gas or thanks to the connection to district heating. For offices and small commercial activities located in buildings, in which district heating connection is provided, the consumption are considered included in the respective residential building as in this case the production of heating and hot water is centralized for the entire building. When natural gas is used, specific consumptions for these functions are considered. For every non-residential function, data founded concern the final consumption $Q_{del}$ for thermal and electricity need. From there, it was possible to calculate the primary energy need $Q_P$ and its renewable and non-renewable part $Q_{P,ren}$ and $Q_{P,nren}$ obtained by the product between the final consumptions of each energy sources and their conversion factor in primary energy need [12]. Furthermore, $CO_2$ emissions could be calculated with the same procedure previously described, too. Concerning small commercial activities data of final consumption for thermal and electricity need were taken from [4], while offices information were found out in [14]. The final consumption of thermal need two data are provided in [14], the first one is related to the offices in the north-west of Italy and the second one is referred to climate zone E and F. We considered the average between these two values. Finally, school final consumptions were found in [4], in the ENEA report [14] and in [15], and also in this case we took the average. In [4] the consumption found was 111 kWh/m²y, in [14] it was 106,5 kWh/m²y related to north-west area of Italy and 102,5 kWh/m²y referred to climate E and F and in [16] it was 115 kWh/m²y. In Table 3, all the final consumptions for non-residential functions are summarized.

Table 3. Consumptions for non-residential functions

| | Shops | Offices | School |
|---|---|---|---|
| FInal consumption Qdel,gas for heating [kWh/m²] | 35,4 | 138 | 110 |
| FInal consumption Qdel,electricity [kWh/m²] | 20,9 | 43 | 16,6 |

We have also decided to estimate the emissions of $PM_{10}$ produced in the entire district and its variation in the various scenarios. For this reason, we evaluated the emission of $PM_{10}$ in the different sector starting from the buildings one. In [17], we find the quantity of $PM_{10}$ produced by each energy source and thanks to these data we can calculate the total emission of buildings sector for the total energy consumption. Below are listed the emission $PM_{10}$ factors

- Natural gas: 0,0067 kg/GJ
- District heating : 0,0067 kg/GJ
- Gas oil: 0,0036 kg/GJ

In the next paragraphs, the results obtained for all the buildings in the current state are listed in comparison with the ones obtained by the retrofit measures.

### 5.1.3. Mobility sector

Another important field that we have taken into account in the definition of the district is the mobility. In fact mobility is, on one side, one of the most relevant producers of $CO_2$ emissions, but, on the other side, it presents a wide range of possibilities to improve its current unsustainable way of act. As already described in the second chapter, thanks to the expansion of information and to the promotion of sustainable means of transport it will be possible to reach easily a model of sustainable mobility. The first challenge in our reference district is to define the current state of mobility concerning both public means of transport and private vehicles. They were both defined thanks to the numerous data referred to the city of Turin.

First of all, regarding public means of transports, we analysed the number of bus lines that cross the selected area of Turin taken into consideration in the first part of the definition of the district framework. Since we kept the street framework of that area, we also decided to maintain the same number of bus lines. Accordingly, the number of lines drawn in the reference district were four. From now on, we will name arbitrarily the four lines of buses: line 1, line 2, line 3 and line 4. In Figure 4, we marked the bus paths in the planimetry of the district. After having drawn all the path travelled by buses, it was easy to estimate the kilometres travelled by each bus in the district.

Moreover, we supposed that buses travel from 5:30 a.m. to midnight with an average frequency of 12 minutes, taking into account that in some hours of the day they are more frequent and in some hours they are less frequent. Furthermore, we have to consider that in Turin bus lines are numerous and with different frequencies of rides depending of the path travelled by buses. Indeed, lines of buses that are covering central areas of the city are more frequent than the ones that travels in the peripheric area. For this reason,

Figure 4. Buses lines, scale 1 : 7.500.


we chose 12 minutes as an overall average. This leads to an average of 92,5 passages per day for each bus line. Counting the passages on both direction the average becomes 185. Below the kilometres travelled by each bus in every bus line are enumerated. Then, they are multiplied by the number of passages to obtain the total distances covered during the entire day for each respective bus line.

**Line 1: 1,47 km ⟶ total distance covered per day: 271,95 km**

**Line 2: 1,45 km ⟶ total distance covered per day: 268,25 km**

**Line 3: 0,66 km ⟶ total distance covered per day: 122,1 km**

**Line 4: 1,16 km → total distance covered per day: 214,6 km**

After having defined the main data of each line crossing the district, we calculated the consumption of fuel, its $CO_2$ emission and the number of passengers that travels on the buses. Another data that had to be found was the number of the typology of buses divided according to the fuel used crossing the district for each line. Indeed, vehicles can be categorized for the fuel used and for different categories indicated as Euro categories, that represent a series of restrictions concerning emissions.

This calculation was possible thanks to the data in [18]. After having analysed these data, it was possible to estimate a percentage of buses for each different typology of fuel. This percentage was reported on the total number of times in which buses cross the district, that are 185, and in this way it was possible to divide the vehicles fleet according to their fuel used. In Table 4 the number of times in which different typologies of buses crossing the district per day and their frequency are listed.

Table 4. Amount of times in which different typologies of buses cross the district.

| | Amount of times |
|---|---|
| Diesel Euro 0 - 1 | 85 |
| Diesel Euro 2 | 36 |
| Diesel Euro 3 | 13 |
| Natural gas | 51 |
| | 185 |

Then, to calculate the total fuel consumption, we needed the consumption of fuel for each typology of bus per kilometre. We found a report [19] in which GTT, that stands for Gruppo Torinese Trasporti, the corporation responsible for the public transportation in Turin, lists the vehicles fleet that circulate in Turin. Furthermore, all the types of buses that are part of public transport in Turin, are described in a detailed way. Indeed, technical features regarding mechanical, dimensional and other characteristics are provided. Among these information, we recovered the consumption per kilometres for each typology of fuel used. As more than one type of bus are using the same fuel, for instance Diesel Euro 0-4, we took an average of the fuel consumed for each type of means of transport.

- Diesel: 0,465 l/km
- Natural gas: 0,58 g/km

Afterwards, we estimated the quantity of $CO_2$ and $PM_{10}$ emissions produced every day by buses that cross the district. $CO_2$ and $PM_{10}$ emissions depend on the kilometres travelled, on the fuel consumed and on the subdivision into the categories Euro. From [18], it was possible to extrapolate the total kilometres travelled by buses daily divided for fuel and 'Euro' categories and the total $CO_2$ and $PM_{10}$ emissions produced for the same categories during an entire day. These data, referred to the city of Turin, can be used to estimate the emissions caused by public means of transport in our reference district. Indeed, proportioning the total kilometres travelled by each category of buses in the city of Turin and their total $CO_2$ and $PM_{10}$ emissions, with the ones travelled by the four lines of buses that cross the district, we quantified the emissions produced in the district by buses every day. We underlined that both fuel consumption and $CO_2$ and $PM_{10}$ emissions are estimated for the only kilometres travelled by each bus line in the district and not for the entire bus rides. In fact, the numbers of kilometres considered to estimate fuel consumption and $CO_2$ and $PM_{10}$ emissions are the ones that each bus line travels inside the district and that was calculated previously.

The last step was the estimation of the number of passengers for each bus line. The main information acquired from [18] regards the passengers per kilometre in the urban area of the city of Turin. As this value is 2.52, we could multiply it by the kilometres travelled for each categories of buses inside the district. The total number of passengers counted is 2210, since the total kilometres travelled are 876.9 km. In the following tables these data are summarized.

Table 5. Main information of buses lines.

**Line 1**

| | Kilometres travelled [km] | Fuel consumed [l] [kg] | $CO_2$ emissions [kg $CO_2$/day] | Number of passengers [-] |
|---|---|---|---|---|
| Diesel Euro 0 - 1 | 124,95 | 58 | 214,76 | 315 |
| Diesel Euro 2 | 52,92 | 24,61 | 94,06 | 133 |
| Diesel Euro 3 | 19,11 | 8,89 | 37 | 48 |
| Natural gas | 74,97 | 43,5 | 127,70 | 189 |
| Total amount | 271,95 | | 473,52 | 685 |

**Line 2**

| | Kilometres travelled [km] | Fuel consumed [l] [kg] | $CO_2$ emissions [kg $CO_2$/day] | Number of passengers [-] |
|---|---|---|---|---|
| Diesel Euro 0 - 1 | 123,25 | 57,3 | 211,84 | 311 |
| Diesel Euro 2 | 52,5 | 24,28 | 92,78 | 132 |
| Diesel Euro 3 | 18,85 | 8,87 | 36,5 | 48 |
| Natural gas | 73,95 | 42,89 | 125,96 | 186 |
| Total amount | 268,55 | | 467,08 | 677 |

**Line 3**

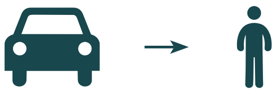
| | Kilometres travelled [km] | Fuel consumed [l] [kg] | CO2 emissions [kg CO2/day] | Number of passengers [-] |
|---|---|---|---|---|
| Diesel Euro 0 - 1 | 56,1 | 26,09 | 96,42 | 141 |
| Diesel Euro 2 | 23,76 | 11,05 | 42,23 | 60 |
| Diesel Euro 3 | 8,58 | 3,39 | 16,61 | 22 |
| Natural gas | 33,66 | 19,52 | 57,34 | 85 |
| Total amount | 122,1 | | 212,6 | 308 |

**Line 4**

| | Kilometres travelled [km] | Fuel consumed [l] [kg] | CO2 emissions [kg CO2/day] | Number of passengers [-] |
|---|---|---|---|---|
| Diesel Euro 0 - 1 | 98,6 | 45,85 | 169,47 | 248 |
| Diesel Euro 2 | 41,76 | 19,42 | 74,23 | 105 |
| Diesel Euro 3 | 15,08 | 7,01 | 29,2 | 38 |
| Natural gas | 59,16 | 34,3 | 100,77 | 149 |
| Total amount | 214,6 | | 373,67 | 540 |

Up to here, all the data enumerated are referred to a working day since the information extracted from the different sources are related to a day. In the following part of the work they will be transformed to annual data to facilitate the comparison with the buildings sector. The main characteristics of each bus lines per day are listed below in Table 5. Total amount of fuel consumed could not be sum up as diesel is expressed in litre, while natural gas in kilograms.

We can now move our attention on the private means of transport, determining the car fleet of our district, its fuel consumption and CO2 emissions. Obviously, the most important information to find was the ratio between the number of cars and the inhabitants in the city of Turin. We found in [18] that one car is present for every 1,54 person.



**1 / 1,54**

For this reason, the total amount of cars obtained, related to our district population, is 5844.

**Number of cars ⟶ 5.844**

Thanks to the data available in [18], it was possible to outline the main features of car fleet of the district and to evaluate the kilometres travelled every day by cars in the district. The information available was the inhabitants of the city of Turin and their numbers of movements per day by car. From these two data, we could obtained the number of movements done by car inside our district, proportioning the number of cars of the entire city and their movements with the number of cars of our district. Thus, the number of movements are 2.831. From [18], we know that the average distance for movement covered with private car inside the city of Turin is 3,47 km. Therefore, multiplying the number of movements for this average distance we obtain the total kilometres travel by car:

**Total kilometres travelled by cars ⟶ 20.232 km/day**

We divided the car fleet of the district according to the fuel used and the Euro category. It was possible since the subdivision into categories of the Turin car fleet is provided in [18]. Thus, a proportion between the total car fleet of Turin and its subdivision in categories was carried out with the car fleet of our district. Then, the total number of kilometres for our district calculated before was divided proportionally between the different categories of cars. The next step was the determination of the consumption of fuel of the total number of kilometres estimated. Here the consumptions of fuel for each kilometre are enumerated:

- Petrol : 0,08 l/km
- Diesel : 0,08 l/km
- LPG : 0,07 l/km
- Natural gas : 0,04 kg/km
- Hybrid : 0,03 l/km
- Electricity : 0,20 kWh/km

We have to underlined that the consumption depends on the kilometres travelled and on the typology of fuel. While, the Euro category does not determine the consumption of cars. The numbers of kilometres covered from each categories of cars were multiplied for the mentioned consumption and the total consumptions of fuels were estimated for the cars of the entire district.

Lastly, we estimated $CO_2$ emissions produced in the district by private means of transport, thanks to[18] where the emissions produced per day per the total kilometres travelled by each category of cars are provided. Here again, we find the emissions produced for one kilometre travelled by each category of cars, thanks to the ratio between the total daily emissions and the total kilometres travelled, and we multiply it for the kilometres travelled by each categories of cars in our district.

**$CO_2$ emissions produced by cars → 6.024,36 kg$CO_2$/day**

### 5.1.4. Waste sector

Concerning waste sector, to understand better what we are going to define in the current state, it is useful to reveal in advance which are the intentions for the application of the sustainable measures. Indeed, the idea was to install underground waste containers to enlarge the size with respect to the usual containers and consequently to increase the amount of garbage contained. With these new waste containers, the frequency of waste collection be decreased. In this way, garbage truck will pick up waste less times than before and will cause less pollution consuming less fuel. It is on this basis that we have defined the current state of the waste sector of our district. We started from the calculation of the garbage trucks needed for our district and the estimation of the total kilometres travelled by them into the district. From [20] we found the number of garbage trucks that work on the entire Turin territory. We could proportion this number considering the surface of our district. Thus, we assumed that the garbage trucks operating in our district are two. We supposed that each of them serve a different area of the district. Then, to estimate the kilometres covered by garbage trucks, we assumed that they travel in every street of the district, estimating almost 7,5 kilometres. In the current state, we assumed that two garbage trucks are collecting waste once a day in all the district and consequently we could estimate the total kilometres:

**Kilometres travelled by garbage trucks → 52,5 km/week**

In this sector it was easier and useful to estimate all the values per week since the sustainable measures will be determined considering weekly variations. We transform all the information in annual values in the next phases, when we need to calculate the total consumptions and emissions in the district.

Afterwards, we considered the consumption of petrol of a truck that is used to collect waste. The value of consumption used was 0,065 litres every kilometre.

**Fuel consumed by garbage trucks → 3,41 l/week**

We assumed that garbage trucks used in the district are of the category 'Euro 3' and we took information concerning $CO_2$ and $PM_{10}$ emissions from [18]. The data considered was 0,32 $kgCO_2/km$ produced. Thus, the total emissions produced per week were estimated.

**$CO_2$ emissions produced by garbage trucks → 16,8 $kgCO_2$/ week**

While, concerning $PM_{10}$ emissions we proportioned the data available in [18] to find the emissions produced by waste sector in our reference district.

#### 5.1.5. Street lighting sector

Public street lighting was the last sector taken into consideration to describe our reference district, its consumptions and emissions. To define the current state of the district, we located one street lamp almost every 50 metres and the total number obtained in the entire district was 351. Then, thanks to [21] and [22] we determined the most frequent typologies of street lamps present in the city of Turin. The three typologies of lightbulbs individuated are high-pressure sodium vapour lightbulbs, mercury vapour lightbulbs and metal halide vapour lightbulbs. Since in [22] the total number of each typology of lamp present in Turin is indicated, we estimated the number of lamps for every typology installed.

**Number of high-pressure sodium vapour lightbulbs → 176**

**Number of mercury vapour lightbulbs → 116**

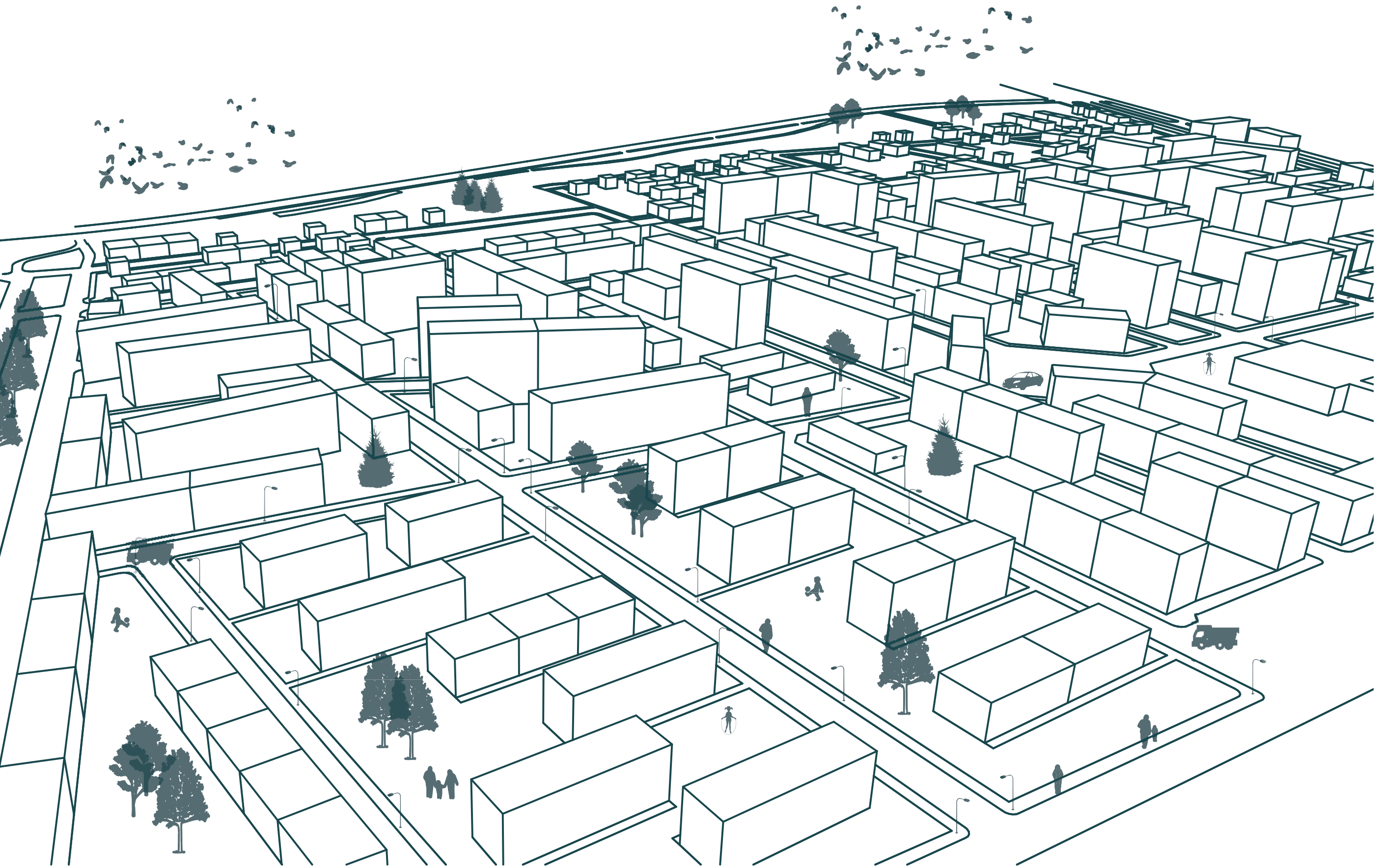
**Number of metal halide vapour lightbulbs → 59**

The total consumption of energy per year was computed, as in [22], the total electricity consumptions per the total number of lamps in Turin divided into typologies are enumerated. Thus, we obtained the electricity consumption for one lamp of each typology per year: an high-pressure sodium vapour lightbulb consumes 0,85 MWh/y, a mercury vapour lightbulb consumes 0,92 MWh/y and a metal halide vapour lightbulb consumes 0,69 MWh/y. Thanks to these data, we could obtain the total annual consumption in our reference district.

**Total electricity consumption → 296,78 MWh/y**

With the same procedure $CO_2$ emissions produced were estimated. Indeed, always in [22], the total emissions produced annually for typology of lamps is expressed. Thus, it was easy too estimate the total emissions.

**Total $CO_2$ emissions produced → 153,13 $tCO_2/y$**



## 5.2. Measures identification

In the first part of the chapter we have defined in detailed how our reference district has been set out and which were the steps to outline an area that could be representative for the entire city of Turin. Firstly, the framework of the district was determined thanks to an average of the data of Turin, then we took into consideration the different sectors of the district: buildings, mobility, waste and public street lighting. Meanwhile, for each sector the main features were outlined in their current state in order to have the possibility afterwards to provide new sustainable measures and interventions. The wide study, regarding already existing and new sustainable policies in the previous chapters, was useful to decide which measures could be applied in our reference district. The idea is that, behind each measure, the primary goal is to decrease as much as possible the consumption of the energy used with the consequent reduction of emissions. Thus, with this goal defined, we can start to think about the better solutions for each sector to achieve our final goal.

### 5.2.1. Buildings sector

The group of measures applied in this sector were four. From a practical point of view, the procedure carried out consisted in the comparison between the consumption results obtained from the energy which define the current state, with respect to the results obtained with the changes related to the different measures. Indeed, the files of MasterClima of the current state were copied and modified according to the retrofits applied to each typology of building. After that, results could be compared.

The applicable measures on buildings sector are several since the field of buildings retrofit is wide. We tried to take into consideration retrofit that could respect the current legislation [12] and that can meet the realistic decisions taken from the city of Turin to improve the energy efficiency of its buildings stocks. To respect the legislation [12], it was assertive to renovate buildings respecting the rules imposed for the improvement of energy efficiency of the envelope. The commitments on already existing buildings are:

- vertical elements towards the outside and non-heated area with a thermal transmittance of U=0,26 W/mK;
- horizontal elements and roofs towards the outside and non-heated area with a thermal transmittance of U=0,22 W/mK;
- horizontal elements (pavement) towards the outside, non-heated area and a ground with a thermal transmittance of U=0,26 W/mK;
- windows that satisfy the thermal transmittance of U= 1,40 W/mK

These values of thermal transmittance were applied on every buildings category built between 1946 and 2005. To implement these rules, it was necessary to modify the stratigraphy and its connected features of all the horizontal and the vertical elements. Moreover, in order to respect the values imposed, the transparent components of every building categories had to achieve an increment of their energy performance.

Another relevant decision was to expand the district heating network in all the four groups of measures taken into consideration, since Turin is one of the European city with the largest number of buildings connected to district heating. Furthermore, in the next years its expansion is one of the main goal set from Turin administration to improve energy efficiency of buildings sector trying to fight against pollution issues. Indeed, in the Turin Action Plan for Energy [22] it is set out as a goal, the intention to reach the 60% of total volume of buildings connected to district heating no later than 2020.

Since in the current state of our reference district, district heating is already covering the 40% of buildings volume, we decided to expand of 20% the buildings volume connected to district heating. With this expansion, we will reach a total coverage of 60% of volume of buildings.

Lastly, we took into consideration the possibility to substitute old boilers with new condensing ones as it is a frequent retrofit in residential buildings. Furthermore, we also considered the substitution of old boilers with heat pumps. In fact, it should be encouraged the use of heat pumps since they consume electricity that can be easily produced with renewable sources. Photovoltaic panel systems, together with heat pumps, were considered to cover the consumption of electricity with a renewable percentage.

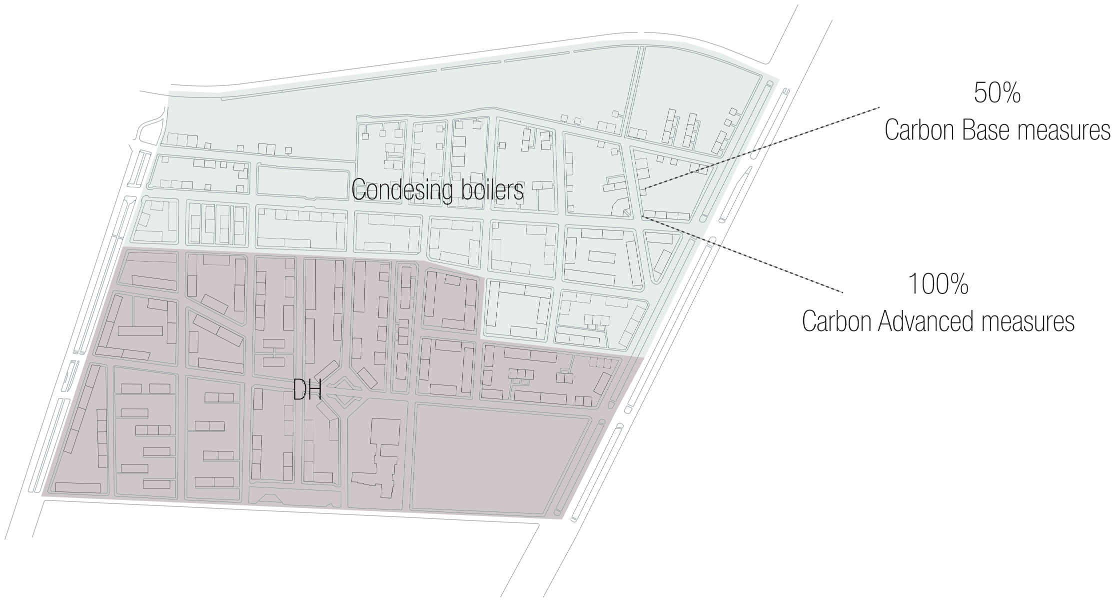
The interventions listed above are the ones that were applied to our district in the buildings sector. The next step was to define the features of each group of measures. Indeed, we applied on buildings different typologies of measures to evaluate which are the energy savings for the entire district obtained by several typologies of interventions. The various retrofit policies were combined into four groups of measures. As already said, we are going to expand, in all the four group of measures, the district heating network and the envelope improvement will be also applied to buildings that will be connected to district heating that were built between 1946 and 2005. For buildings built before 1945 and after 2006 in this area, the district heating will be provided while the envelope improvement will not be applied. Together with district heating expansion, it was decided for two of the four group of measures to substitute old boilers with new condensing ones, while for the others two to replace old boilers with the installation of heat pumps and photovoltaic panels systems. These groups of measures are then divided according to the quantity of buildings on which retrofits are applied. To sum up the four scenarios are:

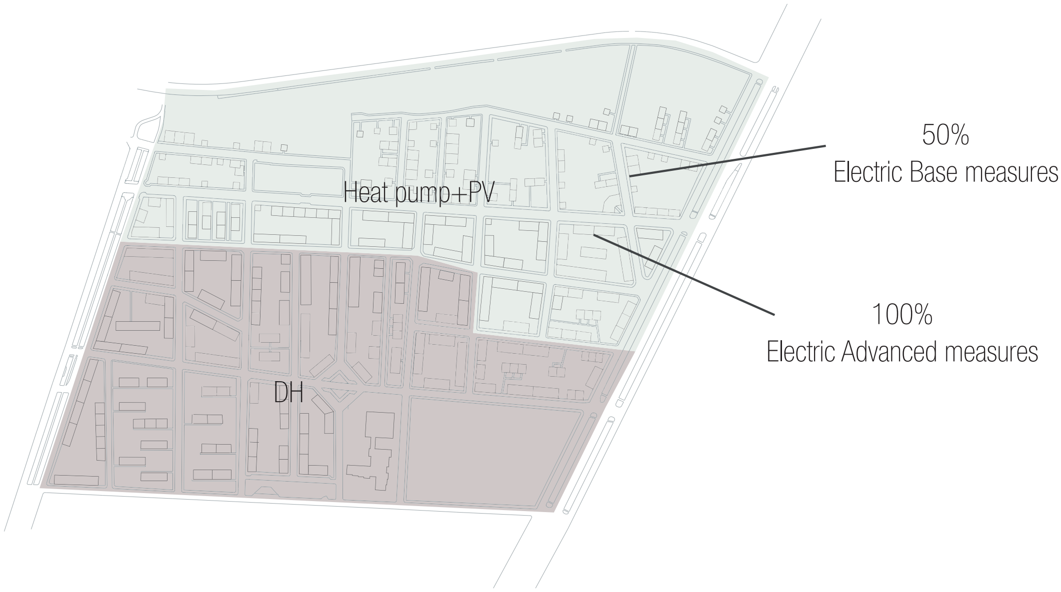
- Carbon base (CB): district heating expansion with envelope improvement + new condensing boilers with envelope improvement on 50% of the buildings
- Carbon advanced (CA): district heating expansion with envelope improvement + new condensing boilers with envelope improvement on all the buildings
- Electric base (EB): district heating expansion with envelope improvement + heat pumps and photovoltaic panels systems installation with envelope improvement on 50% of the buildings
- Electric advanced (EA): district heating expansion with envelope improvement + heat pumps and photovoltaic panels systems installation with envelope improvement on all the buildings

It is important to remember that retrofit measures are applied only on buildings built between 1946 and after 2005 for the reasons already illustrated in the previous chapter. The only exception is the connection to district heating, for buildings built before 1946 and 2005, which are in the area covered by district heating. We took this decision was taken since it is suggested that buildings, near streets that provide district heating, should exploit it. The names chosen for the four group of measures are utterly arbitrary. 'Carbon' and 'electric' is referred to the main fuel used, while 'base' and 'advanced' is related to the quantity of buildings on which is applied the retrofit.

The 'base' scenarios, with a partial application of the retrofit on the total number of buildings, were developed to represent the real percentage of buildings that are annually submitted to renovations. Indeed, in [23] we found

Figures 5. Groups of measures scheme, scale 1 : 10.000



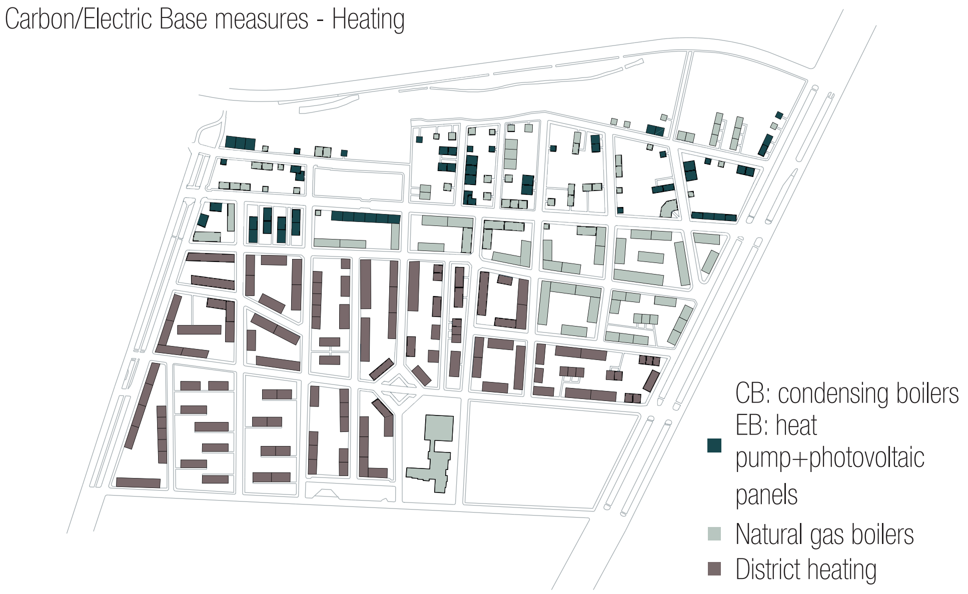



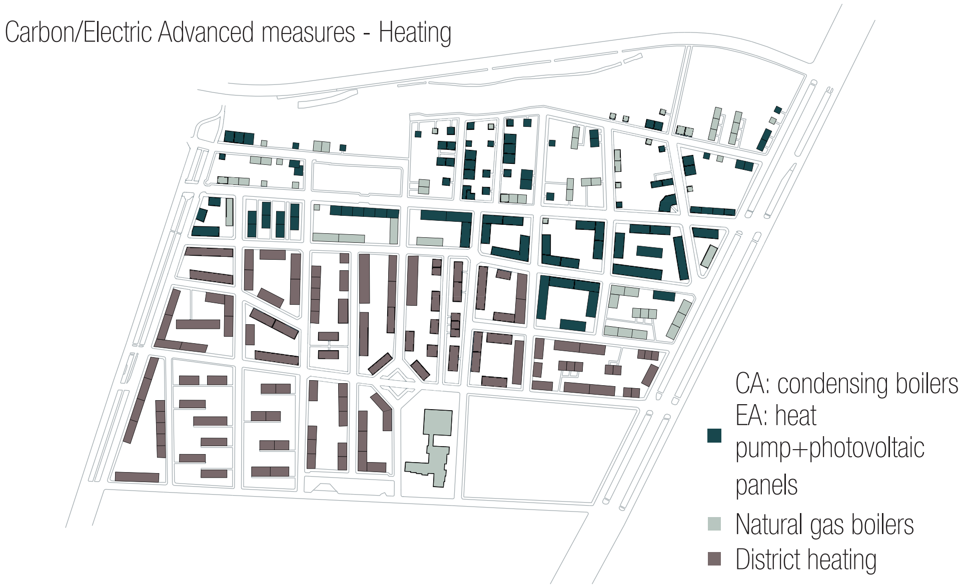

out that the percentage of buildings that is subjected to retrofit annually is almost 50%. It is also known that mainly retrofits are done on single family houses and terraced houses. This is because it is more complex to organize retrofit interventions on larger buildings that are composed by more than one apartments with different landlords. Therefore, in 'base' scenarios, it was decided to apply retrofit on 50% of buildings, among the ones built between 1946 and 2005, and this percentage was chosen mostly among single family houses and terraced houses categories. Thus, we decided to intervene before on the building typologies that in the current state are still using gas oil as fuel and then on other buildings typologies. Below are listed the 50% of buildings chosen:

- 1946-1960 SFH: 11 buildings
- 1946-1960 TH: 22 buildings
- 1961-1975 TH: 10 buildings
- 1946-1960 MFH: 8 buildings
- 1961-1975 MFH: 8 buildings

In the following page three different maps are shown: the current state, the carbon/electric base scenario and the carbon/electric advanced scenario. In the first one it is illustrated which is the district heating area and which are the fuels used currently for the heating system. Then, in the second one and third one, it is outlined which will be the expansion area of district heating and on which buildings will be applied the envelope and technical installation retrofits. The buildings on which, natural gas boilers are still kept in the electric advanced scenario are the ones built before 1945 and after 2005. As previously said, the same age-classes buildings in the district heating area will be connected to its network but their envelopes will not be retrofitted.

Figures 6. Groups of buildings measures, scale 1 : 10.000

Regarding technical installation modifications, in the charts below, Tables 6, 7, 8, the new data to insert in MasterClima energy models are listed. The last detail to underline is that in the cases in which, in the current state water heaters were present, this typology of domestic hot water installation was kept. The decision was taken in order to keep the production of hot water separated for each apartment since the centralization of this installation will be too complex from the interventions and cost point of view.

Table 6. District heating data.

| Heating | Domestic hot water |
|---|---|
| ηe --- > chart 17 UNI-TS 11300-2 2014 | ηe --- > 1 |
| ηd --- > chart 23 UNI-TS 11300-2 2014 | ηd --- > chart 12 Tabula |
| Qaux --- > 1,6. Circulation pump for centralized installation - chart 11 Tabula | Qaux --- > 2. Centralized hot water production with circulation pump - chart 16 Tabula |

Table 7. Condensing boilers data.

| Heating | Domestic hot water |
|---|---|
| ηe --- > chart 17 UNI-TS 11300-2 2014 | ηe --- > 1 |
| ηd --- > chart 23 UNI-TS 11300-2 2014 | ηd --- > chart 12 Tabula |
| Qaux --- > 2,6. Circulation pumps for centralized installation - electric auxiliary for condensing boiler - chart 11 Tabula | Qaux --- > 2. Centralized hot water production with circulation pump - electric auxiliary for condensing boiler - chart 16 Tabula |
| ηgn --- > 0,98 - chart 9 Tabula | ηgn --- > 0,99 - chart 14 Tabula |

Table 8. Condensing boilers data.

| Heating | Domestic hot water |
|---|---|
| ηe --- > chart 17 UNI-TS 11300-2 2014 | ηe --- > 1 |
| ηd --- > chart 23 UNI-TS 11300-2 2014 | ηd --- > chart 12 Tabula |
| Qaux --- > 1,6. Circulation pump for centralized installation - chart 11 Tabula | Qaux --- > 2. Centralized hot water production with circulation pump - chart 16 Tabula |

Furthermore, we took the decision to concentrate our attention on residential buildings. Indeed, interventions and measures are applied on them and do not take into consideration non-residential functions.

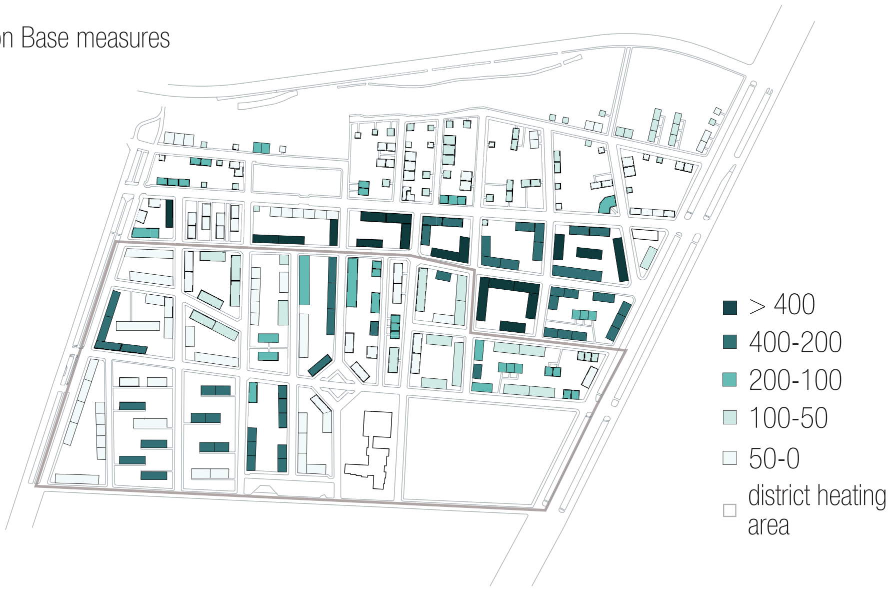
After having created all the energy models for each typology of interventions, we could compare all the results obtained. In the annex A a series of graphs are reported and illustrate the comparison between the energy need QHnd and QWnd before the envelope interventions and after that. Moreover, the consumptions Qdel, divided according to heating system and domestic hot water system and the energy carriers used are indicated, comparing the consumptions before and after the technical installations changes.

In the following pages, we are going to compare data extrapolated using energy maps for the current state and the other four group of measures. Figure 7, ,8, 9, 10 compare the total primary non-renewable energy needed Qnren for the heating and domestic hot water systems. Then, other energy maps, Figure 11 and 12, show the sum of the primary non-renewable energy Qnren needed for heating, domestic hot water and auxiliary systems. After that, the last two energy maps, Figure 13 and 14, represent the $CO_2$ emissions for each building typologies divided in the current state and the four different group of measures. All these data were extrapolated from energy models of MasterClima and multiplied for the area of each building belonging to each typology in order to obtain results referred and to the total surface of each building of the district. Results of consumptions and emissions are referred to an entire year.

Figure 7. Primary energy for heating Qnren [MWh/y], scale 1 : 10.000

Current state


Carbon Base measures




Carbon Advanced measures

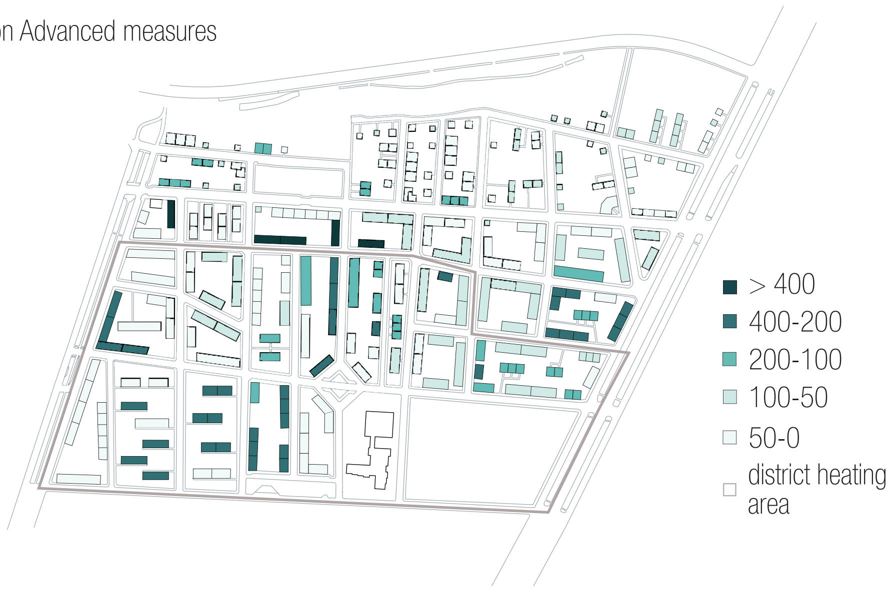


Figure 8. Primary energy for hot water Qnren [MWh/y], scale 1 : 10.000

Current state


Carbon Base measures


Carbon Advanced measures

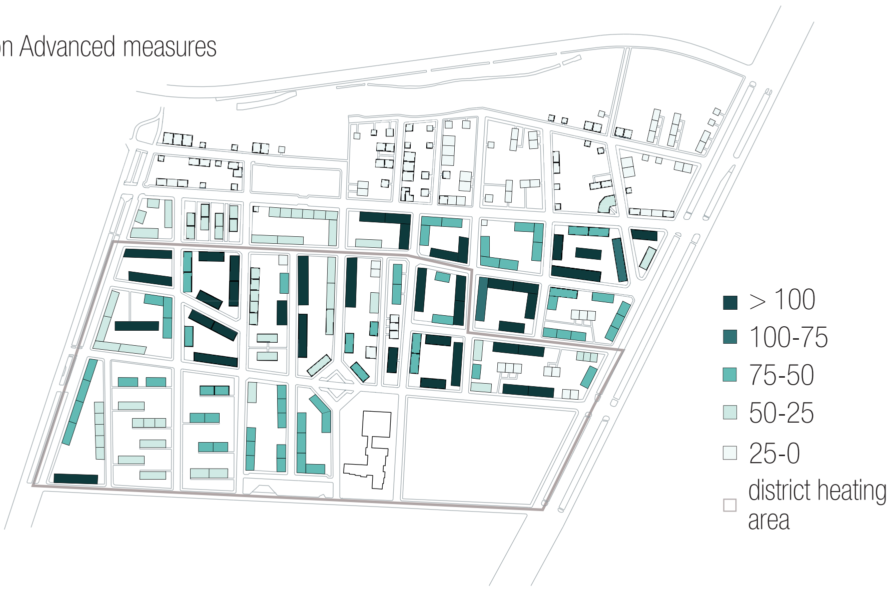


Figure 9. Primary energy for heating Qnren [MWh/y], scale 1 : 10.000

Current state


Electric Base measures


Electric Advanced measures

Figure 10. Primary energy for hot water Qnren [MWh/y], scale 1 : 10.000

Current state


Electric Base measures


Electric Advanced measures

Fig. 11. Total primary energy residential buildings (H+W+aux) Qnren [MWh/y], scale 1 : 10.000

Fig. 12. Total primary energy residential buildings (H+W+aux) Qnren [MWh/y], scale 1 : 10.000

Current state


Electric Base measures


Electric Advanced measures

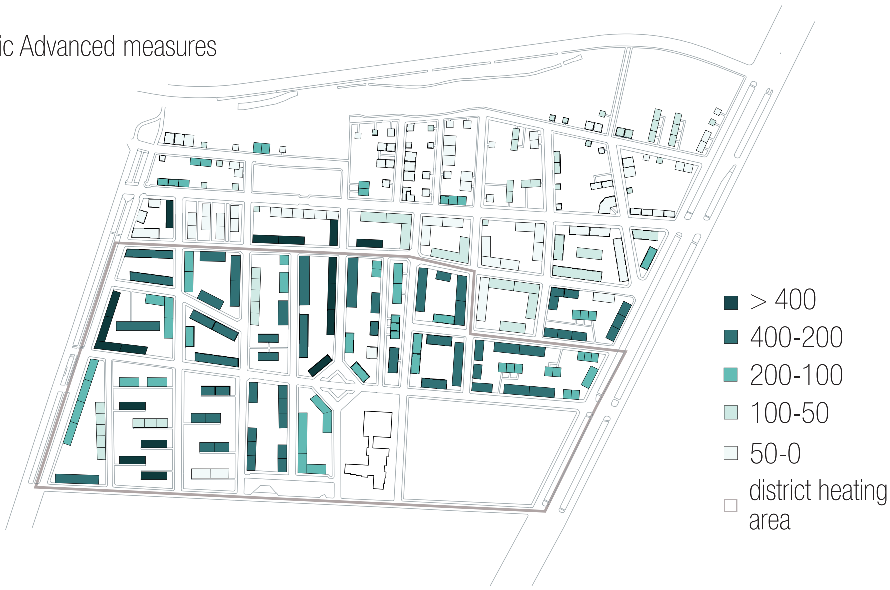


Figure 13. $CO_2$ emissions for heating and hot water [tCO2/y], scale 1 : 10.000

Figure 14. $CO_2$ emissions for heating and hot water [$tCO_2$/y], scale 1 : 10.000

In all the previous comparisons among the manifold groups of maps, we can clearly notice the drastic decrease of primary energy need, and consequently the buildings consumptions, between the current state and the other groups of measures. The measures provided are actually representing good practises to improve the energy sustainability of our reference district. Indeed, the retrofits of buildings applied allowed an improvement of the energy performances of the entire buildings sector. Furthermore, we can underline the drastic reduction of $CO_2$ emissions before and after the application of retrofits.

Afterwards, we summed up the results obtained for each energy source for primary global energy need Qgl and primary non-renewable energy needed Qnren and the total $CO_2$ and $PM_{10}$ emissions. In Tabel 9, we can analyse the improvements among the current state and the various groups of measures.

Table 9. Primary energy and emissions comparison among measures.

**Residential buildings - Carbon measures**

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| Energy need QH,nd [MWh/y] | 42.508,71 | 26.161,61 | 18.050,81 |
| Primay energy need QH,gl natural gas [MWh/y] | 42.156,55 | 24.403,82 | 10.973,67 |
| Primay energy need QH,gl district heating [MWh/y] | 19.852,58 | 13.614,50 | 13.614,50 |
| Primay energy need QH,gl gas oil [MWh/y] | 560,51 | - | - |
| Primay energy need QH,gl electricity [MWh/y] | 1.461,16 | 1.401,90 | 1.551,32 |

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| Energy need QW,nd [MWh/y] | 5.643,54 | 5.643,54 | 5.643,54 |
| Primay energy need QW,gl natural gas [MWh/y] | 6.518,23 | 4.195,03 | 3.058,27 |
| Primay energy need QW,gl district heating [MWh/y] | 2.631,11 | 4.245,37 | 4.245,37 |
| Primay energy need QW,gl gas oil [MWh/y] | 66,70 | - | - |
| Primay energy need QW,gl electricity ([MWh/y] | 5.544,56 | 5.672,03 | 5.861,07 |

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| Primay energy need QH+W,nren natural gas [MWh/y] | 47.800,09 | 28.598,85 | 14.031,94 |
| Primay energy need QH+W,nren district heating [MWh/y] | 22.483,69 | 17.859,87 | 17.859,87 |
| Primay energy need QH+W,nren gas oil [MWh/y] | 627,21 | - | - |
| Primay energy need QH+W,nren electricity [MWh/y] | 5.645,10 | 5.700,07 | 5.972,79 |

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| $CO_2$ emissions H+W [$tCO_2$/y] | 14.550,36 | 9.934,54 | 7.364,93 |
| $PM_{10}$ emissions H+W [$tPM_{10}$/y] | 1,49 | 0,97 | 0,61 |

**Residential buildings - Electric measures**

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| Energy need QH,nd [MWh/y] | 42.508,71 | 26.161,61 | 18.050,81 |
| Primay energy need QH,gl natural gas [MWh/y] | 42.156,55 | 23.844,74 | 8.947,35 |
| Primay energy need QH,gl district heating [MWh/y] | 19.852,58 | 13.614,50 | 13.614,50 |
| Primay energy need QH,gl gas oil [MWh/y] | 560,51 | - | - |
| Primay energy need QH,gl electricity [MWh/y] | 1.461,16 | 1.998,95 | 3.655,72 |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| Energy need QW,nd [MWh/y] | 5.643,54 | 5.643,54 | 5.643,54 |
| Primay energy need QW,gl natural gas [MWh/y] | 6.518,23 | 3.710,11 | 1.049,11 |
| Primay energy need QW,gl district heating [MWh/y] | 2.631,11 | 4.245,37 | 4.245,37 |
| Primay energy need QW,gl gas oil [MWh/y] | 66,70 | - | - |
| Primay energy need QW,gl electricity [MWh/y] | 5.544,56 | 5.913,93 | 7.188,34 |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| Primay energy need QH+W,nren natural gas [MWh/y] | 47.800,09 | 27.554,85 | 9.996,46 |

| | | | |
|---|---|---|---|
| Primay energy need QH+W,nren district heating [MWh/y] | 22.483,69 | 17.859,87 | 17.859,87 |
| Primay energy need QH+W,nren gas oil [MWh/y] | 627,21 | - | - |
| Primay energy need QH+W,nren electricity [MWh/y] | 5.645,10 | 6.376,08 | 8.737,98 |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| $CO_2$ emissions H+W [$tCO_2$/y] | 14.550,36 | 9.518,70 | 6.199,19 |
| $PM_{10}$ emissions H+W [$tPM_{10}$/y] | 1,49 | 0,86 | 0,52 |

Concerning non-residential functions, the consumptions remain unchanged with respect to the current state since we decided not to provide changes in the different groups of measures. For this reason, there is only one map representing the primary non-renewable energy need Qnren by non-residential functions. The decision not to apply measures on non-residential functions was assertive since, it was not possible to create energy models for shops, offices and school. That is why we considered the average consumptions of small commercial activities, offices and schools using average data for gas and electricity consumptions. At variance, as it was not possible to find average consumptions for shops and offices connected to district heating, these consumptions were incorporated to the consumption of residential buildings. Figure 15 shows the variation of primary energy need in the non-residential buildings.

Figure 15. Total primary energy non residential buildings Qp,nren [MWh/y], scale 1 : 10.000


Afterwards, in the Table 10, the total results of buildings sector are shown as the residential and non-residential results are summed up. We divided the global primary energy need Qgl and non-renewable Qnren according to energy sources and the total emissions of $CO_2$ and $PM_{10}$ for the current state and the for four buildings groups of measures. From these results, we can have a complete view on the entire buildings sector of the district.

Table 10. Primary energy and emissions comparison among measures.

**Buildings (Residential and non-residential ones) - carbon measures**

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| Primay energy need QH+W,gl natural gas [MWh/y] | 49.811,02 | 29.711,45 | 15.144,54 |
| Primay energy need QH+W,gl district heating [MWh/y] | 22.483,69 | 17.859,87 | 17.859,87 |

| | | | |
|---|---|---|---|
| Primay energy need QH+W,gl gas oil [MWh/y] | 627,21 | - | - |
| Primay energy need QH+W,gl electricity [MWh/y] | 8.331,82 | 8.400,03 | 8.738,49 |

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| Primay energy need QH+W,n-ren natural gas [MWh/y] | 49.811,02 | 29.711,45 | 15.144,54 |
| Primay energy need QH+W,n-ren district heating [MWh/y] | 22.483,69 | 17.859,87 | 17.859,87 |
| Primay energy need QH+W,n-ren gas oil [MWh/y] | 627,21 | - | - |
| Primay energy need QH+W,n-ren electricity [MWh/y] | 6.713,66 | 6.768,62 | 7.041,34 |

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| $CO_2$ emissions H+W [t$CO_2$/y] | 14.857,06 | 10.231,05 | 7.661,44 |
| $PM_{10}$ emissions H+W [t$PM_{10}$/y] | 1,52 | 1,00 | 0,64 |

**Buildings (Residential and non-residential ones) - electric measures**

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| Primay energy need QH+W,gl natural gas [MWh/y] | 49.811,02 | 28.667,45 | 11.109,06 |
| Primay energy need QH+W,gl district heating [MWh/y] | 22.483,69 | 17.859,87 | 17.859,87 |
| Primay energy need QH+W,gl gas oil [MWh/y] | 627,21 | - | - |
| Primay energy need QH+W,gl electricity [MWh/y] | 8.331,82 | 9.238,98 | 12.170,16 |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| Primay energy need QH+W,n-ren natural gas [MWh/y] | 49.811,02 | 28.667,45 | 11.109,06 |
| Primay energy need QH+W,n-ren district heating [MWh/y] | 22.483,69 | 17.859,87 | 17.859,87 |
| Primay energy need QH+W,n-ren gas oil [MWh/y] | 627,21 | - | - |
| Primay energy need QH+W,n-ren electricity [MWh/y] | 6.713,66 | 7.444,63 | 9.806,53 |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| $CO_2$ emissions H+W [$tCO_2$/y] | 14.857,06 | 9.815,21 | 6.495,70 |
| $PM_{10}$ emissions H+W [$tPM_{10}$/y] | 1,52 | 0,89 | 0,55 |

To complete the comparison of results and to obtain all the information useful to estimate subsequently costs and benefits of the district, it was also useful to summarise the consumptions Qdel of the various energy sources for the entire buildings sector. Detailed information regarding each typology of function are provided in the following tables. Also in these charts we can appreciate the drastic decrease of energy consumptions after the retrofits measures. In Table 11 and 12 we enumerate the gas and district heating consumption for the entire buildings sector for the current state and for the other groups of measures.

Table 11. Gas consumption of buildings sector [MWh/y].

| **Current State** | | |
|---|---|---|
| Gas consumption | residential buildings | 46.388,79 MWh |
| | school | 952,60 MWh |

| | | |
|---|---|---|
| Gas consumption | shops | 114,91 MWh |
| | offices | 14,63 MWh |
| | Total amount | **47.470,93 MWh** |

**Carbon Base measures**

| | | |
|---|---|---|
| Gas consumption | residential buildings | 27.298,79 MWh |
| | school | 952,60 MWh |
| | shops | 92,39 MWh |
| | offices | 14,63 MWh |
| | Total amount | **28.358,41 MWh** |

**Carbon Adavanced measures**

| | | |
|---|---|---|
| Gas consumption | residential buildings | 13.341,69 MWh |
| | school | 952,60 MWh |
| | shops | 92,39 MWh |
| | offices | 14,63 MWh |
| | Total amount | **14.401,31 MWh** |

**Electric Base measures**

| | | |
|---|---|---|
| Gas consumption | residential buildings | 26.277,79 MWh |
| | school | 952,60 MWh |
| | shops | 92,39 MWh |
| | offices | 14,63 MWh |
| | Total amount | **27.337,41 MWh** |

**Electric Adavanced measures**

| | | |
|---|---|---|
| Gas consumption | residential buildings | 9.548,62 MWh |
| | school | 952,60 MWh |
| | shops | 92,39 MWh |
| | offices | 14,63 MWh |
| | Total amount | **10.608,24 MWh** |

Table 12. District heating consumption of buildings sector [MWh/y].

**Current State**

| | | |
|---|---|---|
| District heating consumption | Total amount | 14.968,83 MWh |

**Carbon Base measures**

| | | |
|---|---|---|
| District heating consumption | Total amount | 11.898,38 MWh |

**Carbon Adavanced measures**

| | | |
|---|---|---|
| District heating consumption | Total amount | 11.898,38 MWh |

**Electric Base measures**

| | | |
|---|---|---|
| District heating consumption | Total amount | 11.898,38 MWh |

**Electric Adavanced measures**

| | | |
|---|---|---|
| District heating consumption | Total amount | 11.898,38 MWh |

We have to specify something more when we consider the electricity consumptions. Indeed, until now, we have just taken into account electricity consumptions connected to heating and hot water production considering circulation pumps, water heaters and heat pumps. Beyond that, electricity connected to devices, such as laptops, lightbulbs, kitchen equipment and so on, has not been estimated through energy models on MasterClima. We could calculate this value according to the number of people that is living inside each apartment and building. Hence, we estimated the electrical consumptions due to devices multiplying the number of inhabitants for the average electrical consumption of 900 kWh/y.

Furthermore, we supposed to provide cooling system through multi-split appliances or heat pumps in the four group of measures. The primary energy need and consumption of energy for cooling need were not calculated for all the typologies of buildings in order to simplify the procedure, since we preferred to focus our attention on heating and hot water system that are more common in residential buildings. Concerning cooling system, we took into consideration the typology of building with the highest value of energy need for cooling QW,nd and we estimate the additional consumption of electricity due to cooling system for the entire buildings sector. The typology of building selected was the apartment block built between 1976 and 1990. After having added on its energy model of MasterClima, a multi-split appliance together with the condensing boiler for the carbon scenarios and a heat pump that works also for cooling for the electric scenarios, the additional consumption of electricity was estimated. To simplify the calculation for the entire district, this additional consumption in kWh/m² was multiplied for the total retrofitted building surface for each scenario. In this way we found four different values, one for each group of measures. To better clarify, these values represent the additional consumption of electricity for cooling systems for the entire retrofitted buildings sector at district level. This calculation has been useful to have an annual complete electricity consumption view for the entire district.

The last consideration regards the photovoltaic panels systems installed in both electric scenarios. Indeed, thanks to MasterClima energy models, we extrapolated the quantity of produced and exported electricity for each photovoltaic panels system for each typology of building. Since the electricity produced by photovoltaic panels in certain moments of the day, month and year is more than the one consumed, the surplus of production can be considered to evaluate an annual energy balance considering the total quantity of electricity consumed and produced in the entire district.

Considering the surplus of electricity produced and exported by photovoltaic panels in the two electric measures, we can assume that this energy could be used to cover the electricity need of buildings sector. In Table 13 we listed the electrical consumptions of buildings sector.

Table 13. Electricity consumption of buildings sector [MWh/y].

**Current State**

| | | |
|---|---|---|
| Electricity consumption | residential buildings | 13.684,67 MWh |
| | - water heaters | 1.901,88 MWh |
| | - auxiliary | 1.012,97 MWh |
| | - other devices | 10.769,78 MWh |
| | school | 143,76 MWh |
| | shops | 110,18 MWh |
| | offices | 274,50 MWh |
| | Total amount | **14.213,07 MWh** |

### Carbon Base measures

| | | |
|---|---|---|
| Electricity consumption | residential buildings | 13.987,35 MWh |
| | - cooling | 295,14 MWh |
| | - water heaters | 1.901,88 MWh |
| | - auxiliary | 1.020,55 MWh |
| | - other devices | 10.769,78 MWh |
| | school | 143,76 MWh |
| | shops | 110,18 MWh |
| | offices | 274,50 MWh |
| | Total amount | **14.515,79 MWh** |

### Carbon Adavanced measures

| | | |
|---|---|---|
| Electricity consumption | residential buildings | 16.900,24 MWh |
| | - cooling | 3.086,38 MWh |
| | - water heaters | 1.901,88 MWh |
| | - auxiliary | 1.142,23 MWh |
| | - other devices | 10.769,78 MWh |
| | school | 143,76 MWh |
| | shops | 110,18 MWh |
| | offices | 274,47 MWh |
| | Total amount | **17.428,68 MWh** |

### Electric Base measures

| | | |
|---|---|---|
| Electricity consumption | residential buildings | 13.991,13 MWh |
| | - cooling | 330,18 MWh |
| | - water heaters | 1.799,57 MWh |

| | | |
|---|---|---|
| | - auxiliary | 906,20 MWh |
| | - other devices | 10.769,78 MWh |
| Electricity consumption | - heat pumps | 185,40 MWh |
| | school | 143,76 MWh |
| | shops | 110,18 MWh |
| | offices | 274,47 MWh |
| | Total amount | **14.519,54 MWh** |

| | |
|---|---|
| Electricity of photovoltaic panels exported by buildings | **87,74 MWh** |

**Electric Adavanced measures**

| | | |
|---|---|---|
| | residential buildings | 17.190,05 MWh |
| | - cooling | 3.452,85 MWh |
| | - water heaters | 1.536,65 MWh |
| | - auxiliary | 662,94 MWh |
| | - other devices | 10.769,78 MWh |
| | - heat pumps | 767,83 MWh |
| Electricity consumption | school | 143,76 MWh |
| | shops | 110,18 MWh |
| | offices | 274,47 MWh |
| | Total amount | **17.718,46 MWh** |

| | |
|---|---|
| Electricity of photovoltaic panels exported by buildings | **307,25 MWh** |

We also decided to estimate an indicative quantity of surface of photovoltaic panels to locate in our district to cover the total electricity consumption of buildings sector. Since we know from [24] that in Turin for 1 kWp are produced 1310 kWh/y and from MasterClima [25] that photovoltaic performance is 0,15 kWp/m², we could calculate the total surface necessary per electric base and electric advanced measures. For the first one we will need 73.444 m² of photovoltaic panels, while for the second one 88.607 m². We just calculated these values to raise our awareness on the quantity of panels needed to cover the electricity need of buildings for our reference district, considering also that  electrical storage for electricity accumulation should be provided. We did not take them into account them in the total evaluation of the district, as we know that it is a huge investment that need the availability of enormous areas.

Lastly, in the final Table 14,  we list the primary non-renewable energy needed Qnren obtained for each group of measures for the entire buildings sector.

Table 14. Primary energy buildings Qnren (residential and non-residential ones) [MWh/y].

| **Current State** | |
|---|---|
| residential buildings | 79.635,58 MWh |
| school | 1.280,55 MWh |
| shops | 252,94 MWh |
| offices | 24,25 MWh |
| Total amount | **81.193,32 MWh** |

**Carbon Base measures**

| | |
|---|---|
| residential buildings | 54.339,94 MWh |
| school | 1.280,55 MWh |
| shops | 203,38 MWh |
| offices | 24,25 MWh |
| Total amount | **55.848,12 MWh** |

**Carbon Advanced measures**

| | |
|---|---|
| residential buildings | 40.045,75 MWh |
| school | 1.280,55 MWh |
| shops | 203,38 MWh |
| offices | 24,25 MWh |
| Total amount | **41.553,93 MWh** |

**Electric Base measures**

| | |
|---|---|
| residential buildings | 53.971,95 MWh |
| school | 1.280,55 MWh |
| shops | 203,38 MWh |
| offices | 24,25 MWh |
| Total amount | **55.480,13 MWh** |

**Electric Advanced measures**

| | |
|---|---|
| residential buildings | 38.775,46 MWh |
| school | 1.280,55 MWh |
| shops | 203,38 MWh |
| offices | 24,25 MWh |
| Total amount | **40.283,64 MWh** |

All these obtained information were extrapolated to better define the values related to the consumptions of the entire district. They are both useful to estimate the variation of consumption between the current state and after the manifold retrofits and to evaluate the costs and benefits produced by buildings sector on the entire district.

### 5.2.2. Mobility sector

Transport is another important sector on which it is possible to intervene to reduce drastically the emissions production. Furthermore, the promotion of new ways to move inside the city will increase the sustainability in citizen's life. For these reasons, in our reference district we have also thought about some possible measures to increase the sustainability of mobility. After having focused our attention on the definition of both public and private means of transports, we have chosen to provide two different measures that could fit with the district analysed and consequently the entire city of Turin:

- Transport 1 (T1): replacement of old buses with electrical ones;
- Transport 2 (T2): replacement of old buses with electrical ones + the increment of the number of buses.

In the first measure analysed, we decided to substitute the total number of buses that cross the district per day with new electrical ones. In the definition of the current state, we estimated 185 passages of buses per day in the entire district. The next step was to determine the number of buses needed to meet this request. We considered the average length of a bus line path in Turin, which is 12 kilometres [18], and its average speed, which is 17 km/h [26], [27]. Thanks to these information, we could estimate the average travelling time of a bus line, which is 42 minutes, and that are needed 7 buses for each lines every day. Since we have 4 bus lines, there will be 28 buses per day which cross our reference district. This data will be useful in the next phase to calculate the costs of substitution of buses with new electrical ones. To obtain the total consumption of kWh of electricity per day, we multiplied the total kilometres travelled by buses, which correspond to 876,90 km, by the consumption of electricity:

- Electricity: 1,04 kWh/km

Then, we could estimate the total $CO_2$ emissions emitted in the environment multiplying the total energy consumption for the factor of $CO_2$ emissions, which is 0,4332 kg/kWh. Both electricity consumption and $CO_2$ emissions were firstly estimated per day and then, transformed in annual values to be compared with the other information of the district.

Regarding the second measure, Transport 2, we decided to increase of 20% the frequency of passages of buses with the consequent reduction of number of cars journey. As already said, even in this second measure, buses are using electricity as fuel. The number of passages of buses crossing the entire district in this case are 222 for 1.052,30 kilometres per day. As already previously described, we determined the number of buses needed to satisfy this request. Knowing the average length of the bus path and the average speed of a bus line, we estimated 8 buses for each bus line of our reference district, with a total of 32. Then, we calculated the total consumption of electricity and the total emissions of $CO_2$ produced, in relation with the total kilometres travelled inside the district by buses. The calculation is the same of Transport 1 measure. The following challenge was to determine the reduction of use of cars in the district. Indeed, with the increase of the frequency of buses we assumed that the number of passengers of public means of transports increase and that, consequently, the number of cars used reduce. Knowing that the average of passengers per kilometres on Turin buses [18] are 2,52, we could estimate the additional number of passengers comparing the number of buses of the current state and the ones after the measure applied.

(Kilomestres travelled with the increment * passengers per kilometres) – passengers of the current state

(1.052,28*2,52) – 2210 = 442 number of new passengers

After that, the additional number of passengers was divided for the occupancy rate of cars of Turin that is 1,6, to find the number of cars that will not travel more in the district. Lastly, we obtained the reduction in the number of kilometres through the relation,

number of cars current state : kilometres of cars current state = number of cars in less : X

5.844 : 20.231,67 = 276: X

X = 955,5 kilometres in less.

The total kilometres travelled by cars in this mobility measure are 19.276,12 km. After having obtained this information, the total kilometres travelled were divided among the various typologies of cars categorized for the fuel used and the Euro categories. Consequently, we obtain the total consumption of fuel and the $CO_2$ and $PM_{10}$ emissions for each category. All the detailed calculations and tables are reported in the annex at the end of the work thesis. Below, in the Table 15, we summarize the consumptions, the $CO_2$ and $PM_{10}$ emissions relevant data divided between buses and cars for the current state and each measure.

Table 15. Consumption and emissions of mobility sector.

| | | Current State | Transport 1 | Transport 2 |
|---|---|---|---|---|
| Consumptions |  | 107,80 $m^3$/y petrol+diesel<br>51,18 Mg/y methane | 332,87 MWh/y electricity | 570,27 MWh/y electricity |
| |  | 590,10 $m^3$/y petrol+diesel<br>1,61 Mg/y methane<br>0,65 MWh/y electricity | 590,10 $m^3$/y petrol+diesel<br>1,61 Mg/y methane<br>0,65 MWh/y electricity | 562,23 $m^3$/y petrol+diesel<br>1,53 Mg/y methane<br>0,62 MWh/y electricity |

| | | Current State | Transport 1 | Transport 2 |
|---|---|---|---|---|
| $CO_2$ emissions |  | 557,78 t$CO_2$/y | 144,20 t$CO_2$/y | 247,04 t$CO_2$/y |
| |  | 2.198,89 t$CO_2$/y | 2.198,89 t$CO_2$/y | 2.095,04 t$CO_2$/y |
| $PM_{10}$ emissions |  | 0,36 t$PM_{10}$/y | - | - |
| |  | 0,46 t$PM_{10}$/y | 0,46 t$PM_{10}$/y | 0,44 t$PM_{10}$/y |

### 5.2.3. Waste sector

Concerning the waste management, we decided to provide waste containers in the district underground and to reduce the frequency of passages of garbage trucks. In this way, the total consumption of fuel and production of $CO_2$ and $PM_{10}$ emissions decrease in this sector and in the entire reference district. The two measures provided were:

- Waste 1 (W1): reduction of waste collection twice a week;
- Waste 2 (W2): reduction of waste collection once a week;

considering that currently the collection takes place every day. We could extrapolate the data for the two measures from the current consumption since it was only necessary to rework the results previously obtained for consumptions $CO_2$ and $PM_{10}$ of the current state. Below, in the Table 16, we have summed up the results obtained for the current state and the two measures.

Table 16. Consumption and emissions of waste sector.

| | Current State | Waste 1 | Waste 2 |
|---|---|---|---|
| Consumption | 177,93 l/y | 50,83 l/y | 25,41 l/y |
| $CO_2$ emissions | 0,88 tCO2/y | 0,25 tCO2/y | 0,12 tCO2/y |
| $PM_{10}$ emissions | 0,00012 tPM10/y | 0,000035 tPM10/y | 0,000018 tPM10/y |

### 5.2.4. Street lighting sector

In the last sector, public street lighting, street lightings are renovated. Indeed, the idea was to replace the existing street lightbulbs. Also, in this sector, two measures were analysed:

- Street lighting 1 (SL1): substitution of 50% of street lightbulbs with LED ones;
- Street lighting 2 (SL2): substitution of 100% of street lightbulbs with LED ones;

In the first measure the substitution started from street lamps that consume more in the current state. For this reason, we firstly replaced all the mercury vapour lightbulbs and partially the high-pressure sodium vapour lightbulbs. In the second measure, we introduced the use of LED lightbulbs replacing all the street lightbulbs of our reference district. For LED lightbulbs we considered an average consumption of 80 W and 0,4332 $kgCO_2/kWh$ produced. In Table 17 we summarized the electricity consumptions and $CO_2$ emissions comparing the current state and the other measures.

Table 17. Consumption and emissions of public street lighting sector.

| | Current State | Street lighting 1 | Street lighting 2 |
|---|---|---|---|
| Consumption | 296,78 MWh/y | 197,66 MWh/y | 117,37 MWh/y |
| $CO_2$ emissions | 153,13 tCO2/y | 97,15 tCO2/y | 50,8 tCO2/y |

## 5.3. Costs and benefits for the different scenarios

After having defined the consumptions and the emissions of our reference district at the current state and in the various measures applied for every sector, we moved our attention on the economic analysis. Since one of our main goals is to verify the social and economic sustainability of each policy, besides the environmental one, we decided to use the cost-benefit analysis. As already deepened in the previous chapters, the cost-benefit analysis is the most appropriate tool to choose the most suitable investment, among the ones proposed for the entire society. Indeed, this analysis compares the costs and the benefits for the entire community of each projects, and thanks to its economic indicators, it reveals the most sustainable project from the economic, environmental and social point of view. Before applying the cost-benefit analysis, we had to create scenarios in which one measure for each sector is taken into consideration. We assumed a limited numbers of scenarios as it was not possible to consider all the possible combinations. At the beginning, we hypothesized six scenarios arbitrarily, but after a first analysis it was easier to understand which were the most suitable ones. After having assumed the scenarios, we had to calculate all the costs and benefits for each sector and to generate the matrix of the cost-benefit analysis to obtain the economic indicators with which we can estimate the convenience of the scenario.

### 5.3.1. Scenarios definition

We started our analysis from six scenarios in which we included all the measures applied in each sector. First of all, we took into consideration the least and the most invasive scenarios. To better clarify, we created one scenario in which we included the least invasive measures for every sector and one in which we included the most invasive ones for every field:

- CB+T1+W1+SL1 (the least invasive one);
- EA+T2+W2+SL2 (the most invasive one).

Then, we assumed other four scenarios which could be compared with the first two ones and which included all the measures not considered until now.

- CB+T2+W2+SL2
- EB+T1+W2+SL1
- EB+T2+W2+SL2
- CA+T2+W2+SL2

Since it was necessary to analyse the scenarios before understanding which are the most convenient ones, we kept open the possibility to create other scenarios and to analyse them as they could be better than the ones assumed. Moreover, since we included all the measures proposed in the creation of the scenarios, we found easier to begin from the estimation of all the costs and benefits for every measure of each sector and to merge them afterwards. Before, we analysed the percentage reduction of primary energy need, $CO_2$ and $PM_{10}$ emissions of the current state with respect to the other scenarios. We decided to carry out this comparison as these factors will be considered as benefits for the entire district in the following paragraphs. It was easy to obtain these percentage reductions as we already had all the values for the current state and for the various measures for every sector. Below, in Table 18, these percentage reductions are listed

Table 18. Percentage reductions of primary energy need and emissions in the scenarios.

**SCENARIO CB+T1+W1+SL1**

| | Current State | Scenario | Reduction |
|---|---|---|---|
| Primary energy [MWh/y] | 81.772,04 | 56.233,56 | -31% |
| $CO_2$ emissions [$tCO_2/y$] | 17.767,74 | 12.671,54 | -29% |
| $PM_{10}$ emissions [t $PM_{10}/y$] | 2,34 | 1,46 | -38% |

**SCENARIO CB+T2+W2+SL2**

| | Current State | Scenario | Reduction |
|---|---|---|---|
| Primary energy [MWh/y] | 81.772,04 | 56.076,99 | -31% |
| $CO_2$ emissions [$tCO_2/y$] | 17.767,74 | 12.624,05 | -29% |
| $PM_{10}$ emissions [t $PM_{10}/y$] | 2,34 | 1,44 | -38% |

**SCENARIO EB+T1+W2+SL1**

| | Current State | Scenario | Change |
|---|---|---|---|
| Primary energy [MWh/y] | 81.772,04 | 55.865,57 | -32% |
| $CO_2$ emissions [$tCO_2$/y] | 17.767,74 | 12.255,57 | -31% |
| $PM_{10}$ emissions [t $PM_{10}$/y] | 2,34 | 1,35 | -42% |

**SCENARIO EB+T2+W2+SL2**

| | Current State | Scenario | Change |
|---|---|---|---|
| Primary energy [MWh/y] | 81.772,04 | 55.709 | -32% |
| $CO_2$ emissions [$tCO_2$/y] | 17.767,74 | 12.208,21 | -31% |
| $PM_{10}$ emissions [t $PM_{10}$/y] | 2,34 | 1,33 | -43% |

**SCENARIO CA+T2+W2+SL2**

| | Current State | Scenario | Change |
|---|---|---|---|
| Primary energy [MWh/y] | 81.772,04 | 41.782,80 | -49% |

| | | |
|---|---|---|
| $CO_2$ emissions [$tCO_2/y$] | 17.767,74 | 10.054,44 |
| | -43% | |
| $PM_{10}$ emissions [t $PM_{10}/y$] | 2,34 | 1,08 |
| | -54% | |

**SCENARIO EA+T2+W2+SL2**

| | Current State | Scenario |
|---|---|---|
| Primary energy [MWh/y] | 81.772,04 | 40.512,51 |
| | -50% | |
| $CO_2$ emissions [$tCO_2/y$] | 17.767,74 | 8.888,70 |
| | -50% | |
| $PM_{10}$ emissions [t $PM_{10}/y$] | 2,34 | 0,99 |
| | -58% | |

From this analysis, we noticed that the major percentage reduction of primary energy need, $CO_2$ and $PM_{10}$ emissions is present in the last scenario. In the next paragraphs, we are going to calculate separately costs and benefits, and to analyse the results obtained by the economic indicators of the cost-benefit analysis for each scenario.

### 5.3.2. Costs

As already outlined in the previous chapter concerning the methodology, the costs, to take into account in a cost benefit analysis, are manifold. First of all, we defined the lifetime of the investment considering 30 years, and the costs taken into account:

- Initial investment cost
- Running costs
- Replacement costs
- Residual value

#### 5.3.2.1. Initial investment cost

The initial investment cost of the project is only considered in the first year of the lifetime of the investment, because we assumed that initial investment will run out after the first year. Starting from the buildings sectors, we had to evaluate the costs of all the interventions for the different groups of measures. We included all the prices connected to materials, work hours and technical installations retrofit. To do this, for each typology of building retrofitted, we estimated the cost per square meter of retrofitted envelope and the cost of substitution of the technical systems. The information were extrapolated from the price list available for the Piedmont region [28]. When it was not possible to find some information from this price list, we used the one of the city of Milan [29] or the one of the autonomous province of Bolzano [30]. Then, we multiplied these costs for the total number of buildings retrofitted for each building typology, considering their type of retrofit. In the annex B, at the end of the work thesis, we listed the costs for each typology of intervention and building.

Then, regarding the initial investment cost of mobility sector we only determined the price of new electrical buses. We found that the price for each electrical bus, bought from the city of Turin in 2017, was 370.000 € [31]. Since we already determined the number of buses to substitute in both measure Transport 1 and Transport 2, it was easy to estimate the total initial investment cost for the mobility sector.

After, we moved to the waste sector to estimate the investment cost of the installation of underground waste containers. First of all, we had to determine how many waste containers were necessary for our reference district. To evaluate this, we proportioned the number of the different waste containers in Turin, available in [20], with the number of inhabitants of Turin and our reference district. We estimated 70 waste containers in our reference district. Afterwards, we found the cost of the realization of underground waste containers estimating almost 7.430 € per waste containers installed. This price was acquired by the analysis of two waste management investments occurred in two different Italian towns [32], [33].

Lastly, concerning the public street lighting sector, we estimated the price of the new LED street lamps installed multiplying it by the number of lamps to replace in the two measures considered. We found this price in [34], where the installation of each LED street lamp is estimated around 1.381,05 €. In Table 19, we enumerated all the initial investment costs divided according to the sectors analysed and to the measures applied on them.

Table 19. Initial investments costs divided sectors and mesuares.

| | |
|---|---|
| Buildings sector | CB : 26.279.079,96 € |
| | CA : 43.037.764,29 € |
| | EB : 35.176.756,41 € |
| | EA : 64.905.785,34 € |
| Mobility sector | T1 : 10.360.000 € |
| | T2 : 11.840.000 € |
| Waste sector | W1 : 520.100 € |
| | W2 : 520.100 € |

| | |
|---|---|
| Street lighting sector | SL1 : 243.064,80 € |
| | SL2 : 484.748,55 € |

### 5.3.2.2. Running costs

The next challenge was the determination of the running costs in which are included the maintenance and the operating costs of the project. Moreover, we also added the costs of fuel connected to mobility and waste sectors, and the costs of $CO_2$ and $PM_{10}$ emissions connected to all the sectors considered in our reference district. These expenditures are constant during the entire lifetime of the investment and they started to be considered from the second year.

Concerning the maintenance costs, in the buildings sector, we considered the maintenance of the technical installations components. For this reason, we consulted the EN 15459:2007 [35], in which are enumerated the lifespan and the maintenance costs for energy systems. The second ones are expressed as a percentage on the initial investment cost, representing an annual preventive which include the maintenance, the operation, repair and servicing costs. In the annex B, concerning the buildings sector costs, we can find the percentage of the maintenance costs for each components of the technical installations for each building typology. As it was already done for the initial investment costs, we summed up the maintenance costs for all the buildings retrofitted in each groups of measures.

Afterwards, we focused our attention on the other fields. We did not consider the maintenance costs of the mobility sector as we will include it in the operating costs. This is because we found, in the annual report of GTT (Gruppo Torinese Transporti) of 2014 [36], the price of the maintenance costs together with the operating costs. At variance, we could estimate the maintenance costs of the other two sectors: the waste sector and the public street lighting one. Regarding the first one, we found the information about the maintenance costs of Turin in [37]. On the other hand, concerning the public street lighting we multiplied the number of the street lamps replaced by the maintenance cost extrapolated from this price list [34]. Moreover, for all the sectors considered, we also evaluated the maintenance costs on the non-retrofitted component. To better specify, we had to include the maintenance costs of the buildings that were non retrofitted in each groups of measures and of the street lamps that were not substitute in the first measure, street lighting 1. Thus, we assumed a price for the already exisitng technical installations components and street lamps and on them we applied the percentage of the maintenance costs. In this way we calculated the maintenance costs for each sector and the entire district. In Table 20, we enumerated the maintenance costs divided into the sectors and the measures for each of them.

Table 20. Maintenance costs divided for sectors and measures.

| | |
|---|---|
| Buildings sector | CB : 40.455,05 € |
| | CA : 47.598,29 € |
| | EB : 69.018,05 € |
| | EA : 182.530,98 € |
| Mobility sector | T1 - T2 : included in operating costs |
| Waste sector | W1 : 29.498,83 € |
| | W2 : 29.498,83 € |
| Street lighting sector | SL1 : 41.077,53 € |
| | SL2 : 41.077,53 € |

In the running costs, the operating costs are also included. These expenses are connected to the costs of the resources used to carry out a project, for instance the consumption of energy. Indeed, regarding buildings sector, we took into account the total consumption of energy of the buildings in the district. In the results obtained in the previous part, we listed the total consumption of the entire district of natural gas, district heating and electricity for the various measures. These values were multiplied by the cost of each energy source:

- Natural gas: 0,030 €/kWh
- District heating: 0,077 €/kWh
- Electricity: 0,234 €/kWh

The natural gas cost was found in [38], while the cost of the district heating was extrapolated from [39]. Regarding the cost of electricity we found two sources [40], [41].

Concerning the mobility sector, we found the operating costs of GTT (Gruppo Torinese Transporti) in [36], in which were also included the annual maintenance costs of the buses. These prices were proportioned according to the population of Turin and the one of our reference district. The same procedure was developed for the waste sector, for which we found the operating costs in [37]. Lastly, the public street lighting operating costs are the ones connected to the costs of the electricity consumed by the street lamps. We had already estimated the total consumption of electricity connected to street lighting and we could multiplied it by the cost of the electricity for public street lighting, which is:

- 0,06713 €/kWh

This price was available in [42]. In Table 21 the operating costs according to the sectors and to each measure are listed.

Table 21. Operating costs divided for sectors and measures.

| | |
|---|---|
| Buildings sector | CB : 5.164.546,92 € |
| | CA : 5.427.450,18 € |
| | EB : 5.134.794,42 € |
| | EA : 5.381.466,72 € |
| Mobility sector | T1 : 1.456.603,14 € |
| | T2 : 1.456.603,14 € |
| Waste sector | W1 : 1.234.844,90 € |
| | W2 : 1.234.844,90 € |
| Street lighting sector | SL1 : 13.268,92 € |
| | SL2 : 7.897,05 € |

Another running cost considered, is connected to the expenses for the consumption of fuels. In our reference district, the fuels consumptions are related to the mobility and waste sector. Since we already calculated the total consumption of fuel for both sectors, we had only to multiply these consumptions by the costs of the various typologies of fuels used:

- Petrol : 1,509 €/l
- Diesel : 1,379 €/l
- Natural gas : 0,89 €/kg
- Electricity : 0,02 €/kWh

These costs are referred to the day 5/1/2018, the day in which we started this research. In Table 22, we listed the fuel costs for the mobility and waste sector.

Table 22. Fuel costs for sectors and measures.

| | |
|---|---|
| Buildings sector | CB : - |
| | CA : - |
| | EB : - |
| | EA : - |
| Mobility sector | T1 : 862.107,37 € |
| | T2 : 822.971,34 € |
| Waste sector | W1 : 153,40 € |
| | W2 : 76,68 € |
| Street lighting sector | SL1 : - |
| | SL2 : - |

In the running costs we also included the costs concerning the emissions production. Since in our reference district we estimated the emissions of $CO_2$ and $PM_{10}$, we had also to calculate their social costs. We already enumerated in the previous paragraphs the emissions produced from each sector in the current state of our reference district and after the various sustainable measures applied. The costs of $CO_2$ emissions were estimated considering the forecast of prices carried out in [43] from now until 2050. While PM10 emissions costs were estimated thanks to the value given in [44], which provide an average cost of 4.828,22 € per ton emitted in the atmosphere. Firstly, in Table 23, we enumerated the costs of $CO_2$ emissions per sector and measure. As we can notice, they are different for each year. We assumed that our reference district investment starts in 2017 and, as suggested in [43], we estimated a price of 16,5 € per ton of emission until 2020, of 20 € until 2025, of 35 € until 2030 and of 50 € after 2035. For this reason, the expenses vary in the different years of the lifetime of the investment project.

Table 23. $CO_2$ emissions costs for sectors and measures.

| | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|
| Buildings sector | CB : 168.812,32 € | 204.621,00 € | 368.317,80 € | 511.552,50 € |
| | CA : 126.413,76 € | 153.228,80 € | 275.811,84 € | 383.072,00 € |
| | EB : 161.950,96 € | 196.304,20 € | 353.347,56 € | 490.760,50 € |
| | EA : 107.179,05 € | 129.914,00 € | 233.845,20 € | 324.785,00 € |
| Mobility sector | T1 : 38.165,98 € | 46.261,80 € | 83.271,24 € | 115.654,50 € |
| | T2 : 38.644,32 € | 46.841,60 € | 84.314,88 € | 117.104,00 € |
| Waste sector | W1 : 4,12 € | 5,00 € | 9,00 € | 13,00 € |
| | W2 : 1,98 € | 2,40 € | 4,32 € | 6,00 € |
| Street lighting sector | SL1 : 1.602,97 € | 1.943,00 € | 3.497,40 € | 4.857,50 € |
| | SL2 : 838,20 € | 1.016,00 € | 1.828,80 € | 2.540,00 € |

Then, we multiplied the tons of $PM_{10}$ emitted by the cost of the $PM_{10}$ emissions and we obtained the results enumerated in Table 24.

Table 24. $PM_{10}$ emissions costs for sectors and measures.

| | |
|---|---|
| Buildings sector | CB : 4.828,22 € |
| | CA : 3.090,05 € |
| | EB : 4.297,12 € |
| | EA : 2.655,52 € |
| Mobility sector | T1 : 2.220,98 € |
| | T2 : 2.124,42 € |
| Waste sector | W1 : 0,17 € |
| | W2 : 0,09 € |

| | |
|---|---|
| Street lighting sector | SL1 : - <br> SL2 : - |

### 5.3.2.3. Replacement costs

The next costs estimated were the replacement costs. They took into account the need to replace obsolete technical installations components, means of transport and street lamps during the entire lifetime of the investment. We considered replacement costs only at the years 10, 20 and 30. Concerning buildings sector, we considered the replacement costs for the technical installations. In [35], the lifespan of the main energy systems are listed. As already outlined in the maintenance, in order to have a whole expense for the entire reference district, we had to include in the replacement costs, the substitution of technical installations components of buildings which were not retrofitted.

Regarding the mobility sector, we took into consideration the replacement of buses. We decided to substitute, after 20 years, the 70% of buses that cross the district both for measures Transport 1 and Transport 2. Then, after 30 years we substituted the remaining buses. Since we already knew the cost of one electrical bus, it was easy to estimate the replacement costs. In the meanwhile, we calculated the replacement costs for the waste sector. It was not necessary to foresee the replacement of the underground waste containers as they do not need to be substituted during the lifetime of the investment. On the other hand, we evaluated the costs of the substitution of the waste trucks after 20 years. Since we assumed to have two waste trucks, we had to replace both after 20 years. We hypothesized for the cost of one small waste truck 15.000 €. Lastly, concerning the public street lighting, we substituted all the street lamps at the year 20 of the lifetime of the investment. In Table 25, we listed the replacement costs in the different years of the lifetime of the investment.

Table 25. Replacement costs for sectors and measures.

| | | 10 years | 20 years | 30 years |
|---|---|---|---|---|
| Buildings sector | CB : | - | 1.610.882,52 € | - |
| | CA : | - | 1.876.635,95 € | - |
| | EB : | - | 2.251.243,76 € | 742.615,75 € |
| | EA : | - | 4.864.540,38 € | 2.597.047,97€ |
| Mobility sector | T1 : | - | 7.400.000,00 € | 2.960.000,00 € |
| | T2 : | - | 7.400.000,00 € | 4.440.000,00 € |
| Waste sector | W1 : | - | 30.000,00 € | - |
| | W2 : | - | 30.000,00 € | - |
| Street lighting sector | SL1 : | - | 18.475,24 € | - |
| | SL2 : | - | 17.550,00 € | - |

#### 5.3.2.4. Residual value

Since the residual value represents the value which is attributable to an initial investment at the end of its lifetime, it is estimated and considered only for the last year of the lifetime of the investment. The residual value is subtracted by the costs as it is a positive income for the cash-flows. The residual value for each sector and measure was estimated through the formula illustrated in the methodology chapter. Below, in Table 26, the residual values are listed.

Table 26. Residual values costs for sectors and measures.

| | |
|---|---|
| Buildings sector | CB : 966.529,51 € |
| | CA : 1.125.981,57 € |

| | |
|---|---|
| | EB : 1.350.746,26 € |
| | EA : 2.918.724,23 € |
| Mobility sector | T1 : 4.144.000,00 € |
| | T2 : 4.144.000,00 € |
| Waste sector | W1 : 18.000,00 € |
| | W2 : 18.000,00 € |
| Street lighting sector | SL1 : 11.085,14 € |
| | SL2 : 10.530,00 € |

### 5.3.3. Benefits

After having defined in detail all the costs, we had to identify the benefits produced by the sustainable policies on the entire district and on the single sectors. Indeed, firstly we introduced the benefits that have a relevance on the whole district, while secondly we illustrated the specific benefits for each sector analysed. As already underlined, the main goal of this phase is to monetise all the benefits, in order to use them in the cost-benefit analysis. Most of the benefits were introduced from the second year of the lifetime of the investment.

The benefits, that were considered for the whole district, were the reduction of the primary energy need and the reduction of the $CO_2$ and $PM_{10}$ emissions. Before monetise them, we analysed the decrease in percentage from the current state of our reference district to the different measures proposed, considering these values divided according to the sectors analysed. First of all, in Table 27, we set out the decrease of the primary energy need in the buildings and public street lighting sector.

Table 27. Reduction of primary energy need divided for sectors and measures.

**Buildings sector**

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| Primary energy need Qnren [MWh/y] | 81.193,32 | 55.848,12 | 41.553,93 |
| | | -31% | |
| | | | -49% |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| Primary energy need Qnren [MWh/y] | 81.193,32 | 55.480,13 | 40.283,64 |
| | | -32% | |
| | | | -50% |

**Street lighting sector**

| | Current State | Street lighting 1 | Street lighting 2 |
|---|---|---|---|
| Primary energy need Qnren [MWh/y] | 578,72 | 385,44 | 228,87 |
| | | -33% | |
| | | | -60% |

We can notice that the percentage reduction of the primary energy need is significant from the current state to the different measures applied. Concerning the groups of measures of the buildings sector, we can deduce that the reduction of primary energy need of advanced groups of measures is higher compared to the base groups of measures. Indeed, the first ones have a reduction around 50% of primary energy need compared to the current state, while the second ones, the carbon and electric base groups of measures, have a reduction around 30% compared to the current state. To monetize the benefits obtained by the decrease of primary energy need, we considered the energy consumption, divided according to the energy source used, and multiplied them by the cost of the type of energy. To better clarify, for the buildings sector, we had to take the final consumption of natural gas, district heating and electricity and multiply them by their costs, while concerning the street lighting sector, we had to multiply the consumption of electricity by the cost connected to the public illumination. We are going to better describe this process in the next paragraphs.

Afterwards, we could focus our attention on the reduction of emissions production. Starting from the emissions of $CO_2$, we analysed, in Table 28, the percentage reduction of emissions produced from the current state to the other retrofit measures divided according to sectors.

Table 28. Reduction of $CO_2$ emissions divided for sectors and measures.

**Buildings sector**

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| $CO_2$ emissions [$tCO_2/y$] | 14.857,06 | 10.231,05 | 7.661,44 |
| | | -31% | -48% |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| $CO_2$ emissions [$tCO_2/y$] | 14.857,06 | 9.815,21 | 6.495,70 |
| | | -34% | -56% |

**Mobility sector**

| | Current State | Transport 1 | Transport 2 |
|---|---|---|---|
| $CO_2$ emissions [$tCO_2/y$] | 2.756,67 | 2.343,09 | 2.342,08 |

Current State → Transport 1: -15%

Current State → Transport 2: -15%

**Waste sector**

| | Current State | Waste 1 | Waste 2 |
|---|---|---|---|
| $CO_2$ emissions [$tCO_2/y$] | 0,88 | 0,25 | 0,12 |

Current State → Waste 1: -72%

Current State → Waste 2: -86%

**Street lighting sector**

| | Current State | Street lighting 1 | Street lighting 2 |
|---|---|---|---|
| $CO_2$ emissions [$tCO_2/y$] | 153,13 | 97,15 | 50,8 |

Current State → Street lighting 1: -36%

Current State → Street lighting 2: -67%

Also in the $CO_2$ emissions, we can notice a drastic reduction from the current state to the various measures applied in each sector. In the Table number 29, we monetized the benefits obtained by the reduction of $CO_2$ emissions related to each sector and each measure. To obtain these benefits, we subtracted the cost of emissions at the current state from the prices obtained in the different measures, in order to obtain the $CO_2$ emissions avoided in a monetary value. The costs of $CO_2$ emissions were extrapolated from [43]. These monetary benefits were considered from the second year of the lifetime of the investment.

Table 29. Benefits from the $CO_2$ emissions avoided divided for sectors and measures.

| | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|
| Buildings sector | CB : 76.329,16 € | 92.520,20 € | 166.536,36 € | 418.068,00 € |
| | CA : 118.727,73 € | 143.912,40 € | 259.042,32 € | 359.781,00 € |
| | EB : 83.190,52 € | 100.837,00 € | 181.506,60 € | 252.092,50 € |
| | EA : 137.962,44 € | 167.227,20 € | 301.008,96 € | 418.068,00 € |
| Mobility sector | T1 : 7.319,07 € | 8.871,60 € | 15.968,88 € | 22.179,00 € |
| | T2 : 6.840,73 € | 8.291,80 € | 14.925,24 € | 20.729,50 € |
| Waste sector | W1 : 10,39 € | 12,60 € | 22,68 € | 31,50 € |
| | W2 : 12,54 € | 15,20 € | 27,63 € | 38,00 € |
| Street lighting sector | SL1 : 923,67 € | 1.119,60 € | 2.015,28 € | 2.799,00 € |
| | SL2 : 1.688,44 € | 2.046,60 € | 3.683,88 € | 5.116,50 € |

Then, we analysed the percentage reduction of $PM_{10}$ emissions considering the difference between the emissions counted for the current state and the emissions produced in the other measures for each sector. Below, in the Table 30, it is illustrated the drastic reduction of emissions in all the measures and all the sectors.

Table 30. Reduction of $PM_{10}$ emissions divided for sectors and measures.

**Buildings sector**

| | Current State | Carbon Base measures | Carbon Advanced measures |
|---|---|---|---|
| $PM_{10}$ emissions [t $PM_{10}$/y] | 1,52 | 1,00 | 0,64 |
| | | -34% | |
| | | | -58% |

| | Current State | Electric Base measures | Electric Advanced measures |
|---|---|---|---|
| PM10 emissions [t PM10 /y] | 1,52 | 0,89 | 0,55 |
| | → -41% | | |
| | → -64% | | |

**Mobility sector**

| | Current State | Transport 1 | Transport 2 |
|---|---|---|---|
| PM10 emissions [t PM10/y] | 0,82 | 0,46 | 0,44 |
| | → -44% | | |
| | → -46% | | |

**Waste sector**

| | Current State | Waste 1 | Waste 2 |
|---|---|---|---|
| PM10 emissions [t PM10/y] | 0,00012 | 0,000035 | 0,000018 |
| | → -71% | | |
| | → -85% | | |

As it was calculated for the emissions of $CO_2$, we estimated the benefits of the $PM_{10}$ emissions avoided. Indeed, we calculated the costs due to these emissions, thanks to the price present in [44], in the current state and in the different measures for each sector and we subtracted the first ones to the second ones. These monetary benefits are listed in Table 31 and considered from the second year of the lifetime of the investment.

Table 31. Benefits from the $PM_{10}$ emissions avoided divided for sectors and measures.

| | |
|---|---|
| Buildings sector | CB : 2.510,67 € |
| | CA : 4.248,83 € |

| | |
|---|---|
| | EB : 3.041,77 € |
| | EA : 4.683,37 € |
| Mobility sector | T1 : 1.738,16 € |
| | T2 : 1.834,72 € |
| Waste sector | W1 : 0,41 € |
| | W2 : 0,49 € |
| Street lighting sector | SL1 : - |
| | SL2 : - |

After this global analysis, we focused our attention on the benefits that comes from the single sectors of our reference district.

#### 5.3.3.1. Buildings sector

Concerning the buildings sector, we found more than one benefit that could be monetised. Indeed, in addition to energy consumption reduction, we could also estimate the benefits obtained thanks to the creation of new jobs places with the consequent reduction of unemployment subsidies. Furthermore, we also considered the increment of the real estate market value of each apartment due to the energy performance improvement. Starting from the reduction of consumption of energy, we had to take into account the energy consumptions estimated before for the current state and the other groups of measures. Since we already estimated the costs of the consumptions of natural gas, district heating and electricity, for the current state and the other groups of measures, we had only to subtracte the costs consumption of the current state for the correspondent one of each group of measures. At the end, we will have for each measure a benefit, in monetary value, which corresponds to the total saving that the entire district has for each group of measures. We could consider these savings as a benefit from the second year of the lifetime of the investment.

Then, we evaluated the benefits coming from the creation of new jobs due to the huge investment carried out in the groups of measures of the buildings sector. From [45], we learnt that in the construction sector, for each millions of euro invested, 20,58 new workplaces are generated. Knowing the total initial investment for each group of measures, it was easy to estimate the number of green jobs created. This number was multiplied by the shadow wage, which measures the opportunity cost of labour. The shadow wage is determined by [46]:

$$SW = W \ (1-t) \ (1-u)$$

W represents the average construction gross annual salary, which is around 25.043 € in Italy;

t income tax rate, which is 20% in Italy;

u unemployment rate of the area or country considered, which is 10,6 % in Piedmont region.

The final result is 17.910,75 €. This value was multiplied by the number of new jobs obtained. Thanks to this procedure, we estimated the benefits obtained by the creation of new jobs in monetary value. These benefits can be considered only for the first year of the lifetime of the investment, since it is supposed that the retrofit buildings sites will last not more than one year. After that, the creation of green jobs will be only related to the maintenance work on the buildings. For this reason, we proportioned the cost of the initial investment with the costs connected to the maintenance works, to estimate the number of jobs kept after the first year. To better clarify, the benefits connected to green jobs in the first year of the lifetime of the investment are related to the retrofit works, while the benefits from the second year are connected to the only maintenance works. Furthermore, another social and economic benefit estimated is the reduction of the unemployment subsidies. Indeed, for the average construction salary, 1.206,25 € is the monthly unemployment subsidy provided [45]. Since this benefit is related to the creation of green jobs, we estimated the unemployment subsidies in accordance with the number of green jobs. For this reason, the monetary benefits for the reduction of the unemployment subsidies vary from the first to the second year of the lifetime of the investment.

The last positive impact on the society, that we considered for the buildings sector was, the increase of the real estate market value of each apartment. In [47], we found that the monetary value for the increase of the real estate value, for each energy class change and each apartment, is around 6.280 €. Consequently, since we knew the changes of energy class for each building typology thanks to MasterClima models, we could obtain the increase of real estate market value for each apartment and each measures. Since the real estate market value is in accordance with the single apartments, we extrapolated from Tabula [7] their number for each building typology. In Table 32 the monetary benefits obtained thanks to the buildings sector divided according to the group of measures are listed: the energy costs reduction, the creation of green jobs, the reduction of unemployment subsidies and the increase of real estate market value.

Table 32. Benefits from buildings sector.

| **Energy costs avoided** | **Green jobs** |
|---|---|
| CB : 739.202,35 € | CB : 9.582.251,25 € |
| CA : 476.299,09 € | CA : 15.849.939,11 € |
| EB : 768.954,85 € | EB : 12.895.740,00 € |
| EA : 522.282,55 € | EA : 23.964.538,80 € |

| Subsidies | Real estate market value |
|---|---|
| CB : 7.744.125,00 € | CB : 31.371.047,55 € |
| CA : 12.810.375,00 € | CA : 53.239.713,73 € |
| EB : 10.422.000,00 € | EB : 35.572.695,36 € |
| EA : 19.758.375,00 € | EA : 82.657.528,89 € |

#### 5.3.3.2. Mobility sector

Afterwards, we estimated the economic benefits obtained by the mobility sector for the entire district. Firstly, we evaluated the savings obtained by the fuel costs avoided, considering both the public means of transports and the private vehicles. Indeed, to substitute all the old buses with new electrical ones will allow to reduce the expenses connected to fuel. To find these savings, we considered the expenses related to fuel in the current state and the other measures, both for private vehicles and public means of transports. With these data, we could obtain the fuel costs avoided. These results are listed in the Table 33. In the same table are also indicated the gains obtained by the increase of the sale of tickets. This benefit was only present for the second measure, in which we have the increase of the numbers of buses that cross our reference district. In this case, we had to estimate the gains of tickets in the current state of the reference district and in the second measure of the transport sector, in order to calculate the difference between them. To do this, we considered the average length of a bus path dividing it by the kilometres travelled by each bus line inside our reference district. After having multiplied this value for the costs of the urban ticket, which is 1,50 €, we will obtain the daily gains for tickets for the only kilometres travelled in our district. All these results were then, referred to an entire year.

Table 33. Benefits from mobility sector.

| Fuel costs avoided | Ticket gains |
|---|---|
| T1 : 191.019,10 € | T1 : - |
| T2 : 229.720,05 € | T2 : 26.134 € |

#### 5.3.3.3. Waste sector

In waste sector, the benefit estimated was referred to the cost of fuel avoided. Indeed, thanks to the reduction of the frequency of the waste trucks, the fuels used by them drastically decrease. Knowing the expenses for the fuel in the current state and the ones in the other measures we could obtain the annual savings for both measures. In Table 34, these savings are enumerated.

Table 34. Benefits from waste sector.

| Fuel costs avoided |
|---|
| W1 : 383,60 € |
| W2 : 460,32 € |

#### 5.3.3.4. Street lighting sector

Lastly, concerning public street lighting sector, we considered among the benefits the energy costs avoided. Knowing the expenses of electricity for public street lighting in the current state and in the other measures we just had to subtracted them to find the monetary savings. In Table 35, these savings are listed for both measures.

Table 35. Benefits from street lighting sector.

| Energy costs avoided |
|---|
| SL1 : 6.653,92 € |
| Sl2 : 12.025,79 € |

## 5.4. Cost-benefit analysis and its economic indicators

After having defined the costs and the benefits for all the sectors and measures, we could move to the cost-benefit analysis for each scenario. As already explained in the methodology, we had to sum up the costs and the benefits for each measure considered in every scenario of each sector. In the Figure 16, it is illustrated which is the structure of the cost-benefit analysis matrix.

Figure 16. Cost-benefit analysis matrix.

| | | | Liftetime of the investment | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | ... | 30 |
| Costs | Investment costs | | | | | | |
| | Running costs | Manteinance costs | | | | | |
| | | Fuel costs | | | | | |
| | | Operating costs | | | | | |
| | | $CO_2$ emissions | | | | | |
| | | $PM_{10}$ emissions | | | | | |
| | Replacement costs | | | | | | |
| | Residual value | | | | | | |
| | **TOTAL** | | | | | | |
| Benefits | $CO_2$ emissions avoided | | | | | | |
| | $PM_{10}$ emissions avoided | | | | | | |
| | Buildings sector | Energy costs avoided | | | | | |
| | | Green jobs | | | | | |
| | | Reduction unemployment subsidies | | | | | |
| | | Real estate market value | | | | | |
| | Mobility sector | Fuel costs avoided | | | | | |
| | | Tickets | | | | | |
| | Waste sector | Fuel costs avoided | | | | | |
| | Street lighting sector | Energy costs avoided | | | | | |
| | **TOTAL** | | | | | | |

In the rows we listed both costs and benefits, while in the columns there are the years, from 1 to 30, which indicate the lifetime of the investment. In the white spaces we are going to insert the correspondent costs and benefits in monetary value at a specific year. One of this chart for each scenario was developed in order to obtain for each year the total costs and benefits of our reference district. For this reason, we filled in six charts and with the total costs, benefits and cah-flows obtained, we could calculate the economic indicators to achieve the best environmental, social and economic scenario for our reference district. The Table 36 shows he economic results obtained.

Table 36. Results of economic indicators of different scenarios

| | |
|---|---|
| **Scenario CB+T1+W1+SL1** | **Scenario CB+T2+W2+SL2** |
| ENPV : -150.767.300,30 € | ENPV : -150.707.815,20 € |
| ERR : 64% | ERR : 74% |
| B/C ratio : 0,38 € | B/C ratio : 0,38 € |
| **Scenario EB+T1+W2+SL1** | **Scenario EB+T2+W2+SL2** |
| ENPV : -132.357.499,78 € | ENPV : -132.372.803,70 € |
| ERR : 51% | ERR : 58% |
| B/C ratio : 0,47 € | B/C ratio : 0,47 € |
| **Scenario CA+T2+W2+SL2** | **Scenario EA+T2+W2+SL2** |
| ENPV : -129.753.029,92 € | ENPV : 40.865.803,83 € |
| ERR : 27% | ERR : - |
| B/C ratio : 0,51 € | B/C ratio : 1,14 € |

The results obtained show that all the scenarios, except for one, are not sustainable from the economic point of view. Indeed, their cash-flows are negative for all the years of the lifetime of the investment with a consequent negative net present value of the investment and negative ratio between benefits and costs. The only scenario, in which the net present value and the ratio between benefits and costs is positive, is the most invasive one. For this reason, this will be the most suitable one for our reference district. We can notice that the buildings sector is the most influencial sector as the results of the scenarios change drastically when we modify the measure foreseen for the buildings sector. Indeed, the scenarios, in which the measure for the buildings sector is the same, have almost the same results of ENPV and B/C ratio. After this consideration, we decided to analyse all the possible scenarios that include the measure electric advanced for buildings sector and the measure waste 2 as, from the previous costs and benefits calculations, we noticed that is the most sustainable one for the waste sector. This is because we wanted to be sure to find the most sustainable scenario. For these reasons, the other scenarios analysed were:

- EA+T1+W2+SL1
- EA+T1+W2+SL2
- EA+T2+W2+SL1

We created the same matrix for these three scenarios filling in them with the costs and benefits previously estimated. In Table 37, we listed the results of the economic indicators obtained in these scenarios.

Table 37. Results of economic indicators of different scenarios

| **Scenario EA+T1+W2+SL1** | **SCENARIO EA+T1+W2+SL2** |
|---|---|
| ENPV : 42.079.071,58 € | ENPV : 42.965.375,71 € |
| ERR : - | ERR : - |
| B/C ratio : 1,15 € | B/C ratio : 1,15 € |

**SCENARIO EA+T2+W2+SL1**

ENPV : 42.811.481,52 €

ERR : -

B/C ratio : 1,15 €

We can notice that the results are similar to the ones obtained with the most invasive scenario, but that the best scenario is the EA+T1+W2+SL2 as it has the highest net present value and ratio between benefits and costs.

## 5.5. Bibliography

[1] Città di Torino, Sezioni di censimento, 2017. Available at: http://aperto.comune.torino.it/?q=node/113, last access: December 2017.

[2] Città di Torino, Geoportale del Comune di Torino. Available at: http://www.comune.torino.it/visualizzatore/, last access: December 2017.

[3] Città di Torino. Assessorato all'Urbanistica, Piano Regolatore Generale di Torino. Norme Urbanistico Edilizie di Attuazione, 2006. Available at: http://www.comune.torino.it/ediliziaprivata/prgc/tavole/V07_variante/10_testo_coordinato_var_100.pdf. [Accessed: 12-Nov-2017], last access: December 2017.

[4] G. Mutani, C. Delmastro, M. Gargiulo, S. P. Corgnati, Characterization of building energy consumption at the urban scale, Energy Procedia 101 (2016) 384–391.

[5] I.Stat, Istruzione. Available at: http://dati.istat.it/Index.aspx?DataSetCode=DCIS_SANSCUOLE, last access: December 2017.

[6] DM 18/12/1975 - Norme tecniche aggiornate relative all'edilizia scolastica, ivi compresi gli indici di funzionalità didattica, edilizia ed urbanistica, da osservarsi nella esecuzione di opere di edilizia scolastica. Available at: http://www.edscuola.it/archivio/norme/decreti/dm181275.html, last access: January 2018.

[7] V. Corrado, I. Ballarini, S. P. Corgnati, Building Typology Brochure - Italy. Fascicolo sulla Tipologia Edilizia Italiana, 2014. Available at: http://www.building-typology.eu/downloads/public/docs/brochure/IT_TABULA_TypologyBrochure_POLITO.pdf, last access: May 2018.

[8] C. Delmastro, G. Mutani, S. P. Corgnati, A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale, Energy Policy 99 (2016) 42–56.

[9] G. Vergerio, La questione energetico-ambientale-economica nell'edilizia residenziale: Sviluppo di una metodologia di valutazione semplificata per interventi a scala urbana, Polytechnic of Turin, 2017.

[10] TABULA Web Tool. Available at: http://webtool.building-typology.eu/#bm, last access: May 2018.

[11] Città di Torino. InformAmbiente, Teleriscaldamento, 2016. Available at: www.comune.torino.it/ambiente/energia/fonti_rinn/integrazione-edificio-impianto.shtml, last access: Febraury 2018.

[12] DM 26/6/2015 - Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici, Allegato I, Criteri generali e requisiti delle prestazioni energetiche degli edifici. Available at: http://www.sviluppoeconomico.gov.it/index.php/it/normativa/decreti-interministeriali/2032966-decreto-interministeriale-26-giugno-2015-applicazione-delle-metodologie-di-calcolo-delle-prestazioni-energetiche-e-definizione-delle-prescrizioni-e-dei-requisiti-minimi-degli-edifici, last access: Febraury 2018.

[13] UNI EN ISO 12381:2006, calcolo carico termico di progetto.

[14] F. Toso , A. Mura, Raccolta dati per la determinazione e caratterizzazione delle tipologie di impianto per il condizionamento invernale ed estivo negli edifici destinati a scuole e uffici, 2013. Avalaible at: http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/edifici-pa/2012/rds-2013-141.pdf, last access: March 2018.

[15] S. P. Corgnati, V. Corrado, M. Filippi, A method for heating consumption assessment in existing buildings: a field survey concerning 120 Italian schools, Energy and Buildings 40 (2008) 801–809.

[16] A.-F. Marique, S. Reiter, A method for evaluating transport energy consumption in suburban areas, Environmental Impact Assessment Review 33 (1) (2012) 1–6.

[17] Centro Tematico Nazionale Atmosfera Clima ed Emissioni in Aria, Manuale dei fattori di emissione nazionali, Gennaio 2002.

[18] Città di Torino, Piano urbano della mobilità sostenibile. Sistema della mobilità in città. BANCA DATI - Scenario di riferimento 2008, 2008. Available at: http://www.comune.torino.it/geoportale/pums/cms/images/files/introduzione/PUMS_ALL2_SISTEMA_MOBILITA_IN_CITTA_tabelle.pdf, last access: November 2017.

[19] GTT (Gruppo Torinese Transporti), Parco Veicoli. Schede tecniche, 2015. Available at: http://www.gtt.to.it/cms/risorse/gruppo/veicoli/parco_veicoli_tpl.pdf, last access: January 2018.

[20] AMIAT (Azienda Multiservizi Igiene Ambientale Torino), La carta della qualità dei servizi. Edizione 2014, 2014. Available at: http://www.amiat.it/cms/phocadownload/Carta_dei_servizi/amiat_cartaservizi_2014_web.pdf, last access: May 2018.

[21] Gianpaolo Roscio, Illuminazione pubblica.L'eseperienza di Torino, intervento al convegno "Illuminazione pubblica. Un'opportunità rilevante di risparmio economico ed efficienza energetica", 11 Dicembre 2014.

[22] Comune di Torino, Politecnico di Torino, Piano d'azione per l'energia sostenibile. TAPE Turin Action Plan for Energy, Comune di Torino,

Torino 2009.

[23] ENEA (Agenzia Nazionale Efficienza Energetica), Rapporto Annuale 2017. Le detrazioni fiscali del 65% per la riqualificazione energetica del patrimonio edilizio esistente, 2017. Available at: www.anit.it/wp-content/uploads/2017/08/Detrazioni-65-2017.pdf, last access: Febraury 2017.

[24] EC (European Commission), Sistema informazioni geografiche per il fotovoltaico - mappe interattive. Available at: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=it&map=europe, last access: April 2018.

[25] MC 11300 (MasterClima 11300). Available at: http://www.masterclima.info/page/Software.aspx, last access: March 2018.

[26] G. Guccione and D. Linghin, Torino: GTT taglia le fermate per avere mezzi più veloci, il test della linea 4, in "La Repubblica - Torino" versione online, 4 ottobre 2016. Available at: http://torino.repubblica.it/cronaca/2016/10/04/news/torino_gtt_taglia_le_fermate_per_avere_mezzi_piu_veloci_il_test_sulla_linea_4-149084850/, last access: June 2018.

[27] A. Rossi, A torino i tram più lenti d'Europa, in "La Stampa - Torino" versione online, 5 ottobre 2016. Available at: http://www.lastampa.it/2016/10/05/cronaca/a-torino-i-tram-pi-lenti-deuropa-ZEBXbZlwM2P7rGKvRy8ZRN/pagina.html, last access: June 2018.

[28] Regione Piemonte, Prezziaro della regione Piemonte. Prezzi di riferimento per opere e lavori pubblici nella regione Piemonte, 2016.

[29] Città di Milano, Listino prezzi per l'esecuzione di opere pubbliche e manutenzioni, Volume 1.2, 2018.

[30] Provincia Autonoma Bolzano, Elenco prezzi provinciale online. Available at: http://www.provincia.bz.it/lavoro-economia/appalti/elenco-prezzi-provinciale-online.asp#accept-cookies, last access: May 2018.

[31] GTT (Gruppo Torinese Transporti), Presentata la nuova flotta di bus elettrici da 12 metri, 2017. Available: http://www.gtt.to.it/cms/notizie-eventi-e-informazioni/4223-presentata-la-nuova-flotta-di-bus-elettrici-da-12-metri, last access: April 2018.

[32] Comune di Salerno, Capitolato speciale di appalto per la fornitura ed annesse opere edili per la realizzazione di n°9 isole ecologiche seminterrate ed n°1 isola ecologica interrata, per il potenziamento della raccolta differenziata dei rifiuti urbani nel territorio comunale. Available at: http://www.comune.salerno.it/allegati/7095.pdf, last access: May 2018.

[33] Comun General de Fascia, Piano di gestione dei rifiuti solidi urbani in val di Fassa, 2015. Available at: file:///C:/Users/Elisa/Desktop/2016 Piano Gestione RSU (1).pdf., last access: May 2018.

[34] Friuli Venezia Giulia STRADE, Elenco prezzi unitari. Manutenzione ordinaria e straordinaria impianti elettrici, 2014. Available at: http://www.fvgstrade.it/cms/data/pages/files/000004_resource3_orig.pdf, last access: May 2018.

[35] European Standard EN 15459, Energy performance of buildings - Economic evaluation procedure for energy systems in buildings, 2007.

[36] GTT (Gruppo Torinese Transporti), Relazione e bilancio al 31/12/2014. Available at: http://www.gtt.to.it/cms/risorse/gruppo/GTT-Bilancio_2014_CDM_def.pdf, last access: June 2018.

[37] Amiat, Bilancio d'esercizio 2016, 2016. Available at: http://www.comune.torino.it/commercioeimpresa/bm~doc/bilancio-2016.pdf, last access: May 2018.

[38] IREN, Luce gas e servizi. Available at: https://www.irenlucegas.it/casa/offerte/iren-10x2-gas, last access: May 2015.

[39] Tariffe teleriscaldamento (iva esclusa) in vigore dal 1/1/2018. Available at: https://www.ilteleriscaldamento.eu/pdf/torino/torino_01_01_2018.pdf, last access: May 2018.

[40] Eurostat Statictics Explained, Electricity prices for household consumers, second half 2016 (EUR per kWh). Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Electricity_prices_for_household_consumers,_second_half_2016_(EUR_per_kWh)_YB17.png, last access: May 2018.

[41] Sorgenia, Costo kWh di energia elettrica: qual è il prezzo dell'elettricità in Italia e in Europa? Available at: https://www.sorgenia.it/guida-energia/elettricita/costo-kwh-energia-elettrica-prezzo-in-italia-ed-europa, last access: May 2018.

[42] Sistema elettrico Nazionale, Tariffa per illuminazione pubblica. Available at: https://www.servizioelettriconazionale.it/it-IT/tariffe/illuminazione-pubblica, last access: May 2018.

[43] Commission delegated regulation (UE) n.244/2012 of 16 January 2012. Available at: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex:32012R0244, last access: June 2018.

[44] U. Schirpke, R. Scolozzi, C. De Marco, Modello dimostrativo di valutazione qualitativa e quantitativa dei servizi ecosistemici nei siti pilota. Parte 1: metodi di valutazione, 2014.

[45] F. Dell'Anna, Evaluating co-benefits of nZED projects: methodological approach and experimentation in the city of Turin, Polytechnic of Turin, 2015.

[46] C. Becchio, S. P. Corgnati, F. Dell'Anna, Cost benefit analysis and smart grid projects, NEWDIST (2016) 278- 287.

[47] M. Bottero, M. Bravi, G. Mondini, A. Talarico, Buildings energy performance and real estate market value: an application of the spatial auto regressive (SAR) model, in Appraisal: from theory to practice, 2017, pp. 220-230.

# Conclusions

The aim of this thesis was to identify the most sustainable retrofit scenario, composed by measures applied on the buildings, mobility, waste and street lighting sectors of the reference district that we developed for the city of Turin.

The best retrofit scenario obtained is the EA+T1+W2+SL2, composed by the electric advanced groups of measures for the buildings sector, the transport 1 measure for the mobility sector, the waste 2 measure for the waste sector and the street lighting 2 measure for the public street lighting sector. Indeed, the Economic Net Present Value for this scenario is 42.965.375,71 € and for each euro spent, 1,15 € is gained. During the economic analysis, we noticed that the dominant sector is the buildings one as it is the most influent concerning the reduction of primary energy need and the decrease of emissions. Moreover, it is easier to monetise more benefits for this sector with respect to the other ones. At variance, in the scenarios in which different groups of measures with respect to the electrical advanced for the buildings sector were considered, we noticed that the investment are not sustainable from the economic and social point of view as they do not produce positive cash-flows during the years of the lifetime of the investment.

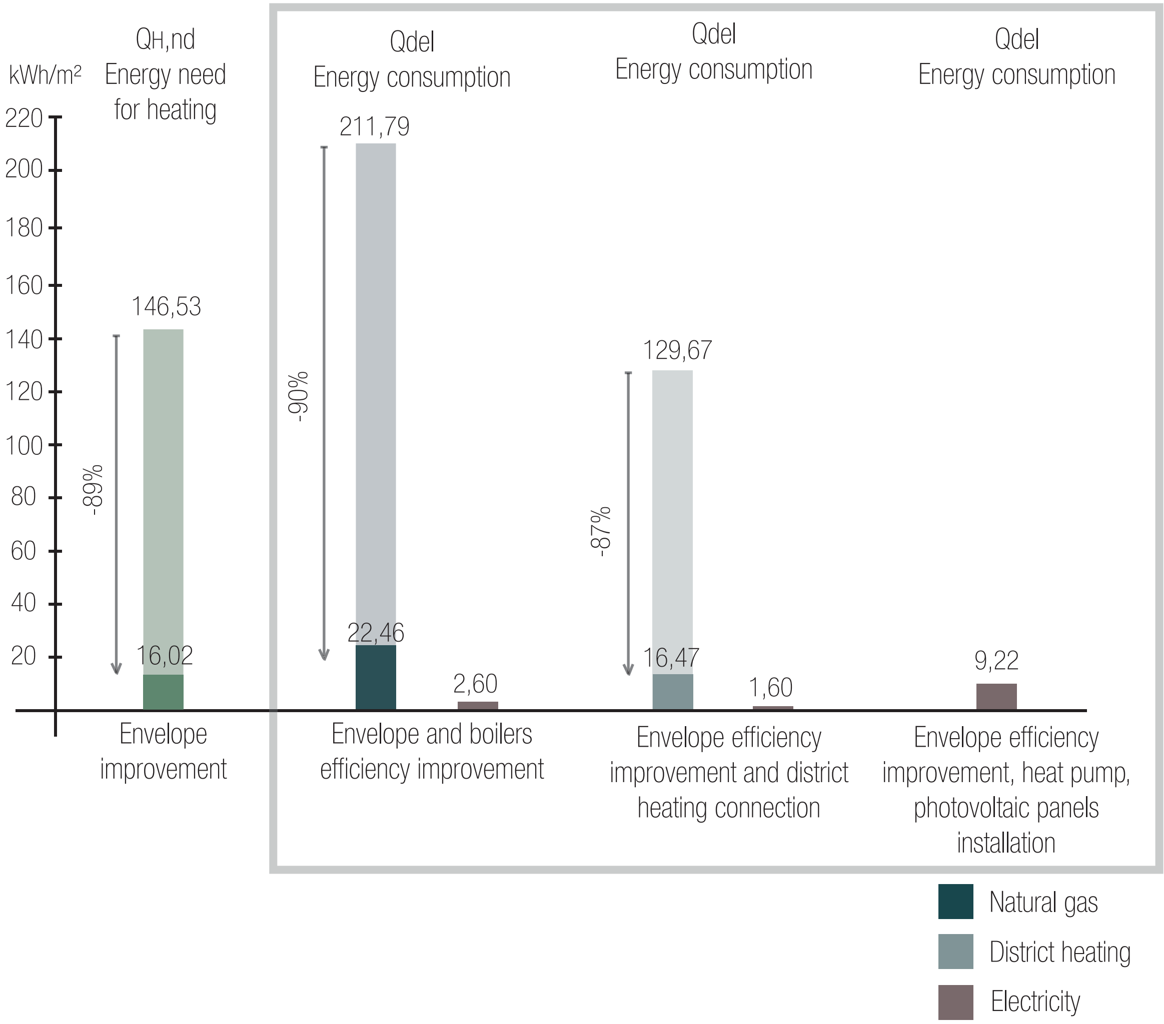
Although the costs of initial investments and the other costs, for instance maintenance and operating costs, are really high in the optimal scenario, the social benefits translated into monetary value allow to have finally a positive feedback. Indeed, benefits rise together with costs and overcome them in the scenarios with the electric advanced measure for the buildings sector. As an example, the economic benefits obtained by the creation of new work places increase with the raise of the initial investment. Moreover, related to green jobs, there are also the benefits obtained by the reduction of unemployment subsidies. Besides, in this scenario, the real estate market of buildings sector also play a key role in the cost-benefit analysis. In fact, in the electric advanced measures, the change of energy classes are more numerous than in the other ones. Furthermore, the introduction in the buildings sector of heat pumps, which consume electricity as energy source, and of photovoltaic panels systems allowed to increase the renewable energy used in the district. Lastly, thanks to the reduction of the primary energy need and the decrease of the production of $CO_2$ and $PM_{10}$ emissions the costs related to them dropped, while the benefits increased.

Concerning the future developments, we met our initial goal to develop an environmental, social and economic sustainable reference district for the city of Turin. The best scenario chosen could be reproduced in the entire area of the urban system considering that, even if the investment costs are high, the entire community will have an economic return. As far as the cost-benefit analysis is concerned, even if we could consider all the costs that have to be covered in the district, we were not able to monetize all the benefits that are obtained by the whole community. For instance, we did not evaluate the benefits connected to the increase of health and wellbeing thanks to the reduction of air and light pollution. When new methodologies will be develop to monetize these and other benefits, the cost-benefit analysis will be more accurate and more reliable so that hopefully the stakeholders will realise the importance of such measures.

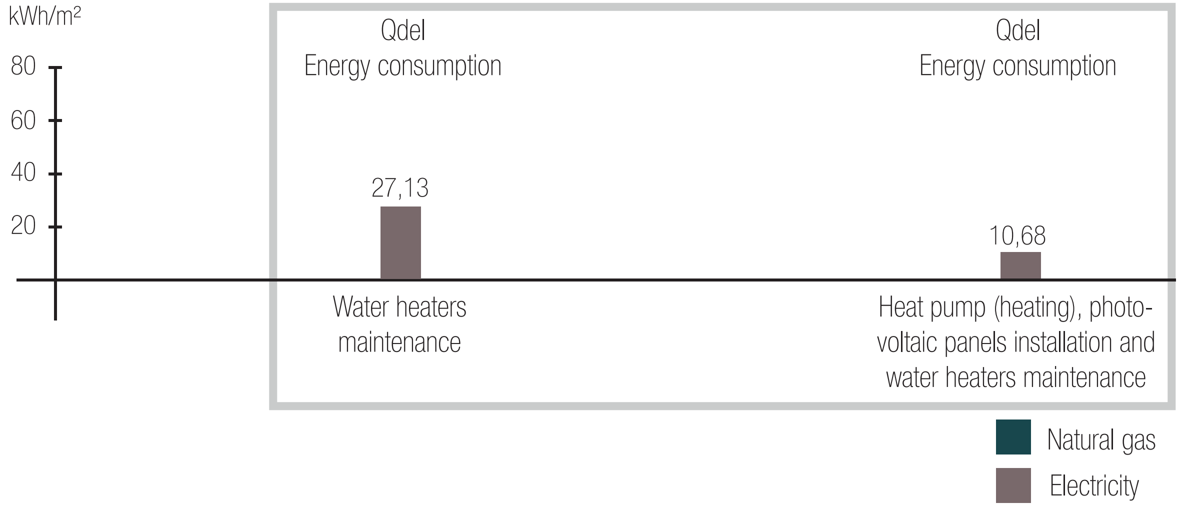
## Annex A - Consumptions of the buildings sector

### 1946-1960 AB

HEATING

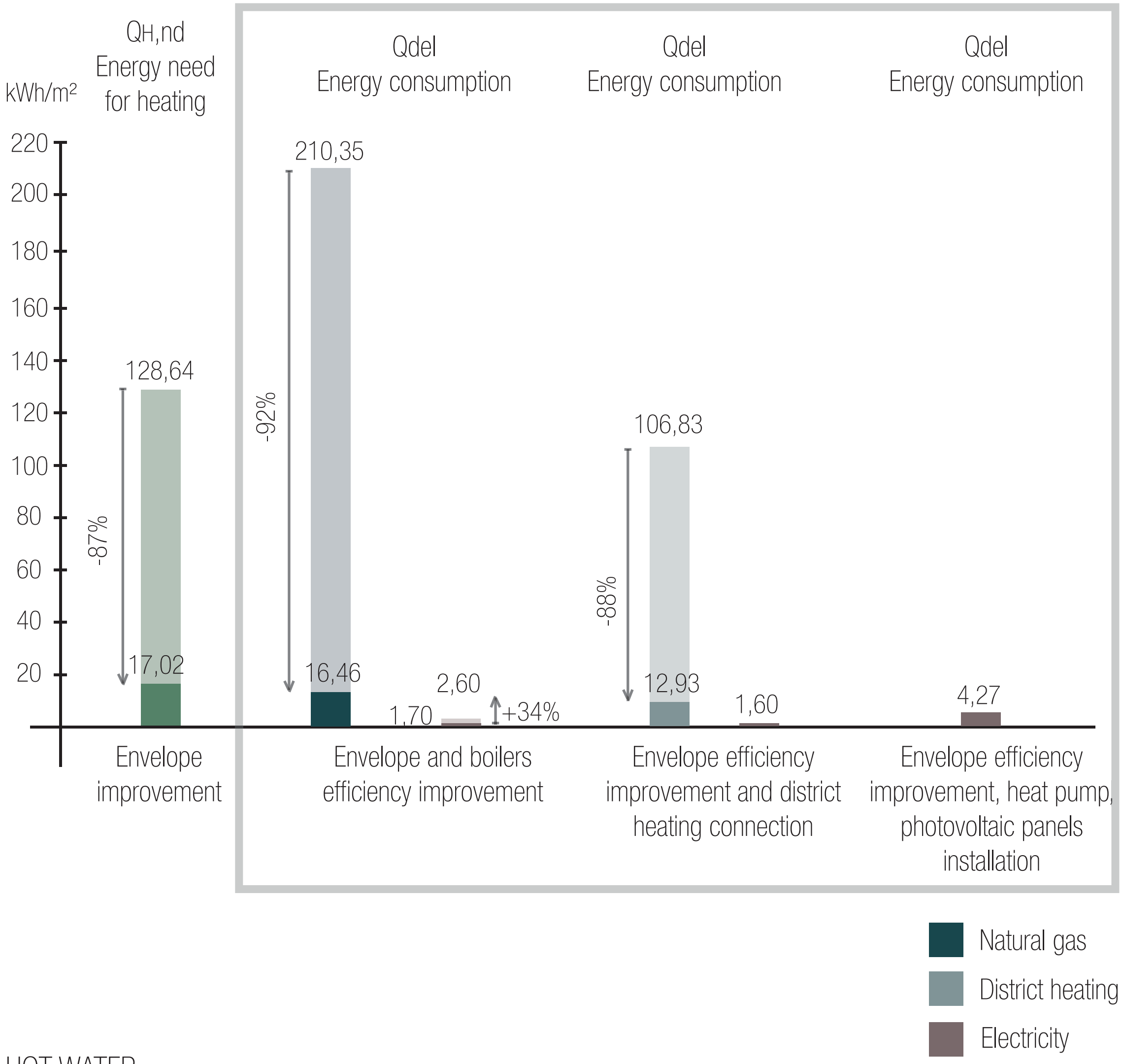



HOT WATER



**1961-1975 AB**

HEATING

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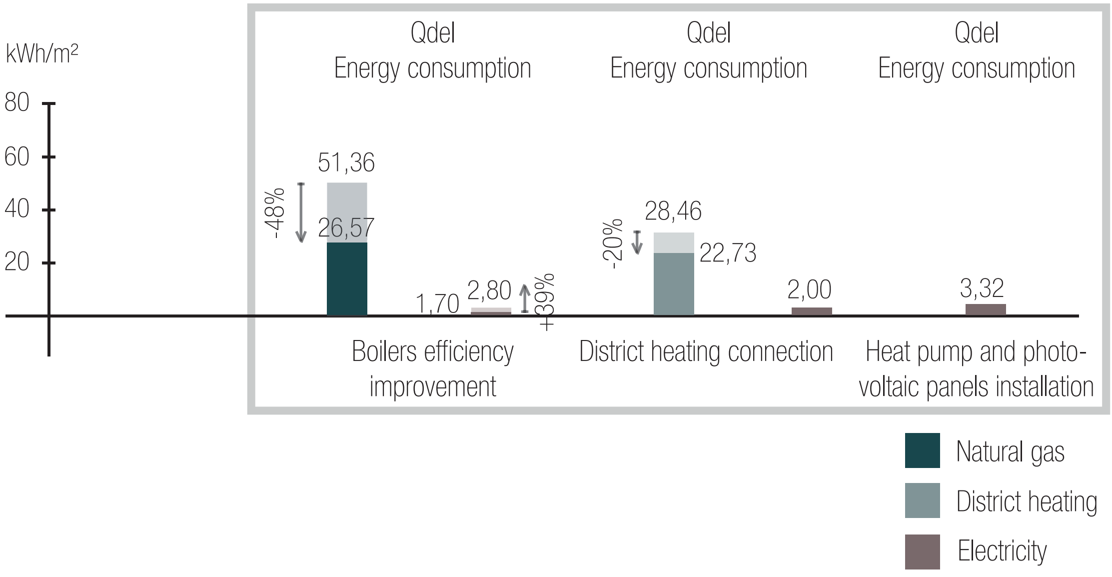
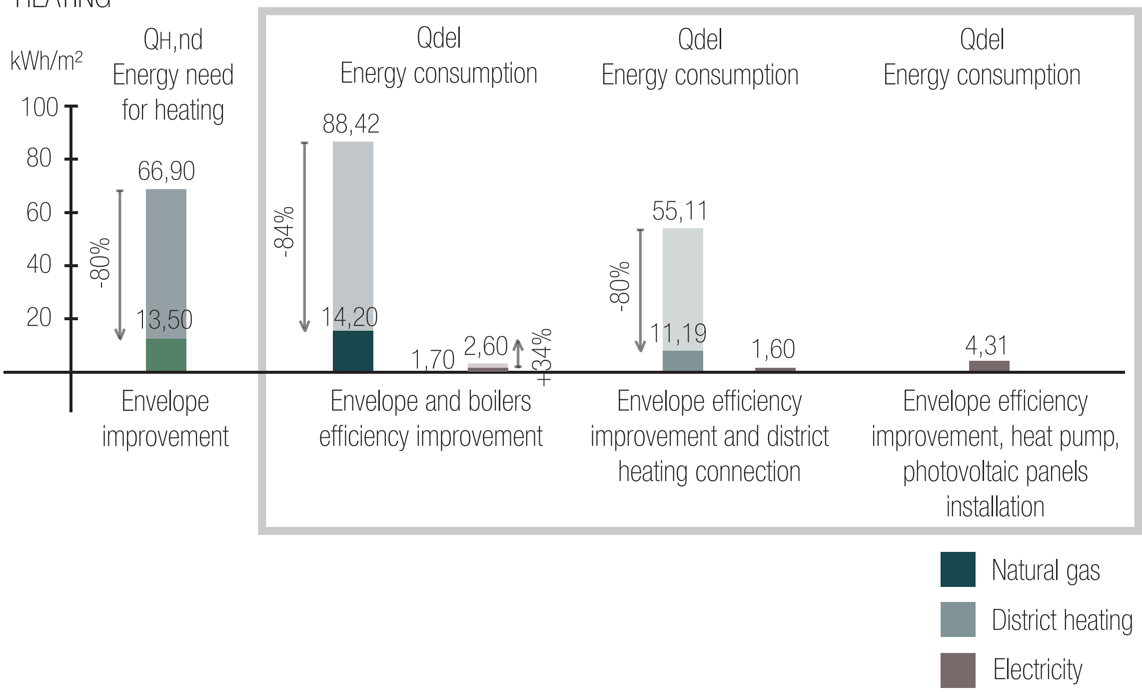
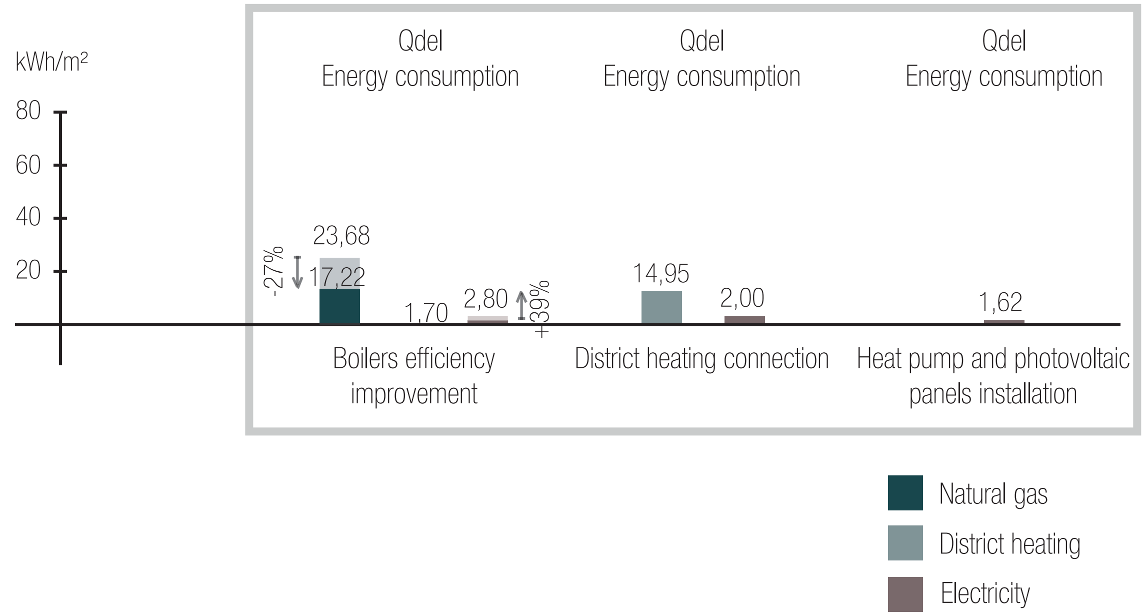


## 1976-1990 AB

HEATING

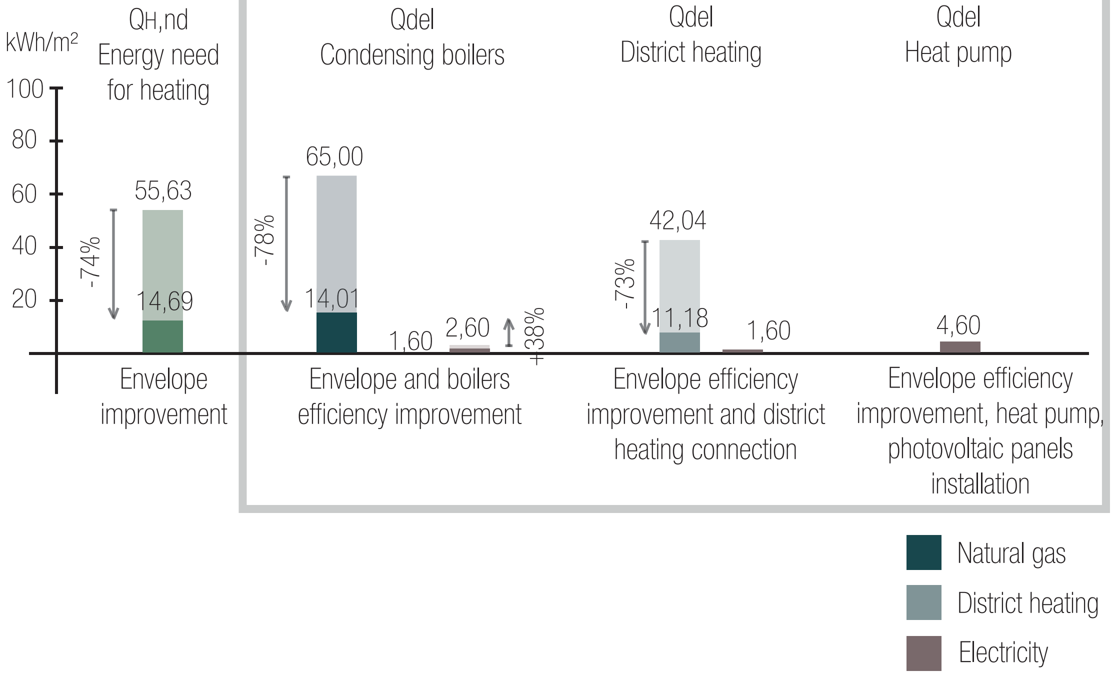



HOT WATER



## 1991-2005 AB

HEATING

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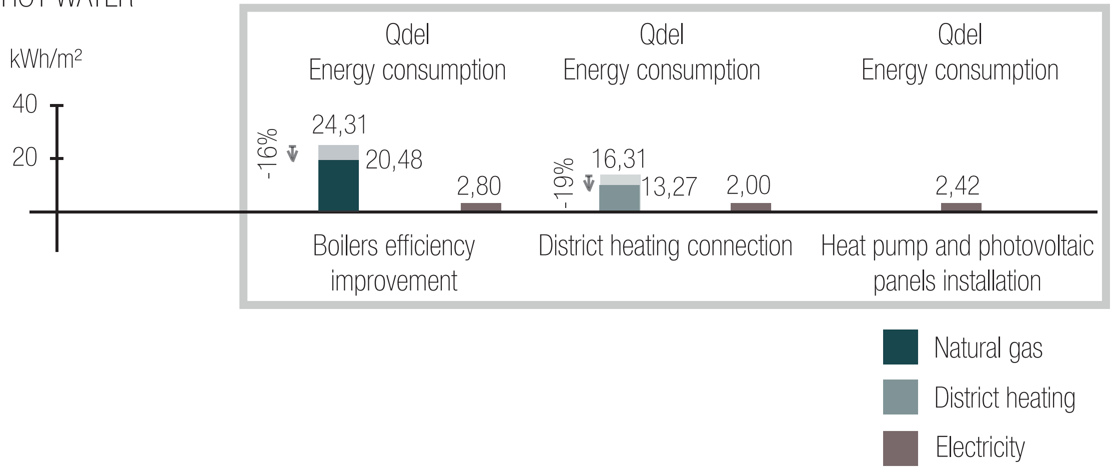
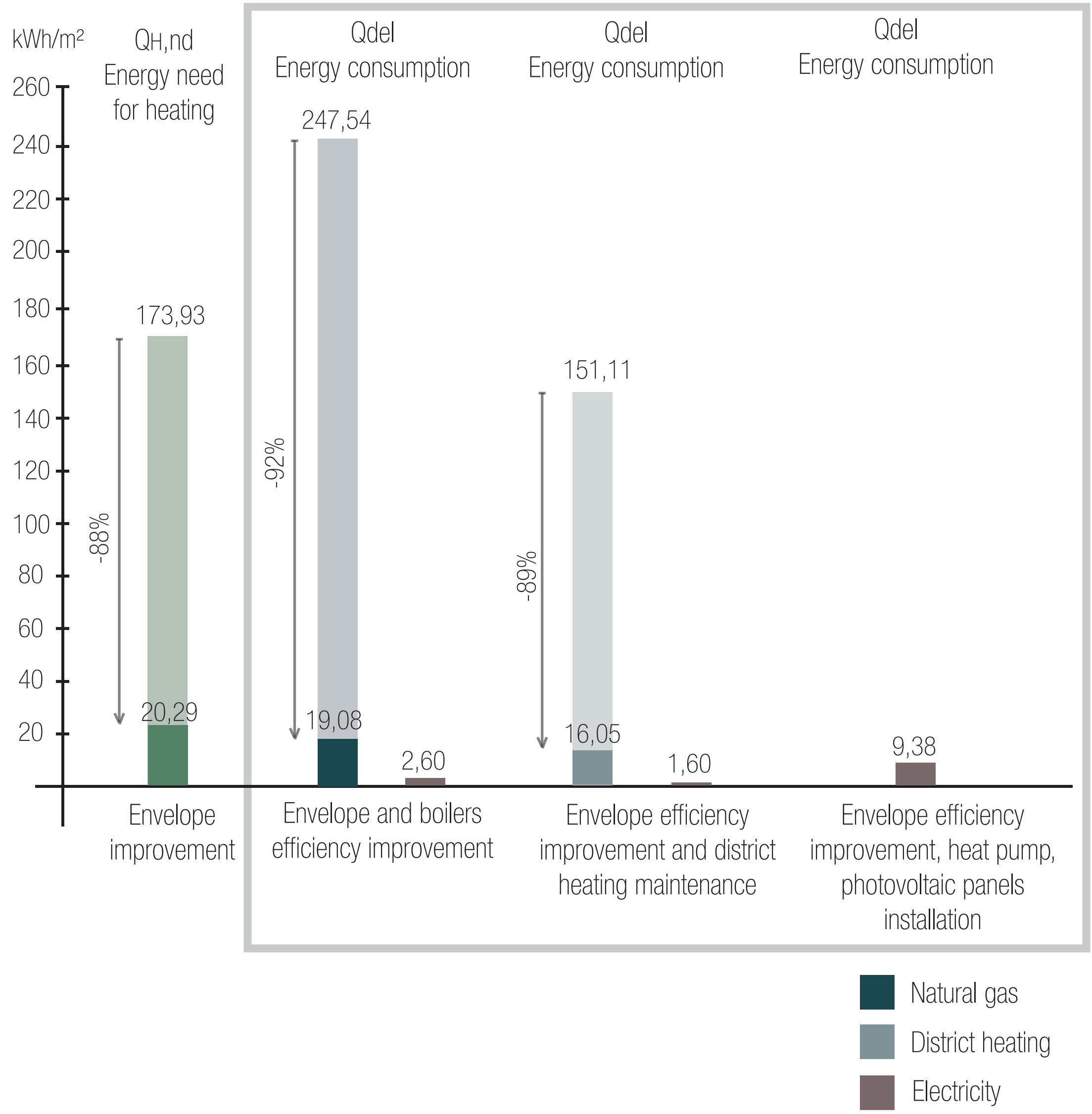


**1946-1960 MFH**

HEATING

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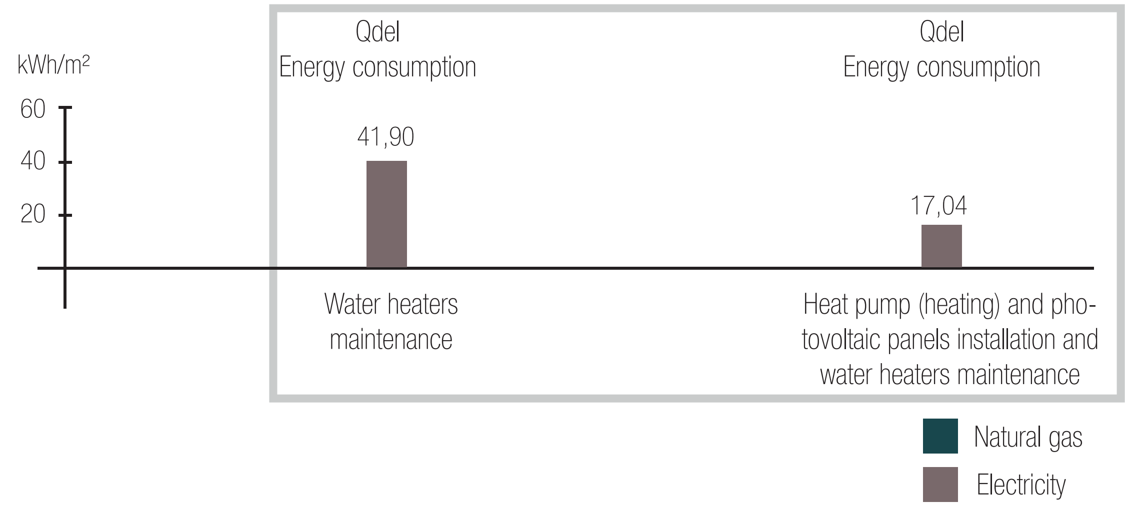
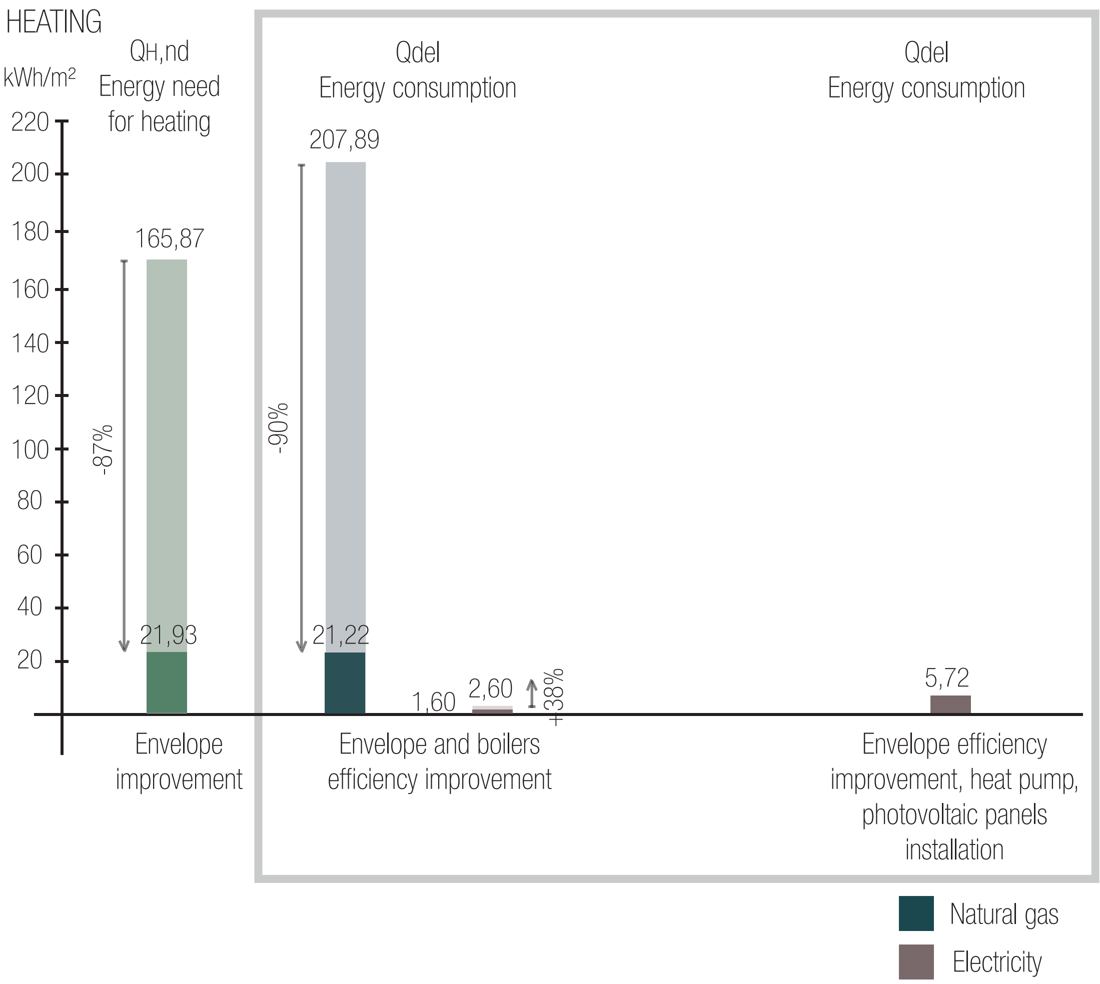
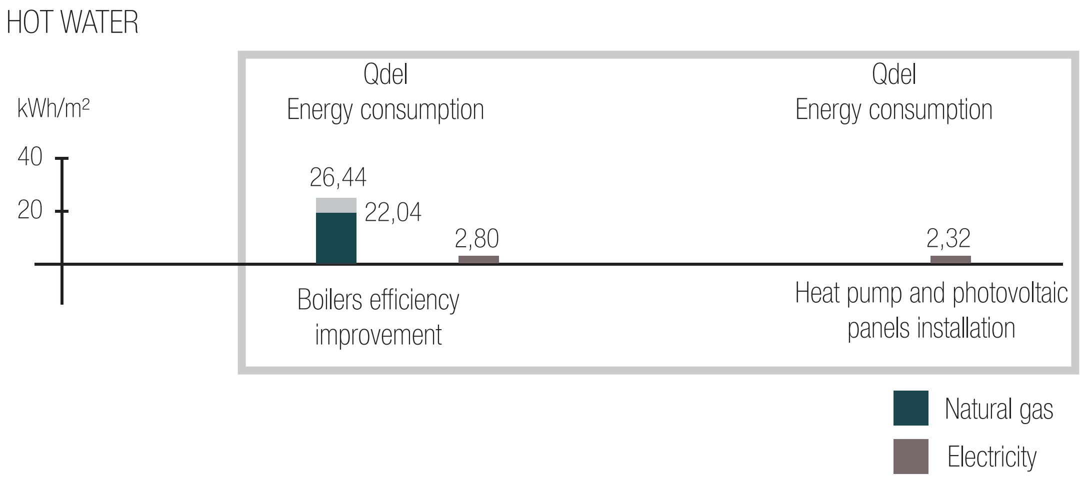


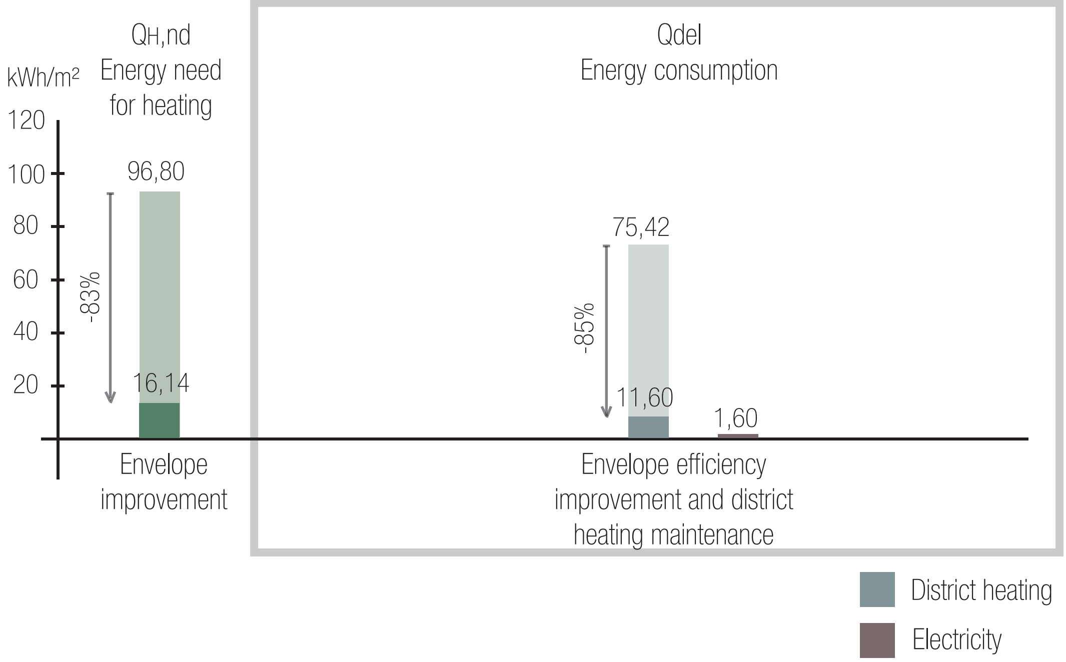
## 1961-1975 MFH



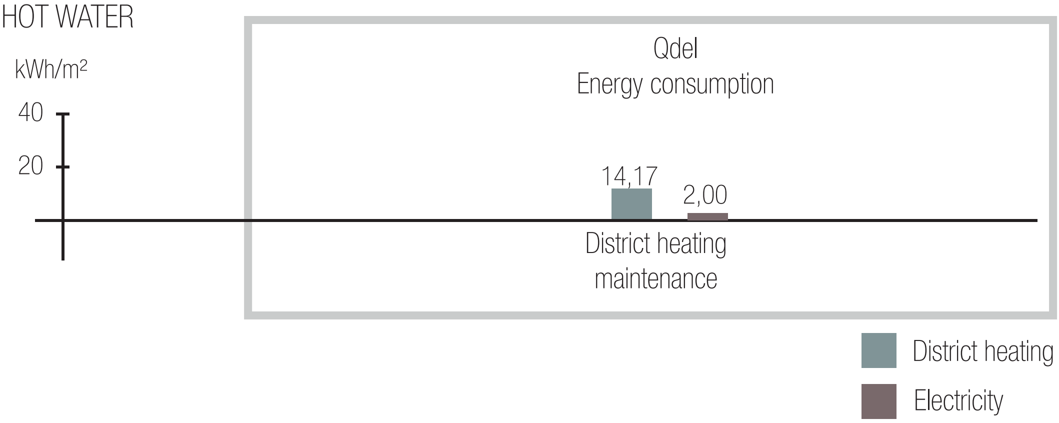



**1976-1990 MFH**

HEATING

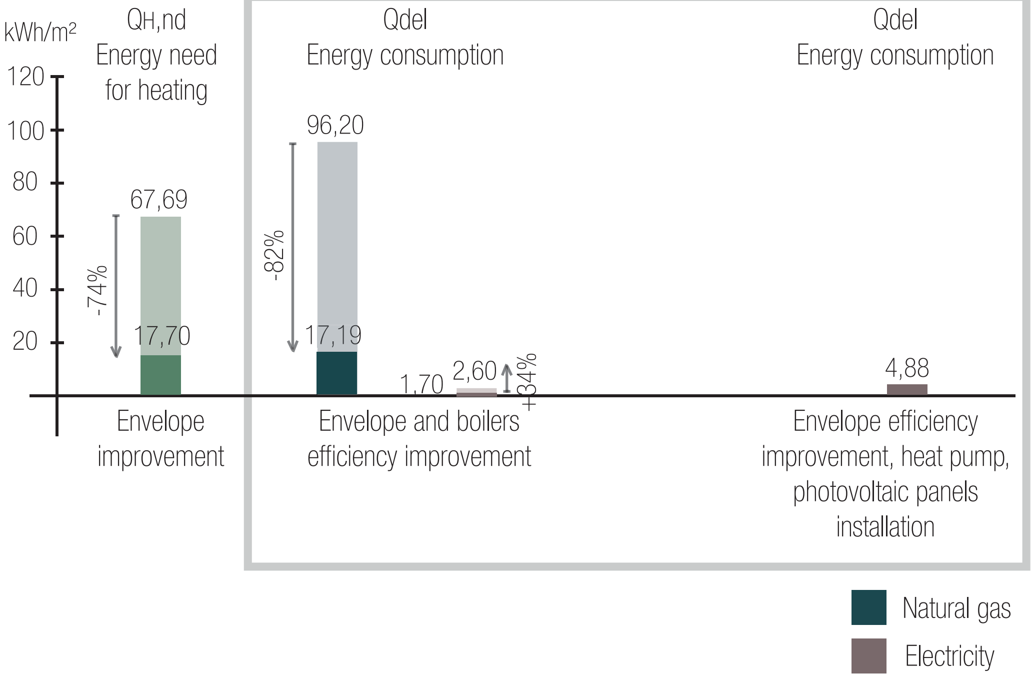



HOT WATER



## 1991-2005 MFH

HEATING

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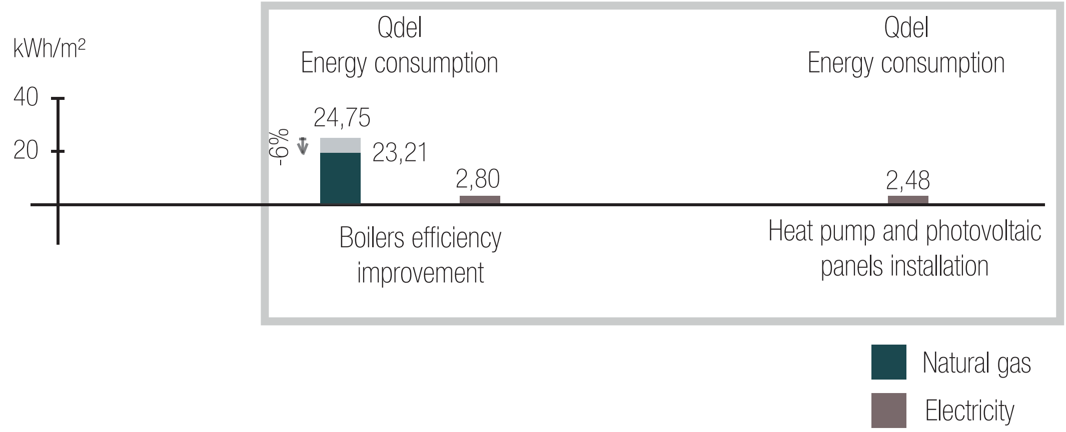
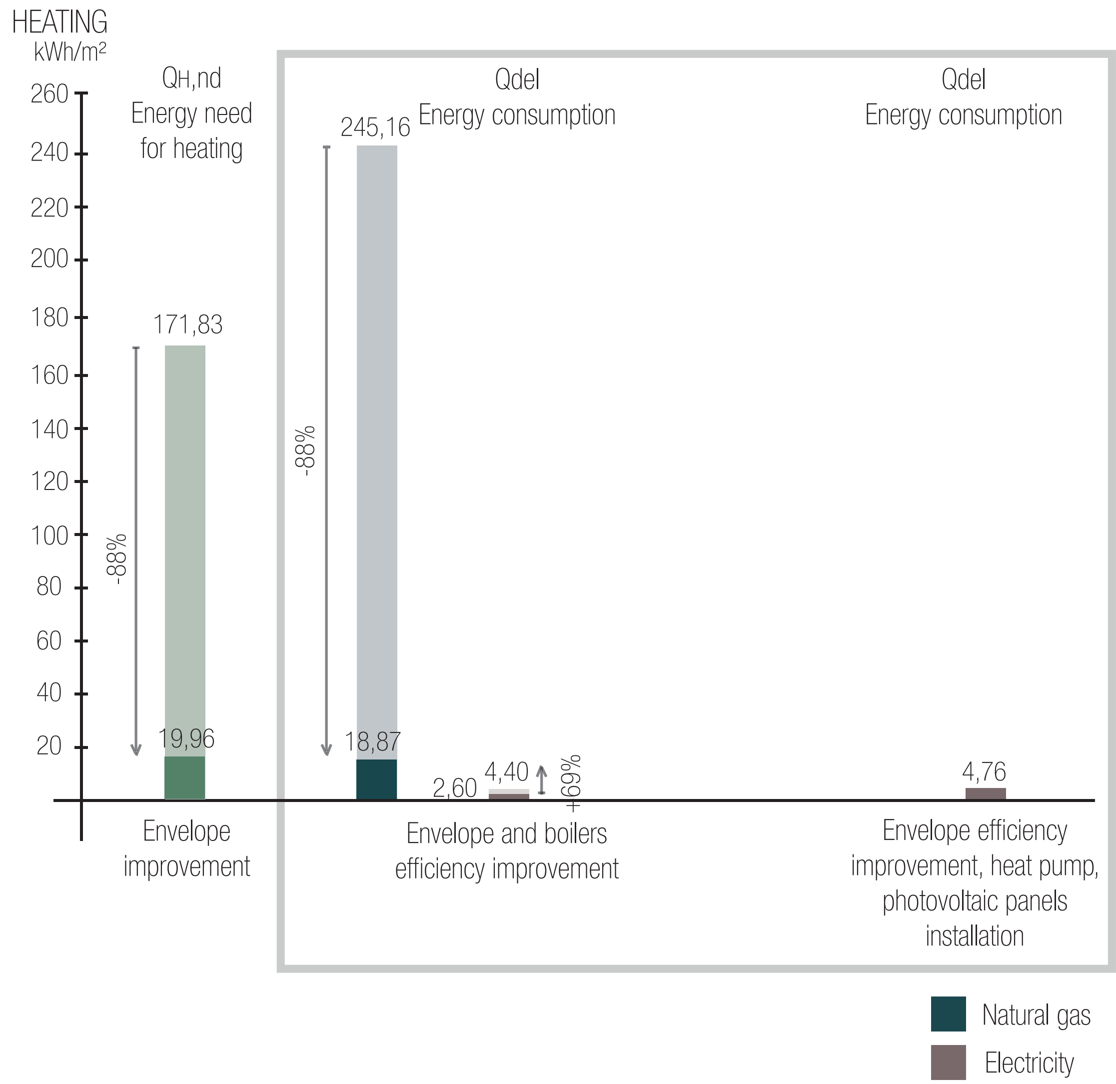
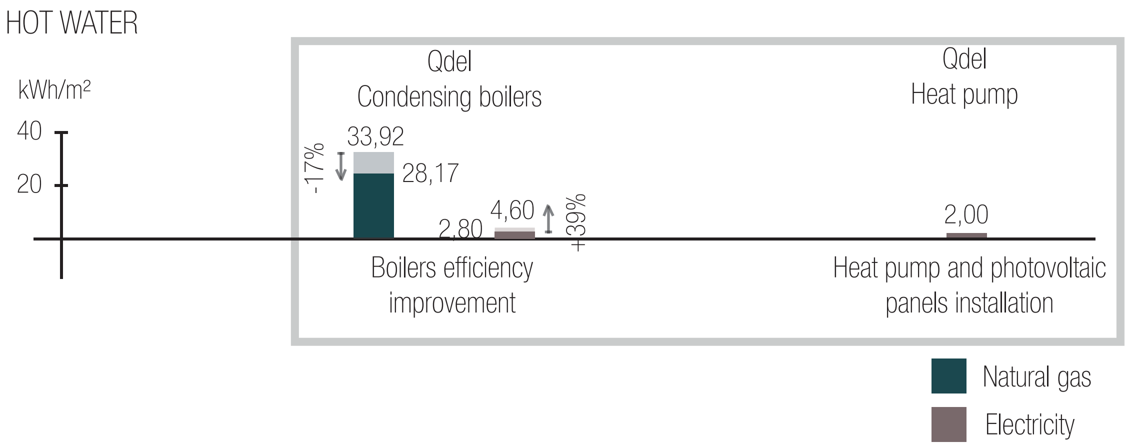
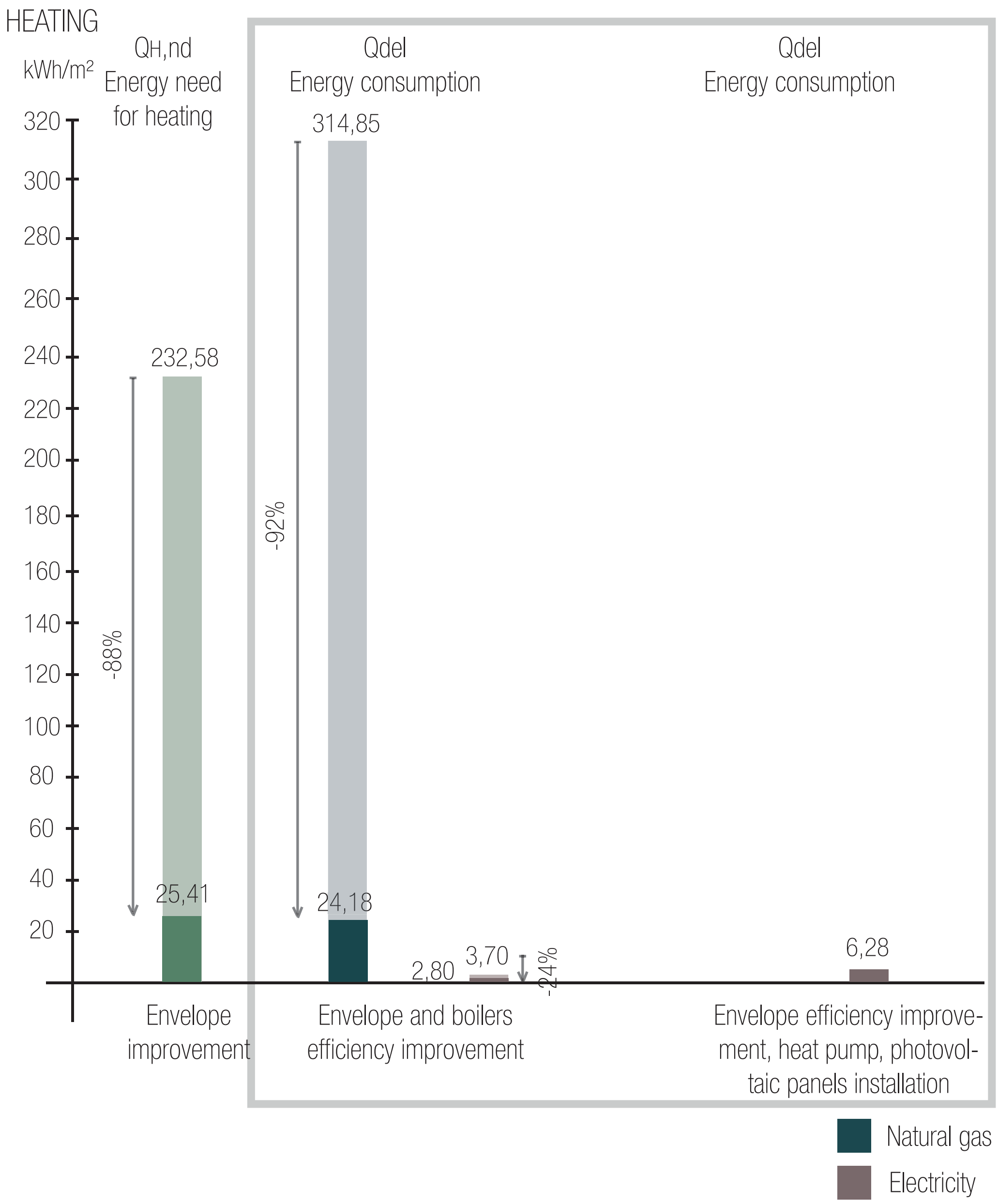


**1946-1960 TH**

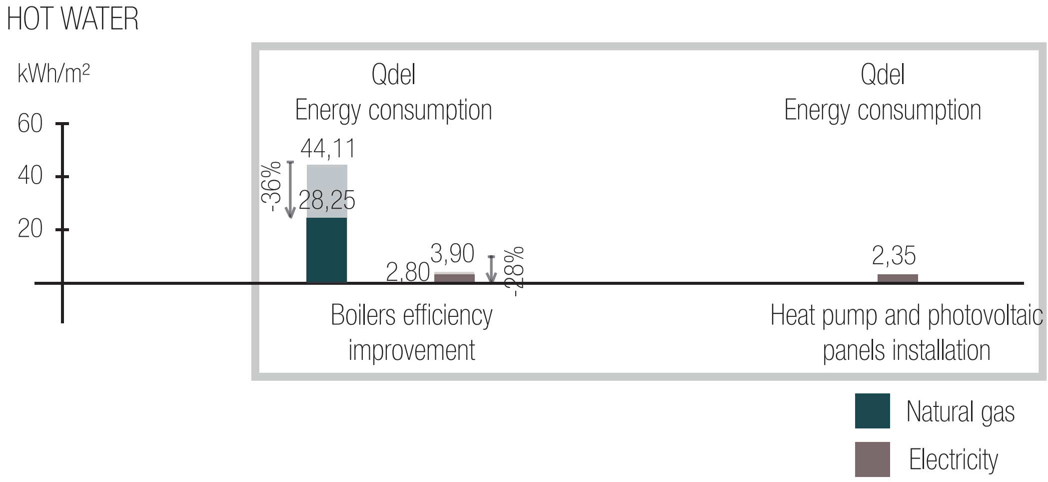

HEATING
kWh/m²
260
240
220
200
180
160
140
120
100
80
60
40
20
QH,nd
Energy need
for heating
171,83
-88%
19,96
Envelope
improvement
Qdel
Energy consumption
245,16
-88%
18,87
2,60
4,40
+69%
Envelope and boilers
efficiency improvement
Qdel
Energy consumption
4,76
Envelope efficiency
improvement, heat pump,
photovoltaic panels
installation
Natural gas
Electricity


HOT WATER
kWh/m²
40
20
Qdel
Condensing boilers
33,92
-17%
28,17
2,80
4,60
+39%
Boilers efficiency
improvement
Qdel
Heat pump
2,00
Heat pump and photovoltaic
panels installation
Natural gas
Electricity

**1961-1975 TH**



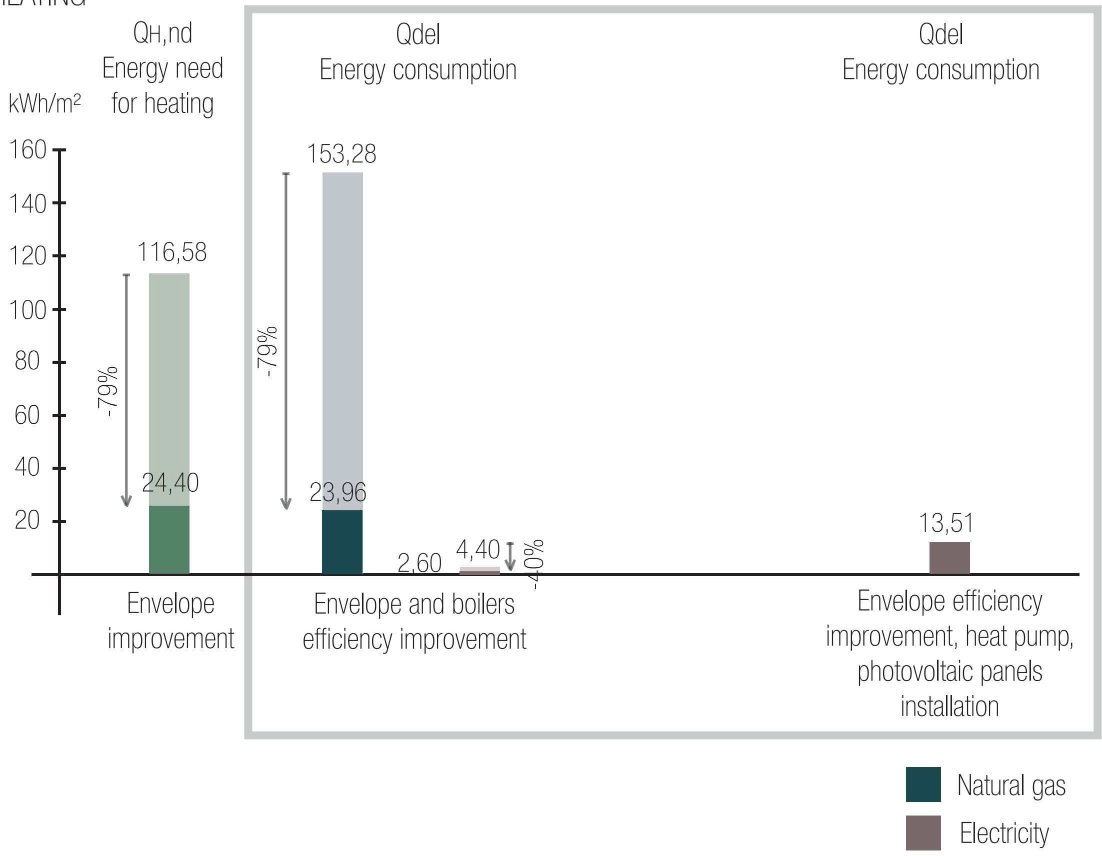
HEATING
kWh/m²
QH,nd
Energy need
for heating
Qdel
Energy consumption
Qdel
Energy consumption
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
232,58
-88%
25,41
314,85
-92%
24,18
2,80
3,70
-24%
6,28
Envelope
improvement
Envelope and boilers
efficiency improvement
Envelope efficiency improvement, heat pump, photovoltaic panels installation
Natural gas
Electricity

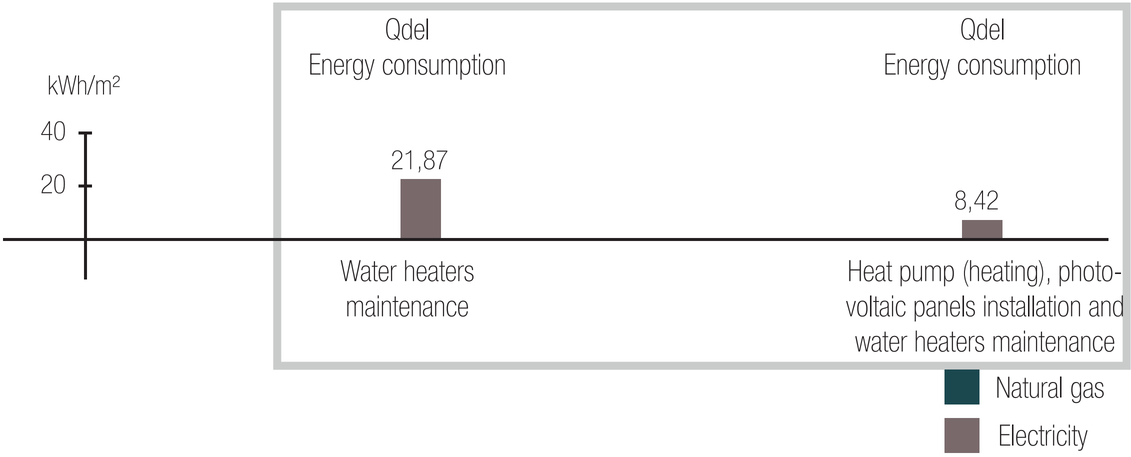
HOT WATER
kWh/m²
Qdel
Energy consumption
Qdel
Energy consumption
60
40
20
44,11
-36%
28,25
2,80
3,90
-28%
2,35
Boilers efficiency
improvement
Heat pump and photovoltaic
panels installation
Natural gas
Electricity

**1976-1990 TH**

HEATING

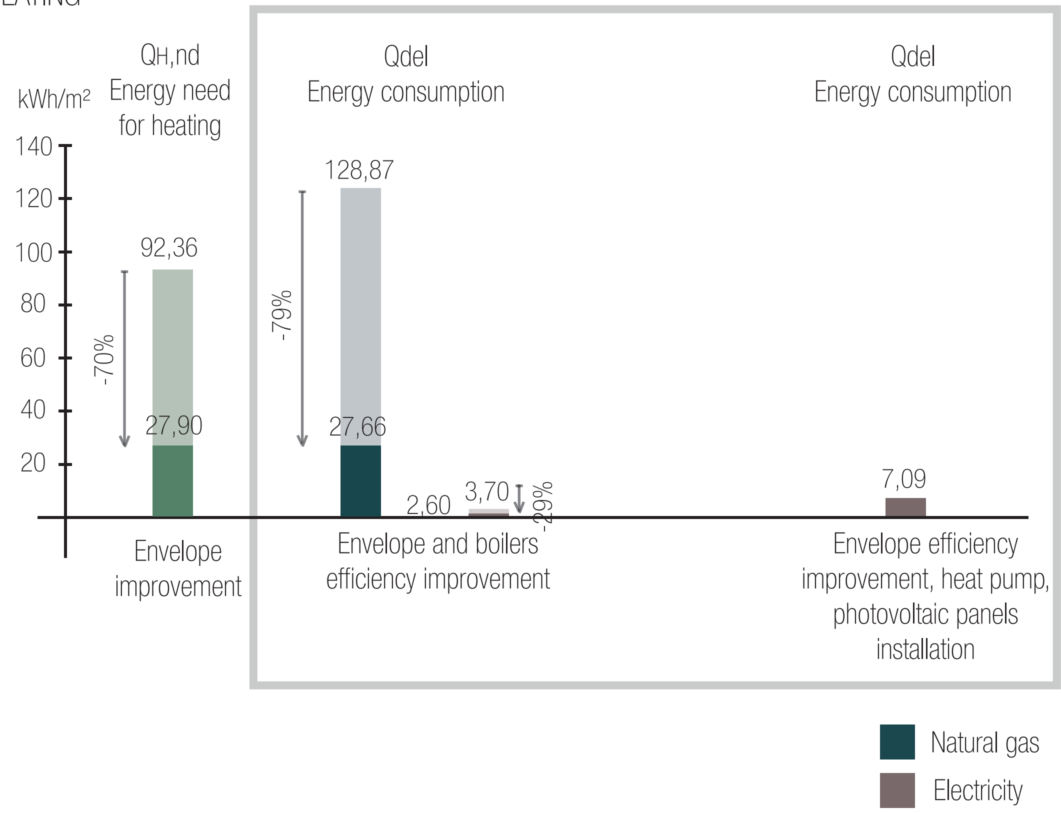



HOT WATER



## 1991-2005 TH

HEATING

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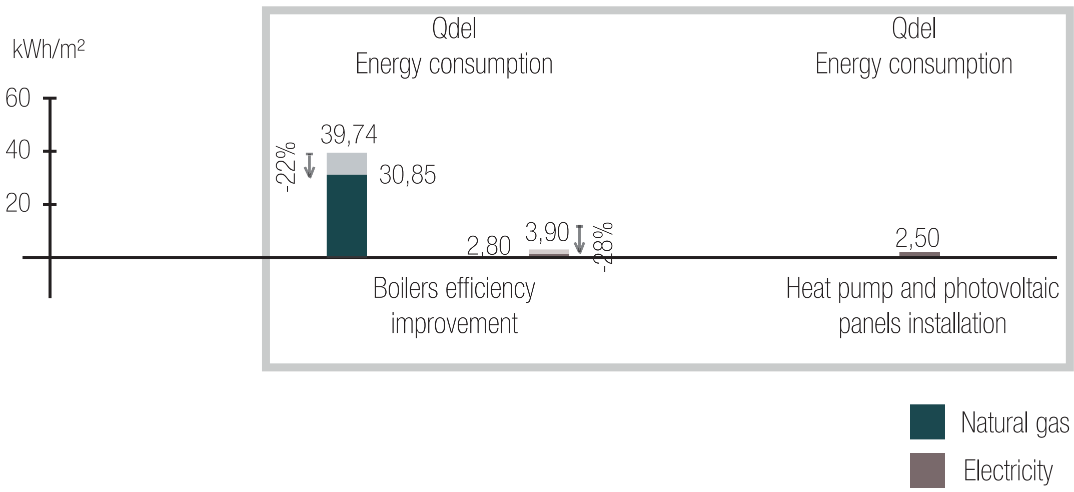
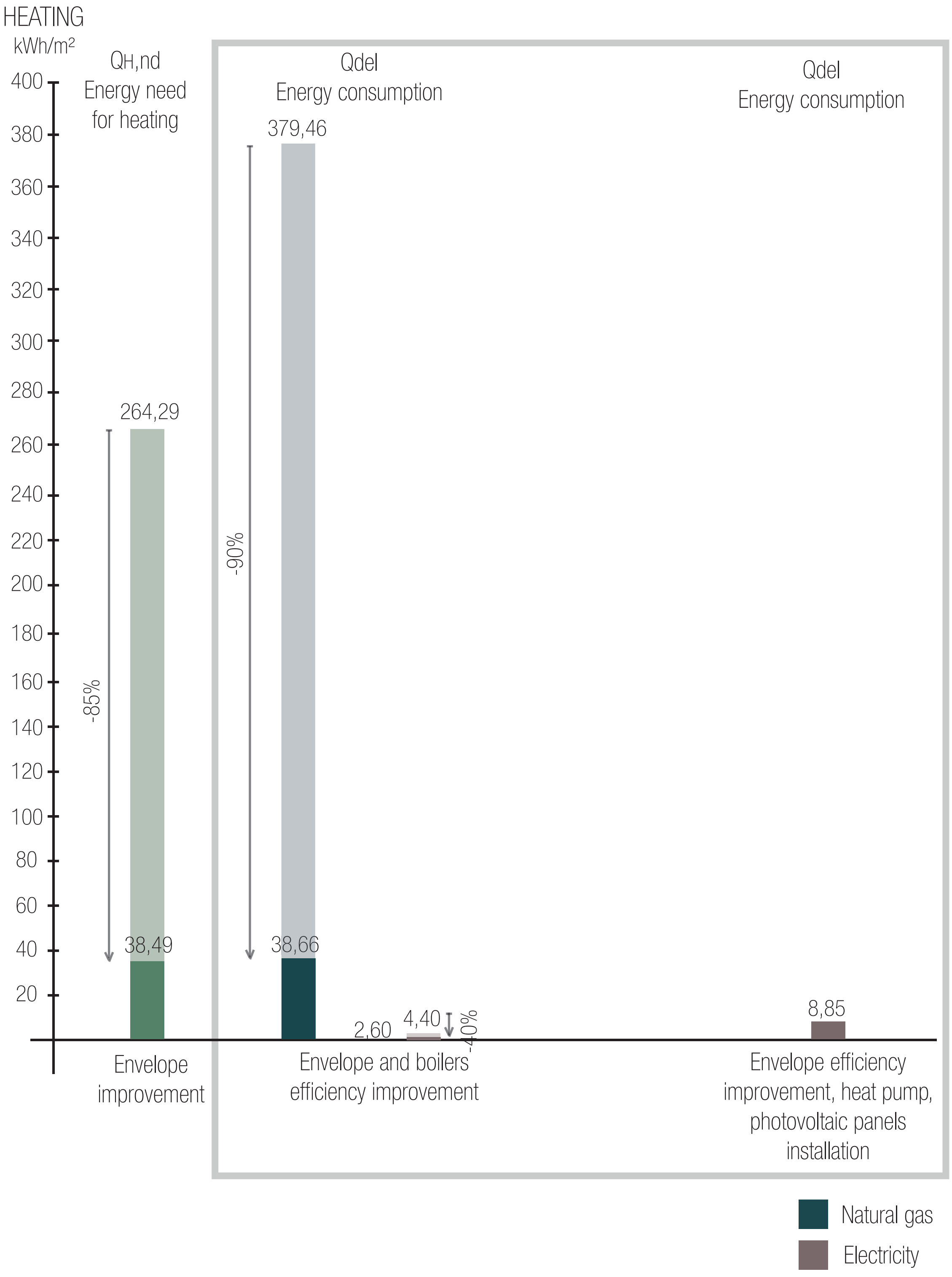
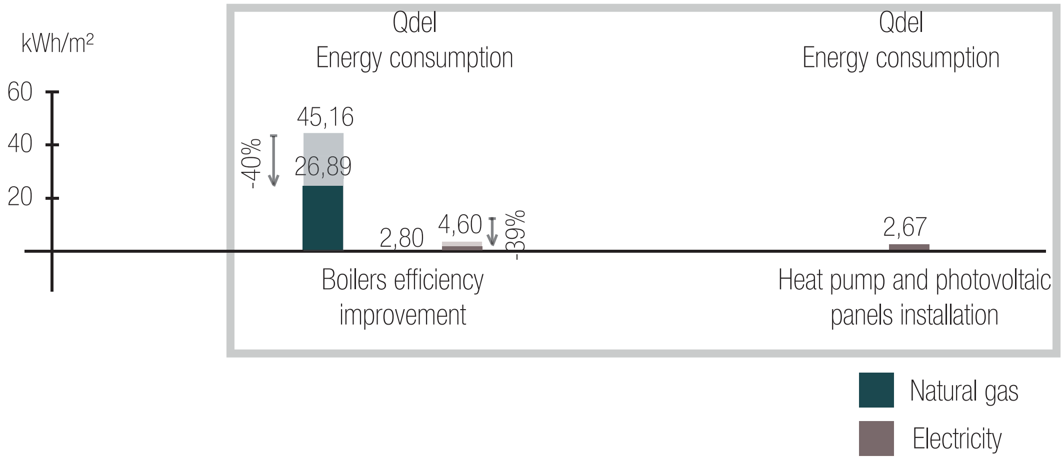
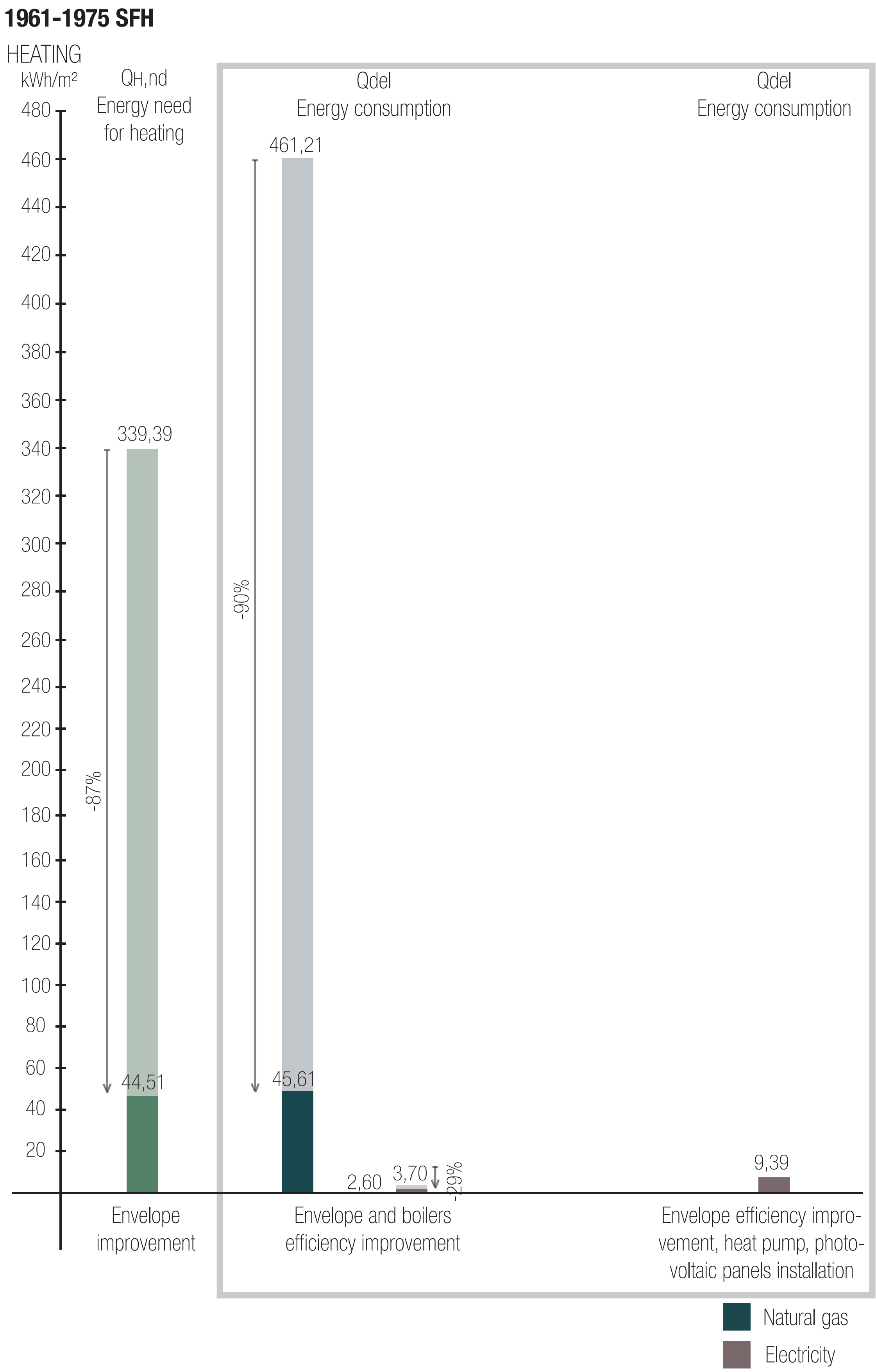


**1946-1960 SFH**

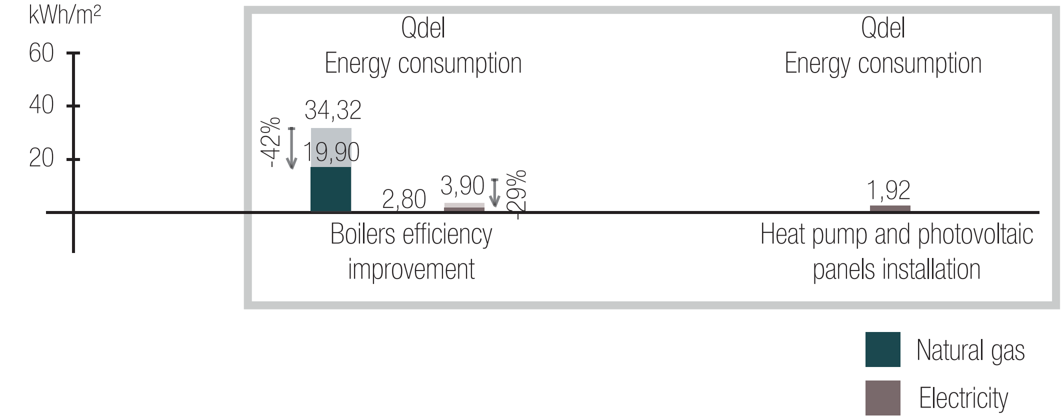


HOT WATER


kWh/m²
60
40
20
Qdel
Energy consumption
45,16
26,89
-40%
2,80
4,60
-39%
Boilers efficiency improvement
Qdel
Energy consumption
2,67
Heat pump and photovoltaic panels installation
Natural gas
Electricity

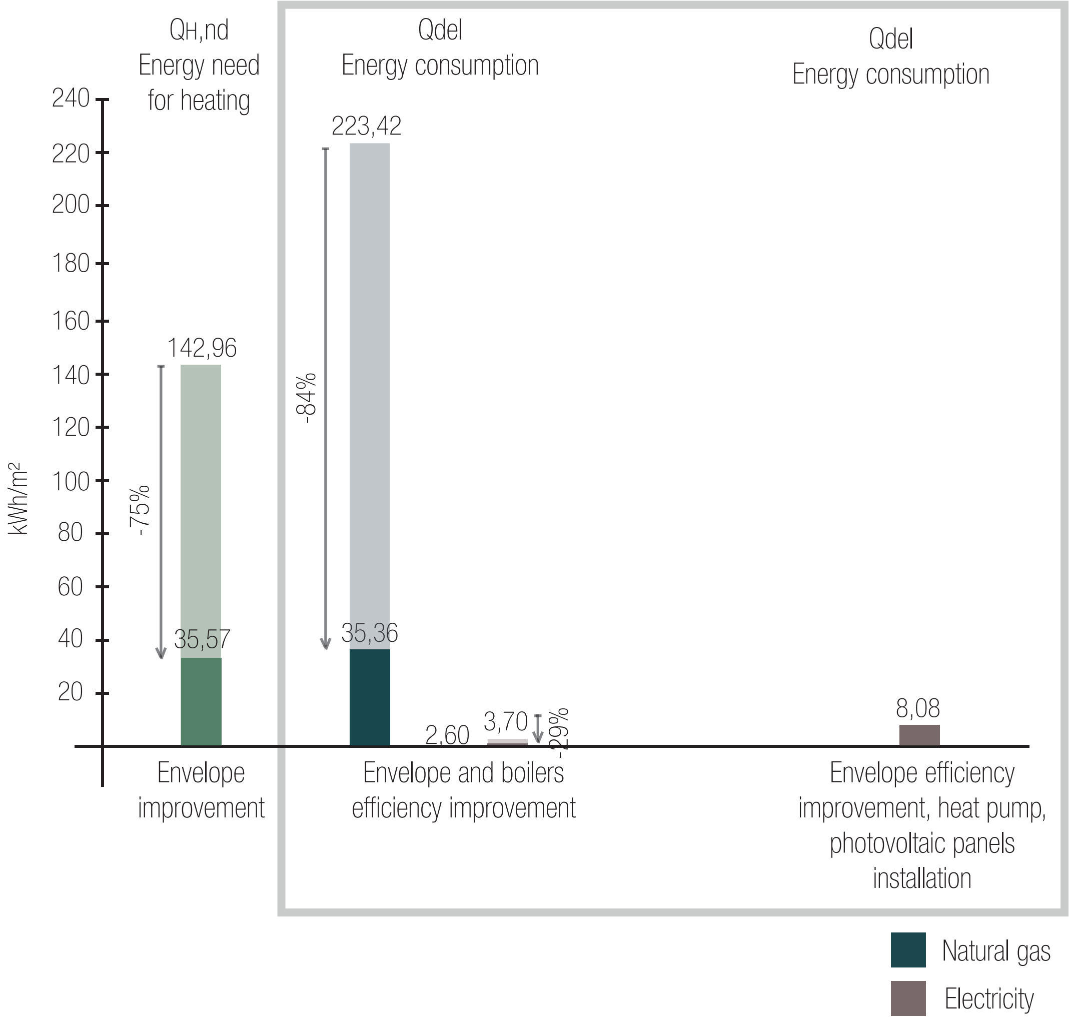

1961-1975 SFH
HEATING
kWh/m²
QH,nd
Energy need for heating
Qdel
Energy consumption
Qdel
Energy consumption
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
339,39
-87%
44,51
461,21
-90%
45,61
2,60
3,70
-29%
9,39
Envelope improvement
Envelope and boilers efficiency improvement
Envelope efficiency improvement, heat pump, photovoltaic panels installation
Natural gas
Electricity

HOT WATER

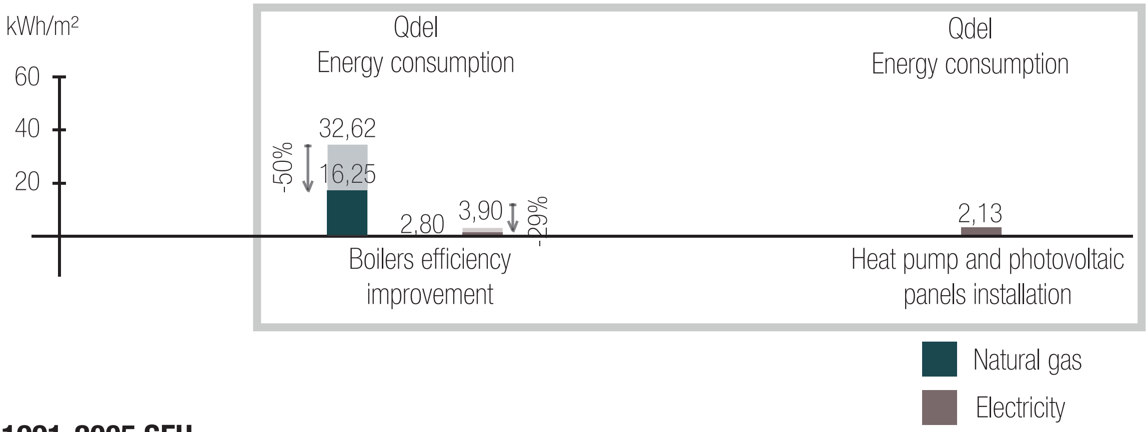



**1976-1990 SFH**

HEATING

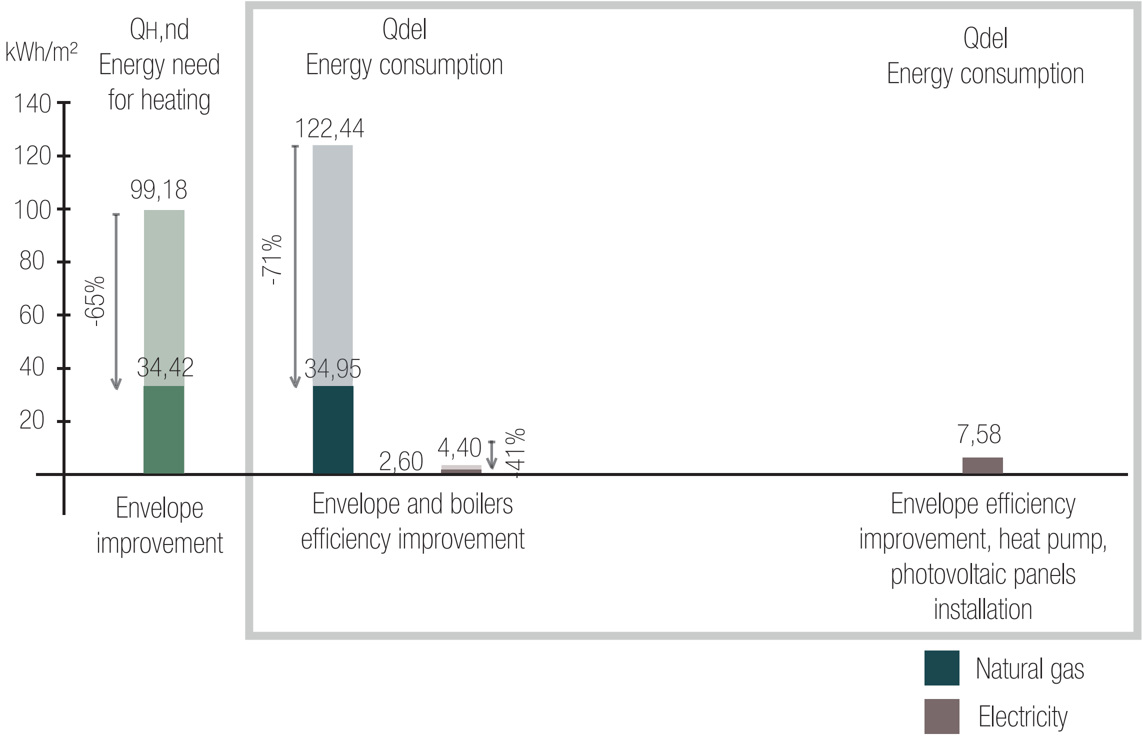


HOT WATER

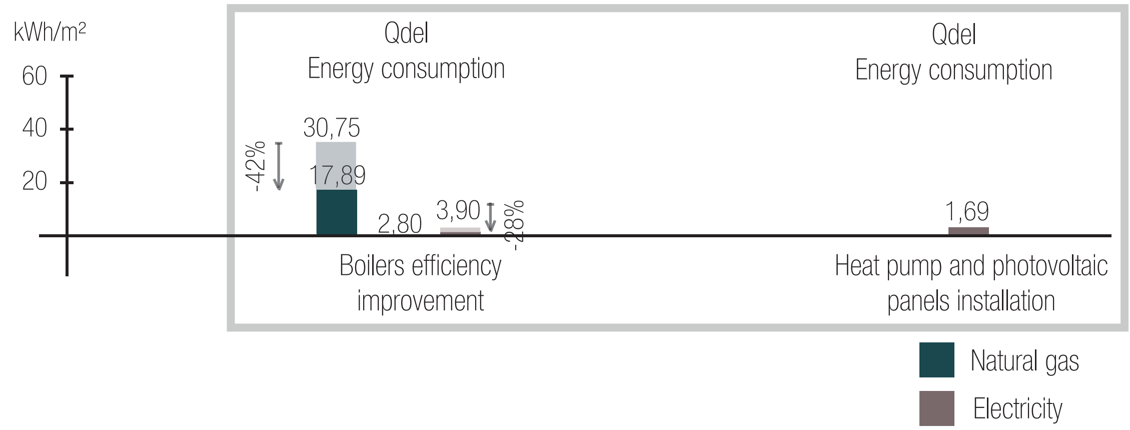



**1991-2005 SFH**

HEATING




HOT WATER



| | | | |
|---|---|---|---|
| **Doors** | Door removal | 01.A02.C00.005 | 12,58 €/m$^2$ |
| | Door | 01.P13.Q10.005 | 690 €/m$^2$ |
| | Door installation | 01.A17.C10.005 | 48,84 €/m$^2$ |
| | Total amount | | **751,42 €/m$^2$** |
| **Windows** | Old windows removal | 01.A02.C00.005 | 12,58 €/m$^2$ |
| | Window | 03.P08.G01.045 | 235,91 €/m$^2$ |
| | Window installation | 01.A17.B30.005 | 39,9 €/m$^2$ |
| | Low-emission glass | 01.P20.B04.025 | 44,67 €/m$^2$ |
| | Total amount | | **333,06 €/m$^2$** |

**1946-1960 AB**

**Envelope improvement**

| | | | |
|---|---|---|---|
| External walls - 1.050 m$^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/m$^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/m$^2$ |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m$^2$ |
| | Blow-in insulating material | 03.P09.G08.005 | 2,64 €/kg |
| | Blow-in insulation | 03.A07.B02.005 | 67,80 €/m$^2$ |
| | Total amount | | **123.412,80 €** |
| Thermal insulation towards non-heated area - 591 m$^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/m$^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/m$^2$ |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m$^2$ |
| | Insulating material | 03.P09.D01.030 | 59,66 €/m$^2$ |
| | Total amount | | **74.300,52 €** |
| Concrete upper slab - 441 m$^2$ | Insulating material | 03.P09.I01.030 | 17,29 €/m$^2$ |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m$^2$ |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m$^2$ |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m$^2$ |
| | Total amount | | **18.411,75 €** |

| | | | |
|---|---|---|---|
| Concrete lower slab - 441 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **18.477,79 €** |
| Windows - 217 m² | Total amount | | **72.274,02 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boilers removal H | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 1.499 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **292.551,33 €** |
| District heating H 100 kW | Total amount | 12.P12.A05.015 | **8.900,84 €** |

| | | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|---|
| Circulation pump H - hp - dh | | 12.P15.A46.005 | | **1.426,83 €** | 28,54 € | 20 |
| Circulation pump H -condensing boilers | | 12.P15.A46.005 | | **1.902,44 €** | 38,05 € | 20 |
| Condensing boiler H | | 05.A01.B01.015 | | **9.363,20 €** | 187,26 € | 20 |
| Heat pump H - W 81 kW | Heat pump | | supplier | 53.970 € | 2.158,80 € | 20 |
| | Heat pump Installation | | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | | **54.754,43 €** | | |
| Photovoltaic panels - 170 m² | | 1E.17.010.0010.c | | **57.034,57 €** | 114,07 € | 30 |

**Total costs for building (envelope improvement+district heating maintenance)**

Carbon base measures : **306.876,88 €**

Carbon advanced measures : **306.876,88 €**

Electric base measures : **306.876,88 €**

Electric advanced measures : **306.876,88 €**

**Total costs for building (envelope improvement+district heating connection)**

Carbon base measures : **317.848,28 €**

Carbon advanced measures : **317.848,28 €**

Electric base measures : **317.848,28 €**

Electric advanced measures : **317.848,28 €**

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **318.786,25 €**

Electric base measures : **- €**

Electric advanced measures : **751.310,82 €**

**Total costs - 19 buildings (envelope improvement+district heating maintenance)**

Carbon base measures : **5.830.660,72 €**

Carbon advanced measures : **5.830.660,72 €**

Electric base measures : **5.830.660,72 €**

Electric advanced measures : **5.830.660,72 €**

**Total costs - 8 buildings (envelope improvement+district heating connection)**

Carbon base measures : **2.542.786,24 €**

Carbon advanced measures : **2.542.786,24 €**

Electric base measures : **2.542.786,24 €**

Electric advanced measures : **2.542.786,24 €**

**Total costs - 12 buildings (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **3.825.435 €**

Electric base measures : **- €**

Electric advanced measures : **9.015.729,84 €**

**1961-1975 AB**

**Envelope improvement**

| | | | |
|---|---|---|---|
| External walls - 2.239 m$^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/m$^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/m$^2$ |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m$^2$ |
| | Blow-in insulating material | 03.P09.G08.005 | 2,64 €/kg |
| | Blow-in insulation | 03.A07.B02.005 | 67,80 €/m$^2$ |
| | Total amount | | **277.783,77 €** |
| Thermal insulation towards non-heated area - 1.033 m$^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/m$^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/m$^2$ |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m$^2$ |
| | Insulating material | 03.P09.D01.020 | 44,75 €/m$^2$ |
| | Total amount | | **114.466,73 €** |

| | | | |
|---|---|---|---|
| Concrete upper slab - 358 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **14.946,50 €** |
| Concrete lower slab - 358 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A55.015 | 16,57 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **13.969,16 €** |
| Windows - 321 m² | Total amount | | **106.912,26 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boilers removal H | Total amount | 05.A01.R25.010 | **1.287,46 €** |
| Under-floor heating system - 2.439 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **476.097,28 €** |
| District heating H - W 75 kW + 100 kW | Total amount | 12.P12.A10 | **25.393,74 €** |

| | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|
| Circulation pump H -condensing boilers | 12.P15.A46.015 | **4.077,12 €** | 81,54 € | 20 |
| Circulation pump W -condensing boilers | 12.P15.A48.015 | **1.972,65 €** | 39,45 € | 20 |
| Circulation pump H - hp - dh | 12.P15.A46.005 | **1.426,83 €** | 28,54 € | 20 |
| Circulation pump W - hp - dh | 12.P15.A48.015 | **1.315,10 €** | 26,30 € | 20 |

| | | | | |
|---|---|---|---|---|
| Condensing boiler H | 05.A01.B01.020 | **11.653,97 €** | 233,08 € | 20 |
| Condensing boiler W | 05.A01.B01.010 | **7.420,22 €** | 148,40 € | 20 |
| Water storage H - 3.00 l | 1M.04.040.0010.f | **1.794,47 €** | 17,94 € | 20 |
| Heat pump H - W 191 kW | Heat pump supplier | 131.070 € | 5.242,80 € | 20 |
| | Heat pump Installation 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | **131.854,43 €** | | |
| Photovoltaic panels - 174 m$^2$ | 1E.17.010.0010.c | **58.376,56 €** | 116,75 € | 30 |

**Total costs for building (envelope improvement+district heating maintenance)**

Carbon base measures : **528.078,42 €**

Carbon advanced measures : **528.078,42 €**

Electric base measures : **528.078,42 €**

Electric advanced measures : **528.078,42 €**

**Total costs for building (envelope improvement+district heating connection)**

Carbon base measures : **559.296,02 €**

Carbon advanced measures : **559.296,02 €**

Electric base measures : **559.296,02 €**

Electric advanced measures : **559.296,02 €**

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **556.284,31 €**

Electric base measures : **- €**

Electric advanced measures : **1.239.148,26 €**

**Total costs - 7 buildings (envelope improvement+district heating maintenance)**

Carbon base measures : **3.696.548,94 €**

Carbon advanced measures : **3.696.548,94 €**

Electric base measures : **3.696.548,94 €**

Electric advanced measures : **3.696.548,94 €**

**Total costs - 9 buildings (envelope improvement+district heating connection)**

Carbon base measures : **5.033.664,18 €**

Carbon advanced measures : **5.033.664,18 €**

Electric base measures : **5.033.664,18 €**

Electric advanced measures : **5.033.664,18 €**

**Total costs - 12 buildings (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **6.675.411,72 €**

Electric base measures : **- €**

Electric advanced measures : **14.869.779,12 €**

**1976-1990 AB**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 2.119 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.020 | 44,75 €/m² |
| | Total amount | | **259.492,74 €** |
| Thermal insulation towards non-heated area - 864 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.020 | 44,75 €/m² |
| | Total amount | | **95.739,84 €** |
| Concrete upper slab - 688 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **28.724 €** |
| Concrete lower slab - 688 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A55.015 | 16,57 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **26.845,76 €** |
| Windows - 363 m² | Total amount | | **120.900,78 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boilers removal H | Total amount | 05.A01.R25.010 | **1.287,46 €** |
| Under-floor heating system - 3.506 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |

| | | | |
|---|---|---|---|
| Under-floor heating system - 3.506 m² | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **683.462,88 €** |
| District heating H - W 100 kW + 100 kW | Total amount | 12.P12.A10.015 | **26.033,88 €** |

| | | | | | |
|---|---|---|---|---|---|
| | | | | MAINTENANCE [€] | LIFETIME |
| Circulation pump H - hp - dh | 12.P15.A46.005 | | **4.077,12 €** | 81,54 € | 20 |
| Circulation pump W - hp - dh | 12.P15.A48.015 | | **1.972,65 €** | 39,45 € | 20 |
| Circulation pump W -condensing boilers | 12.P15.A48.015 | | **2.630,20 €** | 52,60 € | 20 |
| Condensing boiler H | 05.A01.B01.020 | | **11.653,97 €** | 233,08 € | 20 |
| Condensing boiler W | 05.A01.B01.005 | | **6.197,58 €** | 123,95 € | 20 |
| Water storage W - 2.00 l | 1M.04.040.0010.e | | **1.396,77 €** | 13,97 € | 20 |
| Heat pump H - W 222 kW | Heat pump | supplier | 140.100 € | 5.604 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **140.884,43 €** | | |
| Photovoltaic panels - 224 m² | 1E.17.010.0010.c | | **75.151,44 €** | 150,30 € | 30 |

**Total costs for building (envelope improvement+district heating maintenance)**

Carbon base measures : **531.703,12 €**

Carbon advanced measures : **531.703,12 €**

Electric base measures : **531.703,12 €**

Electric advanced measures : **531.703,12 €**

**Total costs - 6 buildings (envelope improvement+district heating maintenance)**

Carbon base measures : **3.190.218,72 €**

Carbon advanced measures : **3.190.218,72 €**

Electric base measures : **3.190.218,72 €**

Electric advanced measures : **3.190.218,72 €**

**Total costs for building (envelope improvement+district heating connection)**

Carbon base measures : **566.471 €**

Carbon advanced measures : **566.471 €**

Electric base measures : **566.471 €**

Electric advanced measures : **566.471 €**

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **554.869,10 €**

Electric base measures : **- €**

Electric advanced measures : **1.476.140,43 €**

**Total costs - 2 buildings (envelope improvement+district heating connection)**

Carbon base measures : **1.132.942 €**

Carbon advanced measures : **1.132.942 €**

Electric base measures : **1.132.942 €**

Electric advanced measures : **1.132.942 €**

**Total costs - 2 buildings (condesing boilers/heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **1.109.738,20 €**

Electric base measures : **- €**

Electric advanced measures : **2.952.280,86 €**

**1991-2005 AB**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 440 $m^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/$m^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/$m^2$ |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/$m^2$ |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/$m^2$ |
| | Insulating material | 03.P09.D01.015 | 37,29 €/$m^2$ |
| | Total amount | | **50.600 €** |
| Thermal coating insulation - 1.328 $m^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/$m^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/$m^2$ |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/$m^2$ |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/$m^2$ |
| | Insulating material | 03.P09.D01.015 | 37,29 €/$m^2$ |
| | Total amount | | **152.720 €** |
| Thermal insulation towards non-heated area - 760 $m^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/$m^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/$m^2$ |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/$m^2$ |
| | Insulating material | 03.P09.D01.015 | 37,29 €/$m^2$ |
| | Total amount | | **78.546 €** |

| | | | |
|---|---|---|---|
| Concrete upper slab - 679 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **28.348,25 €** |
| Concrete lower slab - 545 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A55.015 | 16,57 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **21.265,90 €** |
| Windows - 498 m² | Total amount | | **165.863,88 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boilers removal H | Total amount | 05.A01.R25.010 | **1.287,46 €** |
| Under-floor heating system - 2.780 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **541.737,35 €** |
| District heating H - W 75 kW + 100 kW | Total amount | 12.P12.A10 | **25.393,74 €** |

| | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|
| Circulation pump W - hp - dh | 12.P15.A48.015 | **2.026,65 €** | 40,53 € | 20 |
| Circulation pump H -condensing boilers | 12.P15.A46.015 | **4.756,64 €** | 95,13 € | 20 |
| Circulation pump W -condensing boilers | 12.P15.A48.015 | **2.630,20 €** | 52,60 € | 20 |
| Condensing boiler H | 05.A01.B01.020 | **11.653,97 €** | 233,08 € | 20 |
| Condensing boiler W | 05.A01.B01.005 | **6.197,58 €** | 123,95 € | 20 |

| | | | | | |
|---|---|---|---|---|---|
| Water storage W - 3.000 l | 1M.04.040.0010.f | | **1.794,47 €** | 17,94 € | 20 |
| Heat pump H - W 191 kW | Heat pump | supplier | 131.070 € | 5.242,80 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **131.854,43 €** | | |
| Photovoltaic panels - 174 m² | 1E.17.010.0010.c | | **58.376,56 €** | 116,75 € | 30 |

**Total costs for building (envelope improvement+district heating maintenance)**

Carbon base measures : **497.344,03 €**

Carbon advanced measures : **497.344,03 €**

Electric base measures : **497.344,03 €**

Electric advanced measures : **497.344,03 €**

**Total costs for building (envelope improvement+district heating connection)**

Carbon base measures : **527.846,35 €**

Carbon advanced measures : **527.846,35 €**

Electric base measures : **527.846,35 €**

Electric advanced measures : **527.846,35 €**

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **525.664,35 €**

Electric base measures : **- €**

Electric advanced measures : **1.273.338,66 €**

**Total costs - 1 building (envelope improvement+district heating maintenance)**

Carbon base measures : **497.344,03 €**

Carbon advanced measures : **497.344,03 €**

Electric base measures : **497.344,03 €**

Electric advanced measures : **497.344,03 €**

**Total costs - 1 building (envelope improvement+district heating connection)**

Carbon base measures : **527.846,35 €**

Carbon advanced measures : **527.846,35 €**

Electric base measures : **527.846,35 €**

Electric advanced measures : **527.846,35 €**

**Total costs - 1 building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **525.664,35 €**

Electric base measures : **- €**

Electric advanced measures : **1.273.338,66 €**

**1946-1960 MFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 586 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |

| | | | |
|---|---|---|---|
| Thermal coating insulation - 586 m² | Insulating material | 03.P09.D01.025 | 52,51 €/m² |
| | Total amount | | **76.308,92 €** |
| Thermal insulation towards non-heated area - 193 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.I01.040 | 23,09 €/m² |
| | Total amount | | **17.205,95 €** |
| Concrete upper slab - 320 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **13.360 €** |
| Concrete lower slab -320 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **13.408 €** |
| Windows - 150 m² | Total amount | | **49.959€** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 817 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **159.345,18 €** |

| | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|
| Circulation pump H | 12.P15.A46.005 | **951,61 €** | 19,03 € | 20 |
| Condensing boiler H | 05.A01.A03.005 | **3.718,98 €** | 74,38 € | 20 |

| | | | | | |
|---|---|---|---|---|---|
| Heat pump H 43,9 kW | Heat pump | supplier | 29.020 € | 1.160,80 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **29.804,43 €** | | |
| Photovoltaic panels - 120 m² | 1E.17.010.0010.b | | **48.842,64 €** | 97,68 € | 30 |

**Total costs for building (envelope improvement+district heating maintenance)**

Carbon base measures : **171.837,12 €**

Carbon advanced measures : **171.837,12 €**

Electric base measures : **171.837,12 €**

Electric advanced measures : **171.837,12 €**

**Total costs - 13 buildings (envelope improvement+district heating maintenance)**

Carbon base measures : **2.233.882,56 €**

Carbon advanced measures : **2.233.882,56 €**

Electric base measures : **2.233.882,56 €**

Electric advanced measures : **2.233.882,56 €**

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **175.016,10 €**

Carbon advanced measures : **175.016,10 €**

Electric base measures : **428.086,32 €**

Electric advanced measures : **428.086,32 €**

**Total costs - 8 buildings (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **1.400.128,80 €**

Carbon advanced measures : **1.400.128,80 €**

Electric base measures : **3.424.690,56 €**

Electric advanced measures : **3.424.690,56 €**

**1961-1975 MFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 252 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.025 | 52,51 €/m² |
| | Total amount | | **32.815,44 €** |
| External walls - 945 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Blow-in insulating material | 03.P09.G08.005 | 2,64 €/kg |
| | Blow-in insulation | 03.A07.B02.005 | 67,80 €/m² |
| | Total amount | | **117.242,37 €** |

| | | | |
|---|---|---|---|
| Concrete upper slab - 187 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **7.807,25 €** |
| Concrete lower slab -187 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **7.835,30 €** |
| Windows - 97 m² | Total amount | | **32.306,82 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boilers removal H - W | Total amount | 05.A01.R25.010 | **6.437,30 €** |
| Under-floor heating system - 794 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **154.699,26 €** |

| | | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|---|
| Circulation pump H | | 12.P15.A46.005 | | **951,61 €** | 19,03 € | 20 |
| Circulation pump W | | 12.P15.A48.015 | | **675,55 €** | 13,51 € | 20 |
| Condensing boiler H | | 05.A01.A01.005 | | **1.878,82 €** | 37,58 € | 20 |
| Condensing boiler W | | 05.A01.A03.005 | | **3.718,98 €** | 74,38 € | 20 |
| Water storage H - 800 l | | 1M.04.040.0010.b | | **770,59 €** | 7,70 € | 20 |
| Heat pump H - W 37,2 kW | Heat pump | supplier | | 23.730 € | 949,20 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | | 784,43 € | - | - |
| | Total amount | | | **24.514,43 €** | | |

| | | | | |
|---|---|---|---|---|
| Photovoltaic panels - 62 m² | 1E.17.010.0010.b | **25.235,36 €** | 50,47 € | 30 |

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **212.440,03 €**

Carbon advanced measures : **212.440,03 €**

Electric base measures : **427.208,31 €**

Electric advanced measures : **427.208,31 €**

**Total costs - 8 buildings (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **1.699.520,24 €**

Carbon advanced measures : **1.699.520,24 €**

Electric base measures : **3.417.666,48 €**

Electric advanced measures : **3.417.666,48 €**

**1976-1990 MFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 849 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.020 | 44,75 €/m² |
| | Total amount | | **103.968,54 €** |
| Thermal insulation towards non-heated area - 217 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.030 | 44,75 €/m² |
| | Total amount | | **24.045,77 €** |
| Concrete upper slab - 404 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **16.867 €** |
| Concrete lower slab - 404 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **16.927,60 €** |
| Windows - 121 m² | Total amount | | **40.300,26 €** |

| **Total costs for building (envelope improvement+district heating maintenance)** | **Total costs - 2 buildings (envelope improvement+district heating maintenance)** |
|---|---|
| Carbon base measures : **202.109,17 €** | Carbon base measures : **404.218,34 €** |
| Carbon advanced measures : **202.109,17 €** | Carbon advanced measures : **404.218,34 €** |
| Electric base measures : **202.109,17 €** | Electric base measures : **404.218,34 €** |
| Electric advanced measures : **202.109,17 €** | Electric advanced measures : **404.218,34 €** |

**1991-2005 MFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 868 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.015 | 37,29 €/m² |
| | Total amount | | **99.820 €** |
| Thermal insulation towards non-heated area - 144 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.015 | 37,29 €/m² |
| | Total amount | | **14.882,40 €** |
| Concrete upper slab - 374 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **15.614,50 €** |
| Concrete lower slab - 373 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **15.628,70 €** |
| Windows - 148 m² | Total amount | | **49.292,88 €** |

## Installations

| | | | | | |
|---|---|---|---|---|---|
| Boilers removal H - W | Total amount | | 05.A01.R25.010 | **10.299,68 €** | |
| Under-floor heating system - 952 $m^2$ | Pavement and screed demolition | | 01.A02.A40.005 | 86,80 €/$m^2$ | |
| | Heaters removal | | 1C.01.170.0030.b | 19,26 €/each | |
| | Under-floor heating | | 03.P13.C02.010 | 35,41 €/$m^2$ | |
| | Under-floor heating installation | | 03.A12.C02.005 | +25% | |
| | Screed | | 01.A11.A40.005 | 27,68 €/$m^2$ | |
| | Pavement installation | | commercial price | 21 €/$m^2$ | |
| | Pavement | | 01.P07.B40.005 | 13,88 €/$m^2$ | |
| | Total amount | | | **185.773,12 €** | |
| Photovoltaic panels - 62 $m^2$ | 1E.17.010.0010.b | **25.235,36 €** | 50,47 € | 30 | |
| | | | MAINTENANCE [€] | LIFETIME | |
| Circulation pump W | 12.P15.A48.015 | **675,55 €** | 13,51 € | 20 | |
| Circulation pump H | 12.P15.A46.005 | **1.426,83 €** | 28,54 € | 20 | |
| Condensing boiler H | 05.A01.A03.010 | **4.151,95 €** | 83,04 € | 20 | |
| Condensing boiler W | 05.A01.A03.010 | **4.151,95 €** | 83,04 € | 20 | |
| Water storage H - 1000 l | 1M.04.040.0010.c | **873,15 €** | 8,73 € | 20 | |
| Water storage H - 800 l | 1M.04.040.0010.b | **770,59 €** | 8,73 € | 20 | |
| Heat pump H - W 71 kW | Heat pump | supplier | 47.460 € | 1.898,40 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **48.244,43 €** | | |
| Photovoltaic panels - 64 $m^2$ | 1E.17.010.0010.b | **26.049,41 €** | 52,10 € | 30 | |

**Total costs for building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **217.587,82 €**

Electric base measures : **- €**

Electric advanced measures : **491.717,51 €**

**Total costs - 1 building (condesing boilers/ heat pump+photovoltaic system)**

Carbon base measures : **- €**

Carbon advanced measures : **217.587,82 €**

Electric base measures : **- €**

Electric advanced measures : **491.717,51 €**

**1946-1960 TH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| External walls - 64 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Blow-in insulating material | 03.P09.G08.005 | 2,64 €/kg |
| | Blow-in insulation | 03.A07.B02.005 | 67,80 €/m² |
| | Total amount | | **6.689,92 €** |
| Pitched roof - 98 m² | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Insulating material | 07.01.04.12.h | 71,97 €/m² |
| | Total amount | | **8.194,76 €** |
| Concrete lower slab - 58 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **2.430,20 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 14 m² | Total amount | | **4.662,84 €** |

**Installations**

| | | | | |
|---|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** | |
| Under-floor heating system - 111 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² | |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each | |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² | |
| | Under-floor heating installation | 03.A12.C02.005 | +25% | |
| | Screed | 01.A11.A40.005 | 27,68 €/m² | |
| | Pavement installation | commercial price | 21 €/m² | |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² | |
| | Total amount | | **21.630,52 €** | |

| | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|
| Circulation pump H | 12.P15.A46.005 | **475,61 €** | 9,51 € | 20 |

| | | | | | |
|---|---|---|---|---|---|
| Circulation pump W | 12.P15.A48.005 | | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | 05.A01.A01.010 | | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | 1M.04.040.0010. a | | **664,22 €** | 6,64 € | 20 |
| Heat pump H-W 12 kW | Heat pump | supplier | 7.710 € | 308,40 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **8.494,43 €** | | |
| Photovoltaic panels - 10 m$^2$ | 1E.17.010.0010.a | | **4.658,13 €** | 9,32 € | 30 |

**Total costs for building**

Carbon base measures : **27.558,04 €**

Carbon advanced measures : **27.558,04 €**

Electric base measures : **60.458,89 €**

Electric advanced measures : **60.458,89 €**

**Total costs - 22 buildings**

Carbon base measures : **606.276,88 €**

Carbon advanced measures : **606.276,88 €**

Electric base measures : **1.330.095,58 €**

Electric advanced measures : **1.330.095,58 €**

**1961-1975 TH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 61 m$^2$ | Plaster removal | 01.A02.B60.005 | 6,53 €/m$^2$ |
| | Plaster | 01.A10.B20.065 | 15,91 €/m$^2$ |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m$^2$ |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m$^2$ |
| | Insulating material | 03.P09.D01.025 | 52,51 €/m$^2$ |
| | Total amount | | **7.943,42 €** |
| Pitched roof - 59 m$^2$ | Scaffolding | 01.P25.A98.005 | 11,65 €/m$^2$ |
| | Insulating material | 07.01.04.12.h | 71,97 €/m$^2$ |
| | Total amount | | **4.933,58 €** |
| Concrete base on ground- level - 59 m$^2$ | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m$^2$ |
| | Water-proofing felt | 08.A05.B18.005 | 20,17 €/m$^2$ |
| | Insulating material | 01.P09.B21.015 | 10,19 €/m$^2$ |
| | | 01.P09.B21.020 | 12,74 €/m$^2$ |

| | | | |
|---|---|---|---|
| Concrete base on ground- level - 59 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Water-proofing sheat | 03.P10.A02.005 | 0,75 €/m² |
| | Water-proofing sheat installation | 03.A08.A01.015 | 17,17 €/m² |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **12.798,28 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 11 m² | Total amount | | **3.663,66 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 89 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **17.367,22 €** |

| | | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|---|
| Circulation pump H | | 12.P15.A46.005 | | **475,61 €** | 9,51 € | 20 |
| Circulation pump W | | 12.P15.A48.005 | | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | | 05.A01.A01.010 | | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | | 1M.04.040.0010. a | | **664,22 €** | 6,64 € | 20 |
| Heat pump H-W 9 kW | Heat pump | | supplier | 6.080 € | 243,20 € | 20 |
| | Heat pump Installation | | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | | **6.864,43 €** | | |

| | | | | |
|---|---|---|---|---|
| Photovoltaic panels - 8 m² | 1E.17.010.0010.a | **3.726,50 €** | 7,45 € | 30 |

**Total costs for building**

Carbon base measures : **34.919,26 €**

Carbon advanced measures : **34.919,26 €**

Electric base measures : **60.995,18 €**

Electric advanced measures : **60.995,18 €**

**Total costs - 10 buildings**

Carbon base measures : **349.192,60 €**

Carbon advanced measures : **349.192,60 €**

Electric base measures : **609.951,80 €**

Electric advanced measures : **609.951,80 €**

**1976-1990 TH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 132 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.020 | 44,75 €/m² |
| | Total amount | | **16.164,72 €** |
| Pitched roof - 80 m² | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Insulating material | 07.01.04.12.h | 71,97 €/m² |
| | Total amount | | **6.689,6 €** |
| Concrete lower slab - 69 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **2.891,10 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 16 m² | Total amount | | **5.328,96 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 125 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |

| | | | |
|---|---|---|---|
| Under-floor heating system - 125 m² | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **24.337,09 €** |

| | | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|---|
| Circulation pump H | | | 12.P15.A46.005 | **475,61 €** | 9,51 € | 20 |
| Condensing boiler H | | | 05.A01.A01.005 | **1.878,82 €** | 37,58 € | 20 |
| Water storage H - 500 l | | | 1M.04.040.0010. a | **664,22 €** | 6,64 € | 20 |
| Heat pump H 9 kW | Heat pump | supplier | | 6.080 € | 243,20 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | | 784,43 € | - | - |
| | Total amount | | | **6.864,43 €** | | |
| Photovoltaic panels - 14 m² | | | 1E.17.010.0010.a | **6.521,38 €** | 13,04 € | 30 |

**Total costs for building**

Carbon base measures : **- €**

Carbon advanced measures : **36.239,60 €**

Electric base measures : **- €**

Electric advanced measures : **72.083,68 €**

**Total costs - 3 buildings**

Carbon base measures : **- €**

Carbon advanced measures : **108.718,80 €**

Electric base measures : **- €**

Electric advanced measures : **216.251,04 €**

**1991-2005 TH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 132 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.015 | 37,29 €/m² |
| | Total amount | | **15.180 €** |
| Concrete upper slab - 68 m² | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |

| | | | |
|---|---|---|---|
| Concrete upper slab - 68 m² | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **2.839 €** |
| Concrete lower slab - 68 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A57.025 | 21,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **2.985,20 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 16 m² | Total amount | | **5.328,96 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 111 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **21.626,92 €** |

| | | | | | |
|---|---|---|---|---|---|
| | | | | MAINTENANCE [€] | LIFETIME |
| Circulation pump H | | 12.P15.A46.005 | **475,61 €** | 9,51 € | 20 |
| Circulation pump W | | 12.P15.A48.005 | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | | 05.A01.A01.010 | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | | 1M.04.040.0010. a | **664,22 €** | 6,64 € | 20 |
| Heat pump H 12 kW | Heat pump | supplier | 7.710 € | 308,40 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **8.494,43 €** | | |

| | | | | |
|---|---|---|---|---|
| Photovoltaic panels - 12 m² | 1E.17.010.0010.a | **5.589,76 €** | 11,18 € | 30 |

**Total costs for building**

Carbon base measures : **- €**

Carbon advanced measures : **31.913,48 €**

Electric base measures : **- €**

Electric advanced measures : **71.021,57 €**

**Total costs - 1 building**

Carbon base measures : **- €**

Carbon advanced measures : **31.913,48 €**

Electric base measures : **- €**

Electric advanced measures : **71.021,57 €**

**1946-1960 SFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 232 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.025 | 52,51 €/m² |
| | Total amount | | **30.211,04 €** |
| Pitched roof - 98 m² | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Insulating material | 07.01.04.12.h | 71,97 €/m² |
| | Total amount | | **8.194,76 €** |
| Concrete base on ground- level - 85 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Water-proofing felt | 08.A05.B18.005 | 20,17 €/m² |
| | Insulating material | 01.P09.B21.015 | 10,19 €/m² |
| | | 01.P09.B21.020 | 12,74 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Water-proofing sheat | 03.P10.A02.005 | 0,75 €/m² |
| | Water-proofing sheat installation | 03.A08.A01.015 | 17,17 €/m² |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **18.438,20 €** |

| | | | |
|---|---|---|---|
| Door - 2 $m^2$ | Total amount | | **1.502,84€** |
| Windows - 20 $m^2$ | Total amount | | **6.661,2 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 162 $m^2$ | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/$m^2$ |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/$m^2$ |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/$m^2$ |
| | Pavement installation | commercial price | 21 €/$m^2$ |
| | Pavement | 01.P07.B40.005 | 13,88 €/$m^2$ |
| | Total amount | | **31.501,60 €** |

| | | | | | |
|---|---|---|---|---|---|
| | | | | MAINTENANCE [€] | LIFETIME |
| Circulation pump H | | 12.P15.A46.005 | **475,61 €** | 9,51 € | 20 |
| Circulation pump W | | 12.P15.A48.005 | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | | 05.A01.A01.010 | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | | 1M.04.040.0010. a | **664,22 €** | 6,64 € | 20 |
| Heat pump H-W 15kW | Heat pump | supplier | 8.830 € | 353,20 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **9.614,43 €** | | |
| Photovoltaic panels - 22 $m^2$ | | 1E.17.010.0010.a | **10.247,89 €** | 20,50 € | 30 |

**Total costs for building**

Carbon base measures : **69.085,52 €**

Carbon advanced measures :**69.805,52 €**

Electric base measures : **118.567,21 €**

Electric advanced measures : **118.567,21 €**

**Total costs - 11 buildings**

Carbon base measures : **767.860,72 €**

Carbon advanced measures : **767.860,72 €**

Electric base measures : **1.304.239,31 €**

Electric advanced measures : **1.304.239,31 €**

**1961-1975 SFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 240 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.025 | 52,51 €/m² |
| | Total amount | | **31.252,80 €** |
| Pitched roof - 124 m² | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Insulating material | 07.01.04.12.h | 71,97 €/m² |
| | Total amount | | **10.368,88 €** |
| Concrete base on ground- level - 108 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Water-proofing felt | 08.A05.B18.005 | 20,17 €/m² |
| | Insulating material | 01.P09.B21.015 | 10,19 €/m² |
| | | 01.P09.B21.020 | 12,74 €/m² |
| | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Water-proofing sheat | 03.P10.A02.005 | 0,75 €/m² |
| | Water-proofing sheat installation | 03.A08.A01.015 | 17,17 €/m² |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **23.427,36 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 20 m² | Total amount | | **6.661,2 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 156 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |

| | | | |
|---|---|---|---|
| Under-floor heating system - 156 m² | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **30.339,93 €** |

| | | | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|---|---|
| Circulation pump H | 12.P15.A46.005 | | | | **475,61 €** | 9,51 € | 20 |
| Circulation pump W | 12.P15.A48.005 | | | | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | 05.A01.A01.010 | | | | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | 1M.04.040.0010. a | | | | **664,22 €** | 6,64 € | 20 |
| Heat pump H-W 15kW | Heat pump | supplier | | | 8.830 € | 353,20 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | | | 784,43 € | - | - |
| | Total amount | | | | **9.614,43 €** | | |
| Photovoltaic panels - 26 m² | 1E.17.010.0010.a | | | | **12.111,14 €** | 24,22 € | 30 |

**Total costs for building**

Carbon base measures : - **€**

Carbon advanced measures : **77.290,56 €**

Electric base measures : - **€**

Electric advanced measures : **127.473,83 €**

**Total costs - 6 buildings**

Carbon base measures : - **€**

Carbon advanced measures : **463.743,36 €**

Electric base measures : - **€**

Electric advanced measures : **764.842,98 €**

**1976-1990 SFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 244 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.020 | 44,75 €/m² |
| | Total amount | | **29.880,24 €** |

| | | | |
|---|---|---|---|
| Pitched roof - 133 m² | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Insulating material | 07.01.04.12.h | 71,97 €/m² |
| | Total amount | | **11.121,46 €** |
| Concrete lower slab - 115 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A56.005 | 19,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **4.818,5 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 25 m² | Total amount | | **8.326,50 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |
| Under-floor heating system - 199 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **38.665,70 €** |

| | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|
| Circulation pump H | | 12.P15.A46.005 | **475,61 €** | 9,51 € | 20 |
| Circulation pump W | | 12.P15.A48.005 | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | | 05.A01.A01.010 | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | | 1M.04.040.0010. a | **664,22 €** | 6,64 € | 20 |
| Heat pump H-W 18 kW | Heat pump | supplier | 9.950 € | 398 € | 20 |
| | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | Total amount | | **10.734,43 €** | | |

| | | | | |
|---|---|---|---|---|
| Photovoltaic panels - 26 m² | 1E.17.010.0010.a | **12.111,14 €** | 24,22 € | 30 |

**Total costs for building**

Carbon base measures : - **€**

Carbon advanced measures : **59.727,02 €**

Electric base measures : - **€**

Electric advanced measures : **119.356,06 €**

**Total costs - 2 buildings**

Carbon base measures : - **€**

Carbon advanced measures : **119.454,04 €**

Electric base measures : - **€**

Electric advanced measures : **238.712,12 €**

**1991-2005 SFH**

**Envelope improvement**

| | | | |
|---|---|---|---|
| Thermal coating insulation - 223 m² | Plaster removal | 01.A02.B60.005 | 6,53 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Scaffolding | 01.P25.A98.005 | 11,65 €/m² |
| | Thermal insulation | 03.A07.A01.005 | 43,62 €/m² |
| | Insulating material | 03.P09.D01.015 | 37,29 €/m² |
| | Total amount | | **25.645 €** |
| Concrete upper slab - 96 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 03.P09.I01.030 | 17,29 €/m² |
| | Separation sheath | 03.P10.A02.005 | 0,75 €/m² |
| | Separation sheath installation | 03.A08.A01.015 | 17,17 €/m² |
| | Total amount | | **4.008 €** |
| Concrete lower slab - 96 m² | Insulating material installation | 01.A09.G50.005 | 6,54 €/m² |
| | Insulating material | 01.P09.A57.025 | 21,45 €/m² |
| | Plaster | 01.A10.B20.065 | 15,91 €/m² |
| | Total amount | | **4.214,4 €** |
| Door - 2 m² | Total amount | | **1.502,84€** |
| Windows - 21 m² | Total amount | | **6.994,26 €** |

**Installations**

| | | | |
|---|---|---|---|
| Boiler removal H - W | Total amount | 05.A01.R25.010 | **643,73 €** |

| | | | |
|---|---|---|---|
| Under-floor heating system - 172 m² | Pavement and screed demolition | 01.A02.A40.005 | 86,80 €/m² |
| | Heaters removal | 1C.01.170.0030.b | 19,26 €/each |
| | Under-floor heating | 03.P13.C02.010 | 35,41 €/m² |
| | Under-floor heating installation | 03.A12.C02.005 | +25% |
| | Screed | 01.A11.A40.005 | 27,68 €/m² |
| | Pavement installation | commercial price | 21 €/m² |
| | Pavement | 01.P07.B40.005 | 13,88 €/m² |
| | Total amount | | **33.437,62 €** |

| | | | | | MAINTENANCE [€] | LIFETIME |
|---|---|---|---|---|---|---|
| Circulation pump H | 12.P15.A46.005 | | | **475,61 €** | 9,51 € | 20 |
| Circulation pump W | 12.P15.A48.005 | | | **411,69 €** | 8,23 € | 20 |
| Condensing boiler H - W | 05.A01.A01.010 | | | **1.882,23 €** | 37,64 € | 20 |
| Water storage H - 500 l | 1M.04.040.0010. a | | | **664,22 €** | 6,64 € | 20 |
| Water storage W - 500 l | 1M.04.040.0010. a | | | **664,22 €** | 6,64 € | 20 |
| Heat pump H-W 15 kW | | Heat pump | supplier | 8.830 € | 353,20 € | 20 |
| | | Heat pump Installation | 03.A12.F01.005 | 784,43 € | - | - |
| | | Total amount | | **9.614,43 €** | | |
| Photovoltaic panels - 22 m² | 1E.17.010.0010.a | | | **10.247,89 €** | 20,49 € | 30 |

**Total costs for building**

Carbon base measures : - **€**

Carbon advanced measures : **47.106,2 €**

Electric base measures : - **€**

Electric advanced measures : **105.355,83 €**

**Total costs - 1 building**

Carbon base measures : - **€**

Carbon advanced measures : **47.106,2 €**

Electric base measures : - **€**

Electric advanced measures : **105.355,83 €**