EVALUATION OF HEALTH SOCIAL COSTS DUE TO AIR POLLUTION OF RESIDENTIAL HEATING

TIZIANA BINDA

Master Thesis:

EVALUATION OF HEALTH SOCIAL COSTS DUE TO AIR POLLUTION OF RESIDENTIAL HEATING

Application to the case study of Turin

MSc In Architecture Construction City

Candidate:

Tiziana Binda

Tutor:

Stefano Paolo Corgniati

Cristina Becchio

Marta Carla Botero

A.Y:

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Author	Tiziana Binda
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Supervisors	Stefano Paolo Corgnati Associated professor, Department of DENERG Politecnico di Torino Cristina Becchio Associated professor, Department of DENERG Politecnico di Torino Marta Carla Bottero Associated professor, Department of DIST Politecnico di Torino Giulia Crespi PhD student, Department of DENERG Politecnico di Torino Federico Dell'Anna PhD student, Department of DIST Politecnico di Torino

CONTENTS

PART ZERO

PART ONE

PART TWO

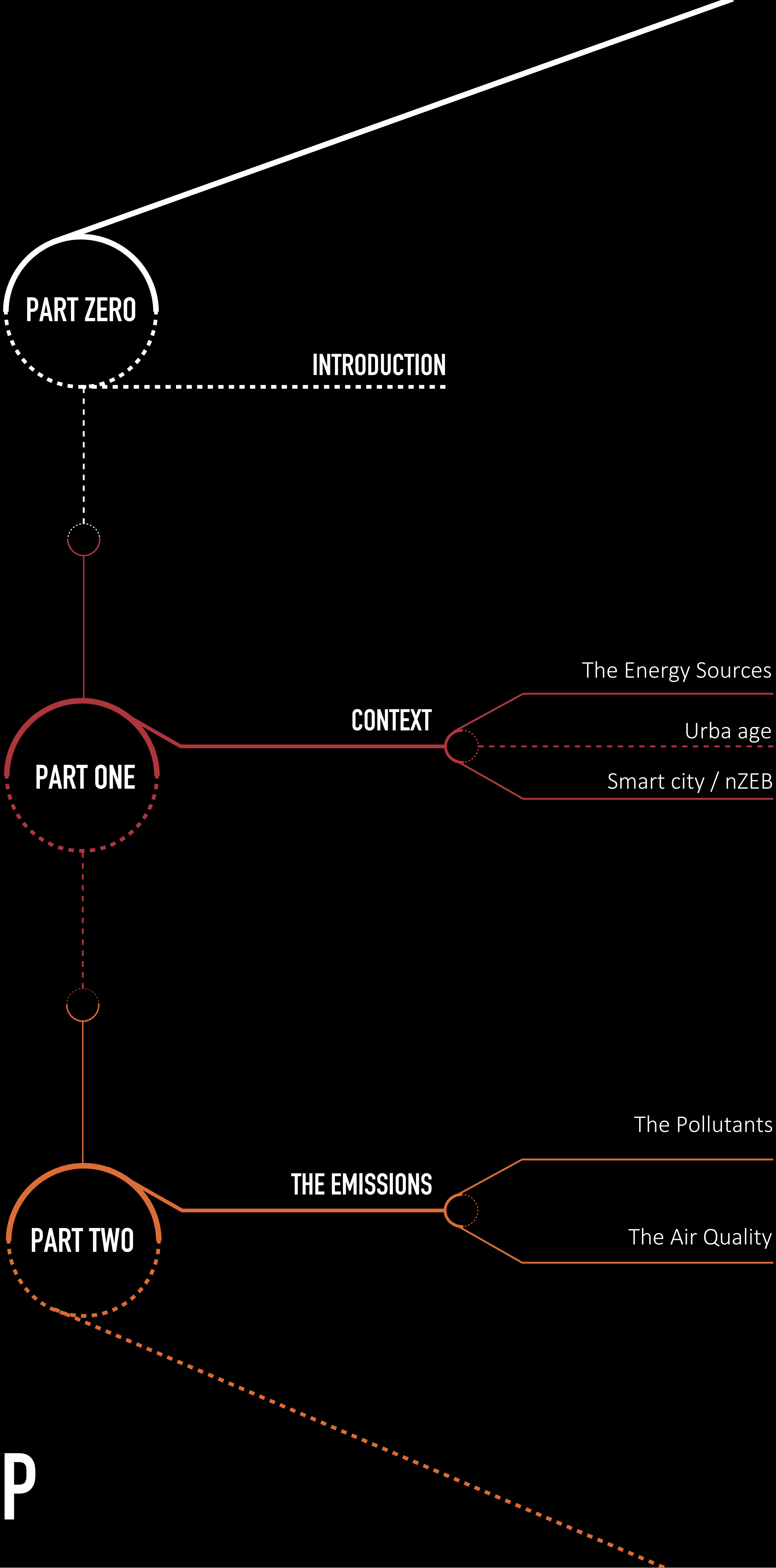
PART THREE

PART FOUR

PART FIVE

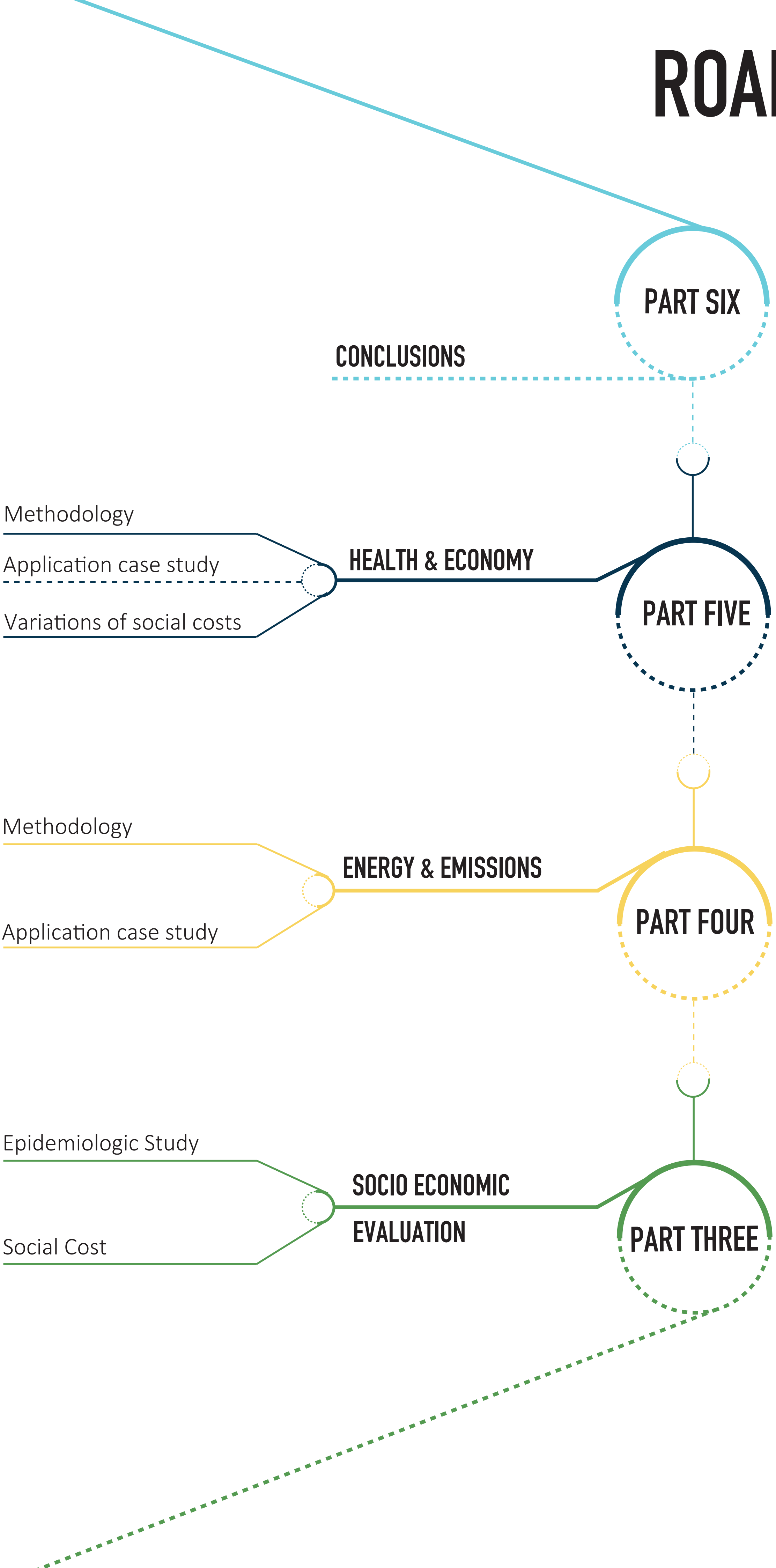
“I filosofi hanno finora soltanto interpretato il mondo in diversi modi; ora si tratta di trasformarlo”

KARL MARX


PART ZERO
INTRODUCTION
PART ONE
CONTEXT
The Energy Sources
Urba age
Smart city / nZEB
PART TWO
THE EMISSIONS
The Pollutants
The Air Quality

ROADMAP

ROADMAP


PART SIX
CONCLUSIONS
Methodology
Application case study
Variations of social costs
HEALTH & ECONOMY
PART FIVE
Methodology
Application case study
ENERGY & EMISSIONS
PART FOUR
Epidemiologic Study
Social Cost
SOCIO ECONOMIC
EVALUATION
PART THREE

PART ZERO

0.0. INTRODUCTION

0.1. BACKGROUND

Nowadays, the concept of outdoor air quality is gaining interest, especially considering the impact that air pollutants have on people's health. This relevance is also clarified by the introduction of the assurance of people's health and wellbeing as an objective for all countries within the Sustainable Development Goals by the United Nations. Surely, the problem is particularly relevant in the urban context, mainly for two reasons. Firstly, since anthropogenic activities represent one of the main sources of pollutants, urban areas tend to present a higher level of concentration of local air pollutants, rather than rural places. In particular, it was estimated that 30% of all air pollutant emissions come from the heating systems in the building sector. Secondly, according to the United Nations Development Programme, it is expected that the urban population will continue to grow, reaching 6.5 million people by 2050.

Due to the significant weight of air pollution on health effects and the high concentration of the people in cities, it is fundamental to include their estimation in urban and economic planning, in order to identify proper solutions to safeguard people and to make the built environment healthier and safer. In doing so, there is the need to identify and provide suitable tools and evaluation methods in support of the decision-making process.

In line with this, the research aims to investigate the relation between air pollutants, health, and people in urban environments. The analysis focuses on the city of Turin, with special attention on the air pollutant emissions emitted by residential building sector. In particular, the thesis has two main objectives. On the one hand, the analysis aims to quantify the emissions caused by the residential sector in its current state, using a Reference Building approach, and to identify possible retrofit scenarios, to evaluate which are the most effective actions in order to reduce the current emissions. On the other hand, the thesis wants to explore and quantify the relationship between air pollutants and health; to do this, a review on epidemiological literature was carried out, to identify the main health diseases associated with air pollution exposure and the main metrics used for their quantification. Moreover, a careful review about the most widespread economic evaluation methods was performed, in order to explore which are the most diffused in scientific literature, able to translate these health effects into monetary terms, and thus to provide estimates of the social costs resulting from outdoor air pollution.

Starting from the review results, two economic evaluation methods were identified and applied to the case study of the city of Turin, namely the Human Capital Approach (HCA) and the Willingness to Pay (WTP). Based on the results in terms of emissions caused by the use of heating systems for either the current state or the developed retrofit scenarios, these methods were applied to quantify the Cost of Illness (as a sum of the direct, indirect and induced social costs) associated to air pollution. The scenario analysis allowed to identify which could be the renovation options for the urban environment able to guarantee the highest emission reductions and benefits (in terms of social cost reduction). The obtained results can provide possible scientific outcomes, to support and guide a new form of urban planning, able to put people at the center, and to include also health and wellbeing aspects.

0.2. OBJECTIVE

Starting from an initial understanding of the principal sources of air pollution and their effects on environment and people's health, the thesis focuses on the residential building sector, at urban scale, aiming to study the current situation of outdoor air quality and to evaluate how different retrofit strategies could help to reduce the emissions created by heating services.

Besides energy and environmental aspects related to the residential sector, the thesis aims to highlight the impact that air pollutants emissions have on people health, by analyzing possible methodological approaches that allow to monetize the effect of air pollutant exposure on health, and thus to evaluate social costs induced by air pollution.

Given the above, the thesis tries to answer to the following research questions: which is the effect of outdoor air pollution on people health? How much outdoor air pollution affect people welfare and the economy?

The thesis is divided into six parts:

- The **first chapter** provides figures on the current situation, with a focus on the urban environment, which needs new solutions for allowing the future transition of cities, towards a sustainable equilibrium between nature, technology and human being. Focusing on the energy sector, the chapter gives a general overview of the main energy sources and how they are used, in the different end-uses.

- The **second chapter** reviews the main pollutants emissions created by the anthropogenic action, which alters the air quality affecting the environment and human health. The analysis will be focused also on a description of the health problems caused by pollutants exposure, specifically in relation to respiratory and cardiovascular diseases.

- The **third chapter** is dedicated to a literature review on the methods used to assess and quantify the impacts of air pollutant exposures on health.

To achieve this objective, the review focused on collecting information on two main areas: i) quantitative assessment, aiming to identify the existing metrics most traditionally used to quantify the health impacts caused by pollutants exposure (i.e. premature deaths, illness), through a review of epidemiological studies; and ii) economic evaluation, aiming to study the different techniques used to assign monetary values to non-marketed goods or services, among which health impacts. Based on the review, some quantification techniques and socio-economic evaluation methods were selected, in order to be lately used for the selected case study.

• The **fourth chapter** focuses on energy analysis at urban scale, in order to provide information on the current pollutant emissions of the residential sector of the city of Torino, selected as case study for the thesis. Moreover, alternative retrofit scenarios were conceptualized and developed, in order to evaluate their capability in reducing the pollutants emissions, by acting solely on the technical systems (i.e. substituting the existing thermal generators for space heating and domestic hot water services with more efficient ones), or on both envelope and technical system (i.e. coupling the substitution of existing thermal generators with interventions on the envelope, either opaque or transparent).

• The **fifth chapter** is devoted to the application of the methods reviewed in the third chapter, for the case study of the residential sector of the city of Torino. In particular, firstly, the results are presented for the current situation both in quantitative terms, to provide estimates of mortality and mobility on the entire population of Torino attributed to PM10 emissions produced by the heating systems. Then, through the application of two economic evaluation methods, namely Human Capital Approach and Willingness to Pay, quantitative information on mortality and morbidity are translated in monetary terms, providing an estimation of the social costs due to health effects of PM10 emissions. Finally, the energy retrofit scenarios presented in the fourth chapter are reported in economic terms, assessing how the reduction of air pollutants related to retrofit actions on residential building could have positive impacts on the social costs.

• Finally, the **sixth chapter** highlights the novelty of the theme and of the application and draws the main outcomes obtained from the thesis, providing some consideration on possible future perspectives.

PART ONE

1.0. CONTEXT

1.0. CONTEXT

This section is dedicate, to understand which sector creates more emissions of pollutant, and the policies that safeguard the environment and people's is important understand and comprehend, which are the majority energy sources that we use, how that are distributed and used the energy in the different sector, in the entire world. At the end going more in deep, to explain how are used the energies sources in the buildings, in particular on the residential sector.

1. 1. THE ENERGY SOURCES and CONSUMPTION

Before start talking about energy resources and their consumption, is important to explain the concept of energy. The term energy comes from the late Latin energīa, or from Greek ἐνέργεια (energeia), and was introduced from the philosopher Aristoteles in the field of philosophy, to distingue the "power" of formless matter, to the capability to change the formal reality of the object, that is the concept of the metaphysic, that have the primary topic to study the nature of "being", becoming, existence or reality, as well as the basic categories of being and their relations. [1]

But in our case, we have to take the concept of energy of the 15 century, where the meaning of "force in action" was moved in the physics area, by definition the energy (energie) is nothing other than the ability to do a job, being careful to not confuse it with the concept of power (mathematical relationship between energy and time) which describes the speed of doing the work.

Energy is verifiable under seven different aspects or forms of energy, which are: thermal energy, chemical energy, electrical energy, electromagnetic or light energy, kinetic energy, gravitational energy and nuclear energy.

This form of energies can be obtained from three different energy sources:

- mineral and plant resources: like coal, oil, gas and biomass from which is possible to obtain the chemical energy.
- Made through the work of mam (infrastructure): as the dam (hydroelectricity),

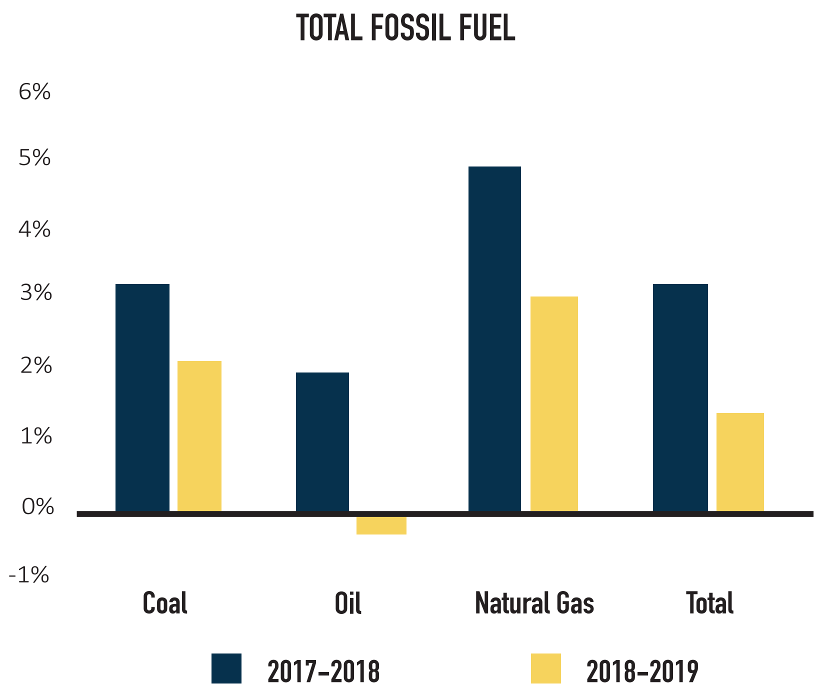
where electricity is produced from hydropower.

• Celestial bodies: such as the Sun which is a source of light energy or the Earth which is a source of thermal energy from the subsoil.

Energy sources, when found directly in nature, such as wind, sunlight, fossil fuels, etc., are defined as **primary** energy sources; if instead a transformation is necessary to facilitate its use, they are defined as **secondary.** Furthermore, an extension distinction can be made considering the regeneration times: **renewable sources** have the ability to renew themselves at the same speed with which they are consumed, i.e. in short times in relation to human history, on the contrary for **non-renewable sources** the times are decidedly longer and, moreover, it should not be underestimated that their use is associated with the release of polluting substances into the atmosphere, including carbon dioxide.

PRODUCTION OF FOSSIL FUELS

The principal fossil-fuel world production are the Coal, Oil and Natural Gas. The graphic down represents the average change in global fossil fuels production by fuel, data given by the report 2020 IEA (International Energy Agency).[2]



Graphic 1. Rappresentation of the total fossil fuel. Sources: IEA world Energy Balances, 2020.

Since the nineteenth century, much of our economy has been based on fossil fuels like coal, oil and natural gas.

The coal is energy produced from fossil sources, it is a hydrocarbon which has a very important role, in fact, it allowed the industrial revolution in 1750, making it one of the main energy sources for the human being. The growth of the production of coal accompanied the development of industrialization that originated in England, with the patent in 1769 of the James Watt steam boilers, and then it spread to Europe and the rest of the world. Nowadays, by the report of IEA (International Energy Agency) the main productor of coal are Indonesia (31.7%) Australia (27. 4%), Russia (15.1%), United Stated (5.9%), South Africa (5.6%), Colombia (5%), Canada (2.5%), Mongolia (2%), and the rest of the world, including Europe (4.9%). [3]

Unlike coal, oil was discovered in the mid-800's, and its demand increased in the early 1900's, with the advent of the car, and the first oil well in history was dug in

Titusville, Pennsylvania, in 1859. Nowadays, especially the new coronavirus (COVID-19) impact the demand of oil, slowing supply growth in the United States and other non-OPEC [1] (organization of the petroleum exporting Countries) countries, in the same time, global energy transitions are affecting the oil industry: companies must balance the investments needed to ensure sufficient supplies against the necessity of cutting emissions. In a decarbonising world, refiners face a big challenge from weaker transport fuel demand. [4]

Instead of the natural gas had a remarkable year in 2018, with a 4.6% increase in consumption accounting for nearly half of the increase in global energy demand. Since 2010, 80% of growth has been concentrated in three key regions: the United States, where the shale gas revolution is in full swing; China, where economic expansion and air quality concerns have underpinned rapid growth; and the Middle East, where gas is a gateway to economic diversification from oil. Natural gas continues to outperform coal or oil in both the Stated Policies Scenario (where gas demand grows by over a third) and the Sustainable Development Scenario (where gas demand grows modestly to 2030 before reverting to present levels by 2040). [5]

The next four graphics show which are the main total energy supply by fuel and which are the main region production, comparisons between 1971 and 2018.

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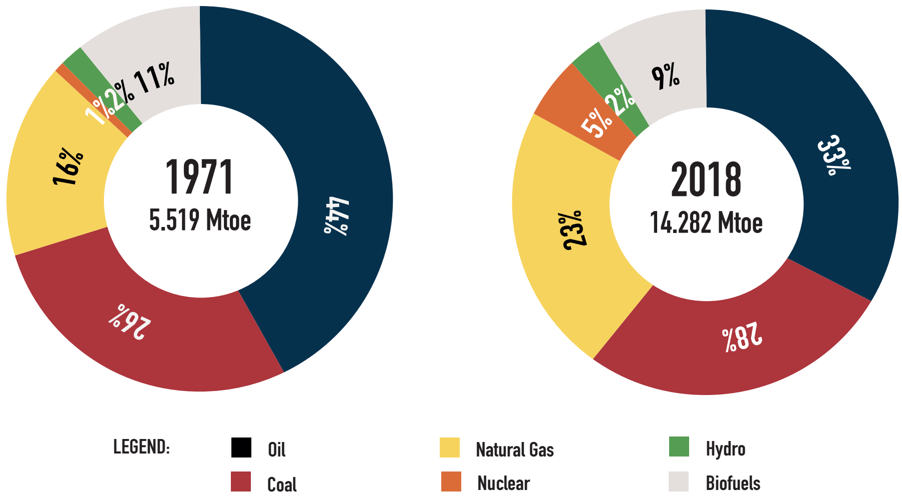
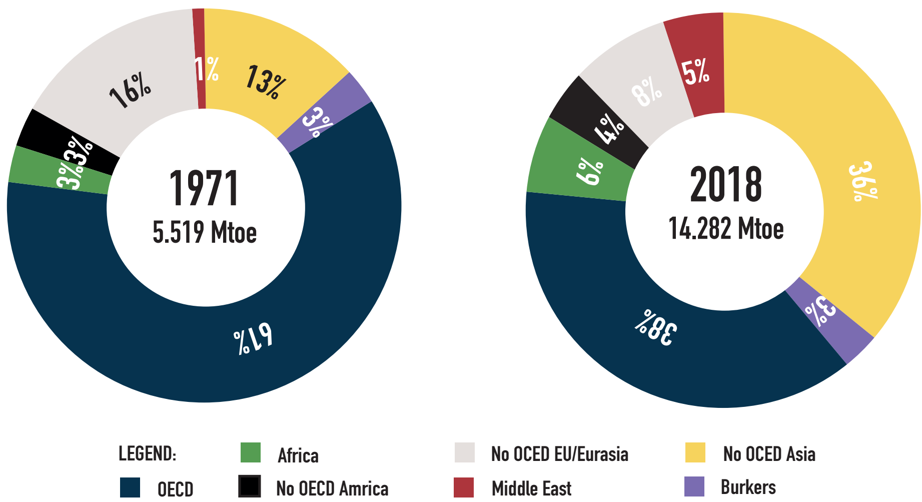
[1] OPEC (Organization of the Petroleum Exporting Countries), founded in 1960, it includes twelve countries that have joined together, forming an economic cartel, to negotiate aspects related to oil production. They control the 78% of the oil reserved and the 50% of natural gas reserved. [6]

TOTAL ENERGY SUPPLY by FLUE



Graphic 2. Total energy supply by fuel. Sources: IEA World Enery Balances, 2020

TOTAL ENERGY SUPPLY by REGION



Graphic 3. Total energy supply by region. Sources: IEA World Enery Balances, 2020

In this graphics is visible that world total energy supply (TES) increased 2.6 times (from 5 519 Mtoe to 14 282 Mtoe). [5].

The oil fell from 44% of 1971 to 32% of 2018, a reason could be regarding the policies of decarbonization and for use the alternative energies, in fact, in the past the oil was used principally in the area of the car, but in the last period, they introduced other sources of energy like the electricity to be more sustainable and reduce the emission. Instead, the natural gas consoled its third rank, growing from 16% in 1971 to 23% in 2018.

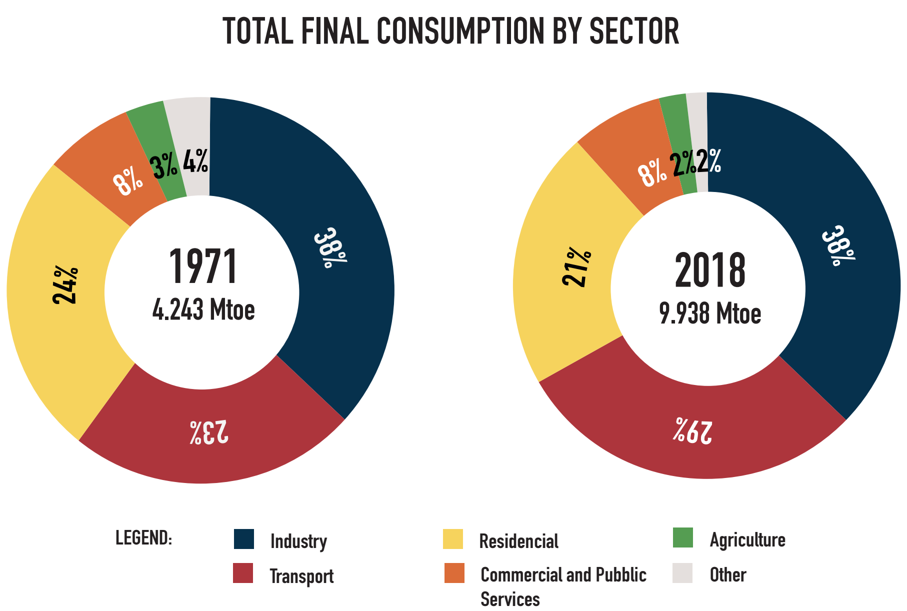
The share coal is one percentage point higher in 2018 compared to 1971 (respectively 27% and 26%).

This increasing constantly is influenced mainly by increased consumption in China (Graphic 3).

In fact, graph 3 shows that China is the main region of production of coal, as well the main production of hydro energy sources, providing 2.5% of global energy production in 2018. The total primary energy supply increased mostly in non-OECD Europe and Eurasia (+ 4.5%) followed by non-OECD Asia (+ 4.1%) and Africa (+ 2.8%). It also increased in OECD countries and in the Middle East but to a lesser extent (+ 1.0% and + 0.7% respectively). Non-OECD Americas is the only region of the globe where it decreased, for the fourth year in a row now (-2.7%).

1. 2. THE ENERGY USE IN THE SECTOR

Until now, there has been talked of global energy consumption, without specifications which are the main sectors of human activity that involve the use of energy. In the graph down (figure 4), represent which is the main sectors that use energies, comparisons between 1971 and 2018.



Graphic 4. Rappresentation of the total final consumption by sector. Sources: IEA World Enery Balances, 2020

Between 1971 and 2018, total final consumption (TFC) pass to 4.244 Mtoe in 1971 reaching 9 238 Mtoe in 2018. The share of energy use of most sectors has been stable for com-

merce and services or industry for instance. However, energy use in transport significantly increased, from 23% of TFC in 1971 to 29% since 2015, the reason could be, that the people moved, and continue to move in the city, especially in the global city. Concept that is very actual and studied as well by the sociologist and economist Saskia Sassen.
She wrote different book regard the concept of global city, and during 2000 she identified three main cities as a global city, which was: London, Tokyo, and New York. [6]
But we are in 2020 and the Global Cities have grown up, in fact, there are, Beinjing, Buenos Aires, Durban, Rio de Janeiro and other. These global cities increased the connection in the city and with the other city, which could be an explanation for the increase in the sector of transportation.
Notwithstanding the growth of the transport sector, in 2018 industry remained the largest consuming sector globally, with the same share as in 1971 (38%). The residential sector ranked third in 2018 (21%).
The other main sector of total final consumption is the residential sector.
But in this area, the consumption decreased, passing from 24% in 1971 to 21% 2008, the reason could be that with the new politics of sustainability, and so with the combination of using technology more performance and renewable sources the energy demande decrease.

1. 3. URBAN AGE

Now that we have the general idea of the energies that are used in the various sectors, and the quantities that are required, it is possible to explain where are most invested this energy and that is possible to use other sources to generate energy.
Is important to understand which period we are living, and how will be the future.
The emission of pollutants, as we have been seen, are created mostly form the human activity, and how will be this situation in the future?
How could we act to try to give a better quality of life for us and the future generation?
I start quoting the words by Neil Breen, Professor of Urban Age at Harvard Graduate School of Design (GSD), and Christina Schmid Professor of Sociology at the Faculty of Architecture of ETH Zurich.

“Foreboding declarations about contemporary urban trends pervade early twenty-first century academic, political and journalistic discourse. Among the most widely recited is the claim that we now live in an ‘urban age’ because, for the first time in human history, more than half the world’s population today purportedly lives within cities.”

Neil Brenner and Christian Schmid,2014 [7]

How they said we are living in the “Urban Age”, in fact, in the city have a relevant role in this era, starting with the industrial revolution (middle 1800 century) the people move in the city for work, so from this period the city begin to have an important role that in the past, at the same time increase the growth of the population.

Nowadays the **world’s population** continues to grow, from an estimated 7.7 billion people worldwide in 2019, the medium-variant projection1 indicates that the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion in 2100. [8]

From this data is important to take into account another trend that will characterize the coming years: the **growth of the urbanization** rate. In fact, according to most of the estimates, that the 10 cities are predicted to gain megacity status by 2030, bringing the total number of megacities to 43.

A number that is reasonable, if we thinking that today, 55% of us live in urban areas, that’s 4.2 billion city-slickers, it is estimated that in 2030 the 70% of the growth of the population will live in the city, so more that 2 billion people will have moved to the city [9]. Basically the 15% of the peoples moved in 10 years.

Consequently, more that 80 milliard o meters square will be built in the urban area to allow people to live in cities. [10]

GROWTH OF THE POPULATION AND THE CITY

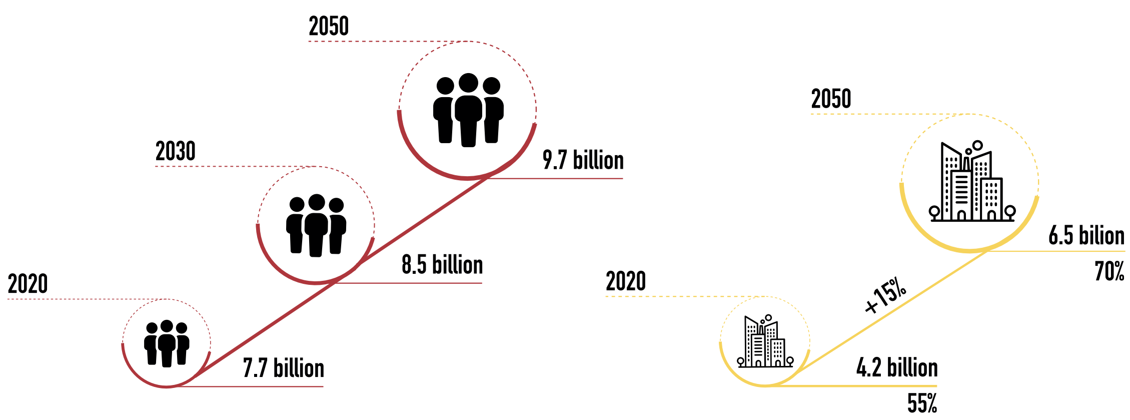


Fig.1. The scheme on the left size rappresent the growth of the population, instead the scheme on the right size schow the increse of the population in the city in the next years. Sources, United Nations, department of economic and social affairs. [11]

An important point is, the sum of these factors has created, an increase in services requirements, the use of resources of the soil and energy, created atmosphere pollutants, and the environment. Now arise spontaneously the question, how can we have a good quality of life, and so to achieve a state of welfare?

1. 4. ALTERNATIVE ENERGY

In order to reduce the emissions of pollutants, which as we have seen that most are given by fossil fuels, represent a convenient and useful way to obtain energy, but are materials that are destined to run out, are the cause of serious damage to environment and human health there are the so-called excellent alternatives, also called clean energies, that is, which do not release harmful substances into the atmosphere and/or which could therefore alter the air.

SOLAR ENERGY

In fact, the earth's luck is that of being able to exploit energy from nature, such as **solar energy**. In fact, the sun generates electromagnetic energy (i.e. light and heat) throughout the earth's surface. The disadvantage is given by the intermittence caused not only by the alternation between day and night, but also due to the weather conditions. The energy from the Sun can be used both for heating through **solar thermal** panel and for the generation of electricity through the use of **solar photovoltaics**. The solar radiation that strikes the surface of the Earth includes a direct contribution, which comes from the sun's rays when the weather is clear, and an indirect contribution through cloud cover; to the center of Europe, almost half of the average amount of solar energy that arrives on a surface every year comes from indirect radiation, which allows solar panels to be used all year round (considering, of course, that in winter the yield will be less than the summer). A lot is being invested in solar technology; now it is not at all strange to observe the roofs of houses covered with these panels, which can be isolated or connected to the distribution network in such a way as to sell the surplus during the day and buy the needs for the hours of darkness. Furthermore, the research also focuses on cogenerate photovoltaics which, through the same panel, is able to meet the double demand for heat and electricity production. [12]

WIND ENERGY

Wind energy in Europe has grown significantly, proving to be a mature technology: it is more and more frequent to come across both individual installations, with a single turbine, and power stations with a few dozen devices that power a district or an industrial area. Before installing a wind power plant, it is necessary to choose the site, evaluating the most favorable areas for the presence of wind, but not underestimating the studies of the ecology of avifauna relating, for example, to migratory passes. Even the wind, like the sun, is by nature intermittent, varying both daily and on a seasonal basis. However, an advantage is the ease of construction; in fact, a 10 MW wind farm, sufficient for the electricity needs of 4000 average European families, can be assembled in just two months. Furthermore, a wind power plant can be easily transferred to another site and, in case you want to upgrade it, it is not necessary to expand it but it is sufficient to replace the existing pale ones with more powerful ones. [13]

HYDROELECTRIC ENERGY

It is an energy available in most countries, it is very simple to manage, economically attractive, but it is characterized by long construction times that require large capital investments. The great advantage is that of being able to store energy to be used later in times when there is a need. For this reason, it is common practice to charge the basins at night using excess thermoelectric energy, in order to have a reserve for the next day, which can be activated in a few seconds, during the daily peaks of electricity demand. To date, hydroelectric power supplies clean energy with continuity and reliability, representing about 16% of total electricity production even if, in reality, it represents only 2% of all primary energy production (which also includes that obtained from transport fuels, heating , etc...).

WAVE ENERGY

This type of energy is generated by the movement of sea water, an inconspicuous but always continuous phenomenon. The movements of water that are exploited with different technologies are associated with the action of gravitational forces (tides), with the generation of surface perturbations due to the effect of winds (waves) and, finally, with differences in temperature or density between the layers shallow and deep oceans (marine currents). It is still a young technology that however has great potential for use as 70%

of the earth's surface is made up of seas and oceans: from this awareness, the creation of some prototypes was promoted, such as the "Iswek Waves for Energy project. "[14] in Pantelleria.

GEOTHERMAL ENERGY

The endogenous heat of the Earth is exploited For the production of energy, by mainly due to two phenomena: the convective movements of the fluid part of the mantle, which convey the thermal energy of the core towards the outside, and the decay of radioactive isotopes (uranium, thorium and potassium) which are enclosed in the earth's crust.

Depending on the specific local conditions, such as morphology and subsoil temperature, geological reservoirs are formed which can be water-dominated or steam-dominated.

In the first, more frequent ones, the water can reach temperatures above 300 ° C and the part that turns into steam is conveyed to the tubes to generate electricity. Geothermal resources are renewable only if well managed and can be used both in the industrial and residential sectors, exploiting sources with a relatively low temperature (30-150 ° C) for fish breeding, pool heating, district heating of housing and greenhouses, drying of agricultural products and timber, etc. [15]

BIOMASS ENERGY

Biomass refers to all materials of biological origin (waste from agricultural activities but also wood, marine vegetable mass, urban organic waste) that have not undergone any fossilization process and from which it is possible to obtain three different products: thermal energy and electricity (biopower), chemical compounds (bioproducts) and biological fuels (biofuels). For biomass, I would like to spend a couple of words, because as we have already pointed out, the deter rioration of air quality in Italy is caused by the heating system, in particular, a study conducted by Enea showed that the biomass are the primary cause. But the pollution of biomass for thermal use fluctuates within a wide range, in fact, it depends on various factors, from the technology of the efficiency of the combustion system to the type of fuel and also from the frequency of use. The tool that Enea used to conduct the research is the PEAR (Programma Energetico Ambientale Regionale), where there are indicated the measures to be used in order not to exceed emissions in various sectors, and also measures regarding the use of biomass as a renewable energy source, with particular attention to the emission phenomena produced by small wood-burning plants.

This is because there are no regulations on the limit of specific emissions of biomass, of small plants, at national level.

1. 5 WHICH ARE THE OTHER TOOLS?

This paragraph is dedicated to seeing the tools that are already present to have sustainable cities. Increasing the possibility to respect the environment and the energy sources for the future generation.
In particular, we will see, the concept of the smart city and the nZeb building, and we will show some cases already existing.

1.5.1 SMART CITY

Now the question could be, how we can act, to create a better city, and so to combine the quality life whit the use of alternative resources? An answer could be the “smart city”. But want is a smart city? The answer depends on who you ask. Solutions providers will tell you it’s smart parking, smart lighting or anything to do with technology. City officials may say it’s about conducting city business online, such as searching records or applying for permits. City residents may tell you it’s the ease of getting around, or about crime reduction. Everyone is right. A smart city, built properly, will have different value for different stakeholders. They may not think of their city as a “smart” city. They know it only as a place they want to live in, work in, and be a part.

The concept of smart city born in Europe with the aim of indicating the path to follow in order to achieve certain objectives.
The most recent definition of “smart city”, was given by Peter Ninkamp, scholar of the sector, in 2010:

“...the city is called “smart” when investments in human and social capital and traditional and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory gov-

ernance. Furthermore, cities can become “smart” if university and industry support government’s investment in the development of such infrastructure.” [16]

The objectives to be achieved for the city for the near future, are environmental sustainability, citizen well-being and economic development. This can be realized using a holistic approach, including, without any distinction, six fundamental components:

- **Smart Governance;** the administration, is sensitive to environmental and social issues and personally promotes projects in this regard, for example, the revitalization of the territory, the enhancement of the existing heritage, tourism, the dissemination of a new language (especially digital) as in able to cancel the differences of ethnicity, gender and disability, with the aim of making everyone aware of and participating in city initiatives, remembering, however, not to exclude people less sensitive to the digital revolution;
- **Smart Economy;** provides a new way to rethink the economy, especially after the economic crisis of the 2008, where, the focus is on issues such as the growing number of families in poverty, unemployment, attention to energy saving and waste of both food and resources;
- **Smart Mobility,** understood as a set of physical infrastructures that involve the connection not only between different areas of the city, but also between different cities, to which it is essential to associate projects that include public services, car and bike sharing initiatives or the creation of cycle and pedestrian paths that urge the citizen to limit (up to the complete inactivity) of the private car;
- **Smart Environment** is the most discussed topic in recent years following the growing awareness that the quality of the surrounding environment affects the health and well-being of citizens. For these reasons, discussions on atmospheric, acoustic and light pollution are increasingly frequent, also regarding policies for the protection of fauna and flora, was disposal, aimed to create a real civic and environmental education;
- **Smart Energy,** has the objective to monitor the decrease in energy consumption and the need to adopt energy requalification policies; moreover, this is partly possible if the production of energy at the local level will originate from clean and renewable sources that can be stored and distributed through an intelligent network, the Smart Grid;
- **Smart People** and **Smart Living,** is based on the concept of a livable city in which an improvement in the quality of life, implemented by interven ing, for example,

on health care, on vulnerable groups such as the disabled, the elderly, and the poor. In parallel to this, educational and cultural participation projects must be promoted, spreading projects of equality and integration, in order to create a climate of serenity and satisfaction.

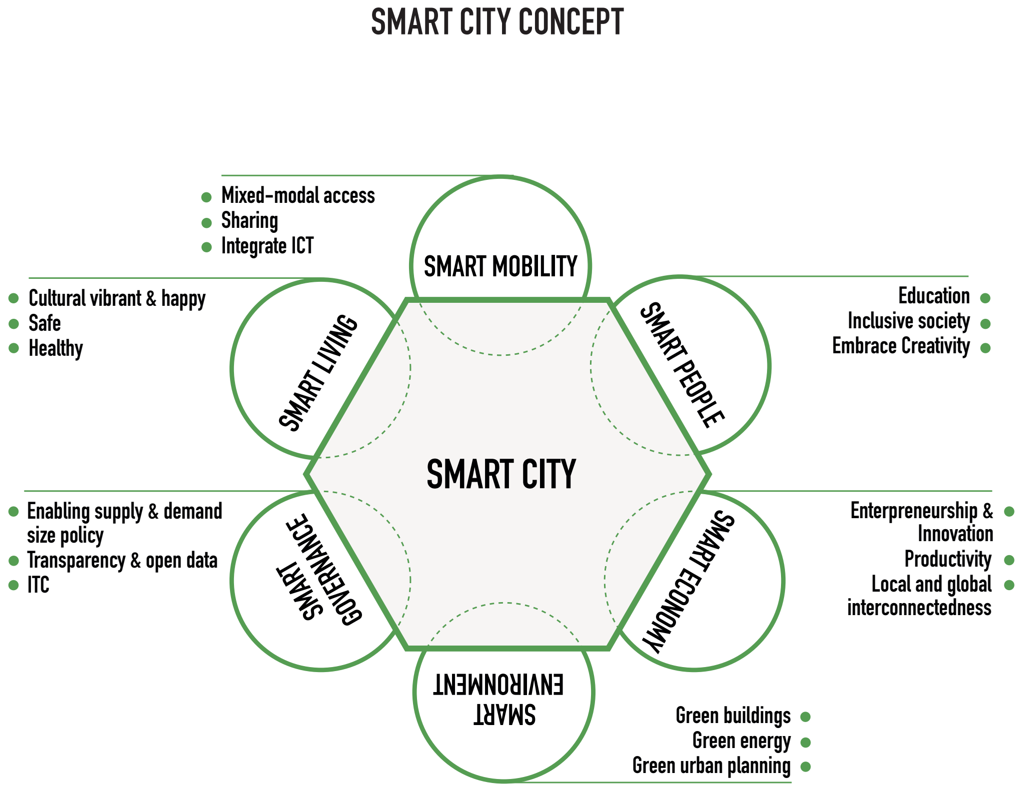


Fig.2. Figure which reppresenta a schematic illustration how wor a smart city.

The two principal elements that give the possibility for the realization of the concept of "smart city", are material infrastructures (**physical capital**) and infrastructures dedicated to information and communication technologies (**ICT**).

Regarding this last point the , the IBM (Institute for Business Value) has promoted a collection of ideas in which it is stated that the system underlying Smart Cities can be defined as "instrumented", that is, it is digitized with the aim of creating and collecting information, "interconnected", in how much they bind the various parts to the central system by disseminating the information collected, and "intelligent", as it is able to create behavioral models aimed at giving rise to informed actions [17]

The other important element for the creation of the smart city is the collaboration between different stakeholders, so the "social capital", in fact the city is created and composed by the human being and the relationship between they, in that sense is fundamental the participation of the citizens for the development of the city.

1.5.2. SMART ENERGY

Regarding to the topic of the master thesis, I focus the attention on the topic of smart energy city, in particular on the Smart Energy city, characterized by a high efficiency of resources and energy, the use of renewable energy sources and a resilient resource system, so to improve the energy efficiency of the city.

The most specific definition of Smart city energy is given by the Technical university of Denmark (DTU) [18], introducing eight indicator level of “smartness” to valuating if the city satisfies the required to be smart energy city, and to help to the energy transaction [19]

This “eight-key element “are:

- **resources system integration**, or a strategic planning both physical and digital, in which any system is not isolated, but a combination of different sources is created;
- **access to energy services,** access to reliable and sustainable energy services for all energy users;
- **resilience**, the ability to guarantee, in the long term, the well-being of the community and the economy, following important events and stresses (including climate change;
- **energy efficiency**, the ability to optimize the scarcity of both resources and energy, taking into account the high cost and impact of some energy sources;
- **renewable energies**, incentivizing the use of renewable energy sources and reducing carbon emissions, in order to prevent further climate change;
- **active and engaged users**, the ability to involve all stakeholders, active and engaged in the development of strategies, aimed at the operational management of the city and its services;
- **sustainable economy**, that is a low-emission economy that is financially competitive and efficient, also favoring the growth of industrial sectors and “green” services;
- **smart governance**, that is a condition in which city users must have a direct and immediate influence on the necessary decisions and solutions; this can be achieved through new intelligent and interactive decision-making systems Underlying the concept of smart cities energy there is another factor, the smart grid, also called “smart system”. This is an electrical system that manages the energy sources (centralized or distributed), from the production to the use, through the transmission and distribution that occurs through the widespread use and integrated communi

cation systems, processing and control.

The smart grid is the latest system of integration in the management of both the demand for electric energy and surplus. To realize the smart grit is necessary the intervention for the final users of energy, so to associate a “smart building.”

1.5.3. SMART BUILDING /nZEB

From smart city to smart building. While for the smart city, technology is one of many factors that characterize it, for the smart building it is the most important factor. The evolution of architecture design has led today to the need to use a computer integrated building management, thank to some devices like:

- Sensors; monitoring and presentation messages in case of changes;
- Controller, control units and devices based on programmed rules set by the user;
- central unit, which allows programming of units in the system;
- Smart Meter> allows communication between the building (users) and the Smart Grid.

According that the 27% of European energy consumption (2017) [20] and the 30% of pollutant emissions are attributable to real estate and evaluating that it is a value appreciated over time, it was a decrease of energy consumption between 2005 to 2017, the energy was reduced by 4%, but this is not enough, the measures are needed to contain this consumption.

With the implementation of the EPBD 2010/31/EU, Member States may obtain these very high energy performance buildings called nZEB, “nearly Zero Energy Buildings”.

The EPBD promotes the improvement of the energy performance of buildings, taking into account outdoor climatic and local conditions as well as effectiveness in terms of costs.

In order to optimize consumption, Member States will have to establish minimum efficiency requirements for systems and promote the introduction of active control system in new constructions or major renovations.

The Directive also provide, by 31 December 2021, the transformation of building sector, be it public or private, in nZEB, i.e. very **high energy performance**, in which the very low energy requirement is covered to a very significant extent from **renewable sources** produced on-site or nearby. [22]

That is why today we hear a lot of energy saving, plant efficiency and environmental sustainability, factors that characterize smart buildings.
The "smart" appellation characterizes a structure in which information management is integrated, economically, and energy-efficient, enabling optimized consumption of the building-plant system and a reduction of waste.
In other words, the smart building, then, consists in passive technologies reducing the energy demand; active technologies covering the remaining demand with the use of renewable energies; building automation which allows an adjustment, management and monitoring systems, integrating the whole.

1.5.4. THE REALITY

Until now we have seen that cities will have to host an increase of population, then we see which there are renewable sources that can be used to replace the energies that are used mostly today, which allow the reduction of pollution. So we can summarize that cities in the near future must be based on the concept of **sustainability,** which says:

"*Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs*"
(Brundtland report, 1987)

And with the help of **technology**, such as the smart city concept expressed in the previous paragraph, without forgetting that technology is a tool, it must be considering in mind that at the center of everything, there is the well-being of man and for feel-good man in a healthy environment, so to create an equilibrium between nature and the human beings.
An example of a city that is being built, and which aims to be the most sustainable city in the world, is **Amaravati**, a city designed by Foster, the capital of the district of Guntur, in the Indian state of Andhra Pradesh located along the Krishna River, it enjoys a continuous supply of water.
The goal of the Indian government is to create one of the most sustainable cities in the world. For this reason, the entire metropolis is designed to comply with the highest standards of green building, using all the latest technological achievements in the sector devel-

oped in India, first of all photovoltaics. .Transportation will be ensured by electric vehicles, water taxis and bicycles; to encourage mobility on foot, special infrastructures will also be created consisting of a network of shaded avenues and squares.

For Amaravati city, the international studio Foster + Partners signs the masterplan of the new government complex, the heart of the new city. It is a portion 1 kilometer wide and 5.5 long and is part of a rigid urban grid that governs the entire anthropized environment, defining its spaces and dictating precise rules.

The backbone of Norman Foster's entire project is a strip of green that runs the entire length of the intervention area; the architect himself describes it as a "green thorn" for which he and his team were inspired by the famous Central Park in New York and the lesser-known Lutyens district, in the Indian capital New Delhi.

Fig.3. Amaravati masterplan 2025 - Andhra Pradesh, India a project by norman foster + partners.

Fig.4. Amaravati city, a project by norman foster + partners, focusing on the legislative assembly building.

This large linear park, in addition to having a strong compositional value, allows compliance with rigorous environmental strategies imposed in the design of the entire city, first of all that at least 60% of the land is occupied by vegetation and stretches of water.

The particular geometric frames, such as the legislative assembly building, respect the principles of bioclimatics, guaranteeing adequate obreggiation, and at the same time, the natural ventilation of the building. In addition to the shape, this building and the entire project recalls the tradition of the place by creating elements with a strong symbolic meaning, in fact this building was designed following the principles of "**Vaastu**", a 5000 year old doctrine according to which the laws of nature affect human dwellings. [22]

A high-level project by Foster + Partnes, which aims to promote the development of renewable energy and clean technologies, demonstrating to the world that there is "a life beyond oil", is **Masdar City** located in the Arabian emiates, a city approved by the government of Abudabi.
This project dates back to 2007 while the construction of the first buildings dates back to 2010.

Fig.5. Masdar City, Abu Dhabi UAE a project by Norman foster + partners.

In the general design the city is divided into two distinct sectors, connected to each other by a linear park. In the event of a future increase in the number of inhabitants, a plan for the growth of the city is also envisaged; the aim is to create rational planning, avoiding the phenomena of disordered and uncontrolled growth which contemporary cities are often victims of.

The Masdar City masterplan is also conceived to be built in successive phases; the primary core (the largest sector) represents a sort of pilot project while each expansion allows to improve, from a technological point of view, the realization of the next one.
There are many solutions in terms of clean energy and sustainability thanks to which Masdar City can be defined as an example of the city of the future: the use of solar and wind energy, water saving and recycling of materials as well as the entire system of mobility.[23]
These are just some of the examples that show how it is possible by combining sustainability and technology to create cities where there is communication and union between human needs, supporting the environment, not damaging it.

PART
TWO

2.0. THE EMISSIONS

2.0. THE EMISSIONS

Now that we have the general idea about the energies that are used in the various sectors, and the quantities that are required, it is possible to explain the emissions that they generate, therefore of pollutants.

2. 1. THE POLLUTANT

Generally with the expression environmental pollution it indicates the presence in a specific place the presence of one or more foreign substances called pollutants, which have the ability to alter the components of the environment in which the human being lives, therefore air, water and soil , it can be of **natural** origin or produced by human activities, so called **artificial**.

Natural pollution is mainly due to volcanic activities and wind factors as well as to local natural contamination, such as landslides in rivers, natural gas emissions, etc. The rivers of active volcanoes have the ability to release a large amount of dust and sulfur dioxide into the atmosphere. Equally large are the quantities of dust that are carried by the winds in areas far from the origin.

However, pollution caused by natural events generally has limited importance, in fact when we talk about pollution, we mean that produced by human activities.

Driven by the desire for comfort, man has changed the environment in which "nature" lives, to the point that he has developed urban centers and industrial plants, the increase in motorization, the use of chemicals in agriculture, using natural resources in an excessive way and related waste.

In the study of pollution, the effects are often not seen at the local level but at the global level, as these activities create problems for the planet, increasing atmospheric acidity, resulting in acid rain, or the change in climate due to the increase of the percentage of carbon dioxide in the atmosphere (greenhouse effect) and the depletion of the ozone layer of the beautiful stratosphere (ozone).

Pollutions can be classified into:

- Atmospheric

- Of the waters
- Of the soil

Due to changes in environmental conditions there is also noise, radioactive and electromagnetic pollution.
In this thesis we will focuses on the pollution of the air.

What is mean by air quality? and why has this aspect begun to be considered?
We started talking about air pollution when this caused death of human being, creating the era of ecological disasters. We recall some striking episodes such as that of the Meuse Valley in Belgium, December 1930, where industrial fumes combined with air and wind creating silent extermination, where 60 people died, in Donora, in Pensylvania, in the United States October 1948 , where there were dozens of deaths and hundreds of hospitalizations, but the most striking and was recorded in 1952, from these tragedies, started the attention to air quality. [1]

Atmospheric pollutants can be classified in relation to their origin, the mode of release in internal (internal) or external (external) environments and their physical state. After having classified the position of the pollutant, a further subdivision must be made into: **primary** pollutants emitted directly by human activities or by natural events and **secondary** pollutants, which are created subsequently, following reactions between the substances emitted and the substances present the atmosphere.

THE ATMOSPHERE

To correctly frame the assessment of air quality it is good to start from a non-intuitive concept, the concentrations of gases that make up the earth's atmosphere today are over 99% the same as we would have found millions of years ago, despite the countless natural events, even catastrophic ones, and anthropogenic activities, which have only minimally changed its composition. To better under stand the air, it is right to take a step back and understand how the earth's atmosphere is composed.
The atmosphere surrounds the earth with about 2000 km of non-homogeneous gaseous mass beyond the moon. It is mainly divided into two main parts: 1. **lower atmosphere,** also called hemisphere because its chemical composition is quite homogeneous: it extends from the surface of the planet and up to about 100 kilometers high, the motions of the air in this region they mix the gases keeping the ratio between its various constituents

more or less constant. 2. **upper atmosphere**, extends above 100 kilometers, also called heterosphere because it is not uniform: gases are extremely rarefied and are stratified according to their density.
Another classification of the atmosphere is made by the WMO (World, Meteorogical Organization) [2] which divides the layers of the atmosphere by convention into five zones that are characterized by height from the ground, thermal gradient and different chemical-physical properties.

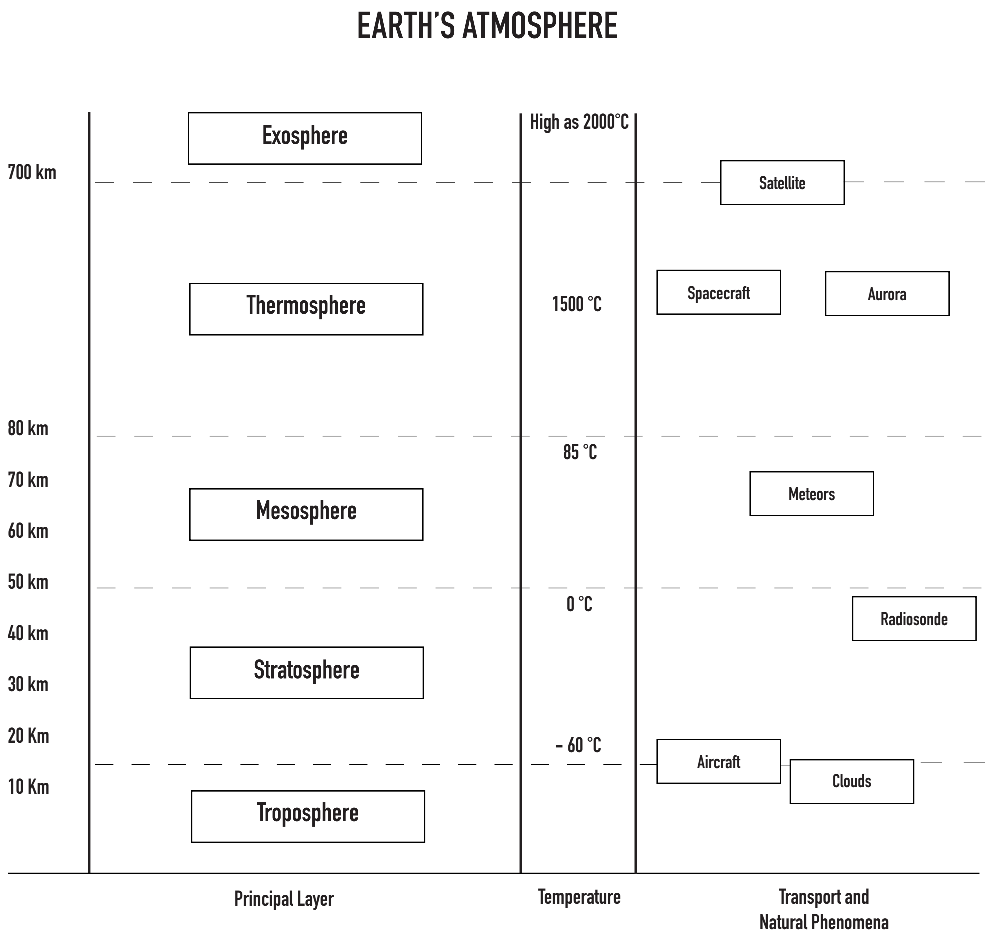


Fig.1. Schematic illustration of the levels Earth's atmosphere and the trend of temperatures as a function of height.

The diagram divides the layers of the Earth's atmosphere, the parts we take into consideration the **troposphere** and the part of the **stratosphere**.
The **troposphere**, because it is the gaseous spheroidal belt of the atmosphere that is in direct contact with the earth's surface, of variable thickness depending on the latitude (average height of about 10-12Km). It is the layer where most of the meteorological phenomena occur, caused by the circulation of air masses and which give rise to winds, clouds and atmospheric precipitation. Most of the emitted air pollutants remain confined in the troposphere, some concentrated near the earth's surface, others such as O3, CO2, CH4,

are distributed more evenly. The troposphere is the place of life, all the plants and animals that live in it, but not all the layer of the troposphere is breathable. The atmosphere is breathable, it is mainly composed of nitrogen (75% of the volume), oxygen (21%) and argon (less than 1%), in addition to water vapor the concentration in the lower atmosphere is highly variable and can reach 3% of the volume. The **stratosphere,** a layer of the earth's atmosphere, above the troposphere and below the mesosphere. Its altitude and thickness vary with latitude and the seasons of the year (about 12 to 50 km). Taken into consideration as there are some planes (such as military fighters) that travel in this sphere. **Mesosphere** extends from 50 to 90 Km. **Thermosphere** from 90 to 600 km, site of intense phenomena due to particles charged by radiation. The last layer is the **Exosphere** which starts over 600km.

2. 2. THE QUALITY OF THE AIR

Once the classification of the atmosphere has been made, we can talk about the concentration of pollutants in the atmosphere which is regulated by the emissions and by the chemical-physical transformations to which they are subjected, and so the quality of the air.

Besides the concentration is important to take in account the meteorological phenomena that more than the first two factors allow to understand the dynamics of air quality and, more often than not, explain peak events.

Important meteorological phenomena are:

- Wind, causes horizontal transport
- The temperature
- The intensity of solar radiation
- Thermal inversions

In the alternation of these elements, they can produce mixing in the lower layers or increase the concentrations of pollutants. At this point it is necessary to take into account the **atmospheric stability**, which can last or days, causing those periods favorable to the accumulation of pollutants such as to induce the numerous efforts of the legal limits [D.LGS 155.10, Italy, which refers to the limits of 'European Union] which are repeated, usually in winter. [3]

After this explanation regard how is compose the air, is possible to give a definition of this concept, whit **air quality** we mean the qualitative and quantitative

The concept of air quality is based on an evaluation of the pollutants present in the atmosphere, which are dangerous for the **health** of people and the **environment**. [4]

Links between emissions and ambient air quality, emission reductions have not always produced a corresponding drop in atmospheric concentrations.

The area that interest the quality of the air in the ecosystem, and the human health.

The links between emissions and ambient concentrations can only become evident and fully understood by means of air quality modelling.

2.2.1. THE DISTRIBUTION OF POLLUTANT IN DIFFERENT SECTOR

To evaluate the effect that emissions can have on air quality, on the environment and the human's health is better explain which are the pollutant, and the principal sources that create this emission. The diagram reproduced below divides the concept of pollutant emissions, dividing into two Macro-groups which are **anthropic** and **natural.**

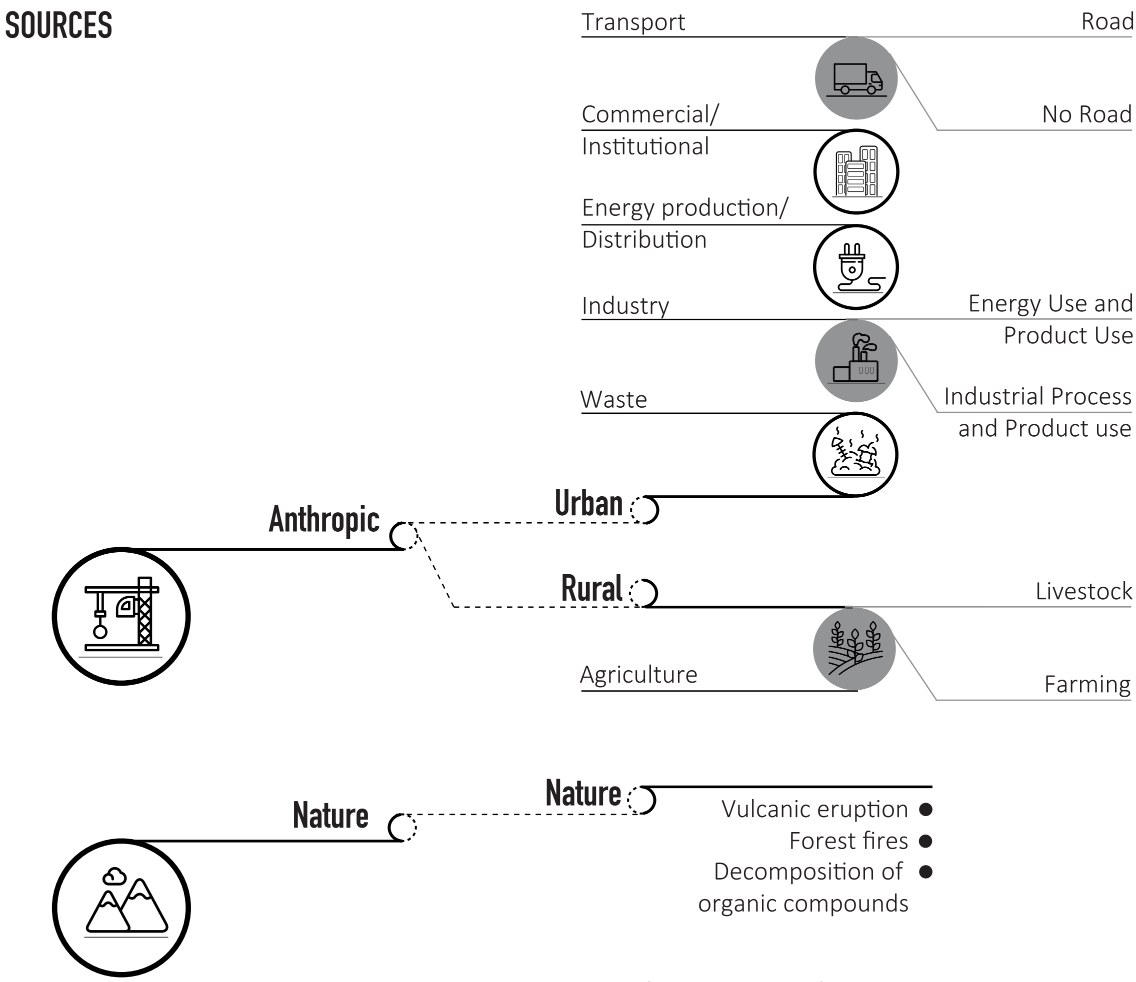


Fig. 2 Scheme of sources, produced from EU Air Quality 2019 report data.

Each sources create a pollutant, which are Particulate matter, (PM 10, PM2.5) Ozone (O3), Nitrogen Dioxide (NO2), Sulphur dioxide (SO2), Carbon monoxide (CO), heavy metals arsenic (As), cadmium (Cd), lead (Pb) and nickel (Ni), Benzene and Benzo (a) pyrene (IPA).

PARTICULATE MATTER

PM10 PM2.5

Particulate matter is the general term used for a mixture of particles (solid and liquid) suspended in air, collectively known as aerosols, with a wide range in size and chemical composition. PM2.5 refers to 'fine particles' that have a diameter of 2.5 micrometres or less. PM10 refers to the particles with a diameter of 10 micrometres or less. PM10 includes the 'coarse particles' fraction in addition to the PM2.5 fraction. Particulate matter is either **primary** because the particles enter the atmosphere directly (e.g. from smokestacks) or formed in the atmosphere from oxidation and transformation of primary gaseous emissions. The latter are called **secondary** particles. The most important precursors (gaseous pollutants contributing to particle formation) for secondary particles are SO2, NOX, NH3 and VOC (which represent a class of chemical compounds whose molecules contain carbon). The main precursor gases SO2, NOX and NH3 react in the atmosphere to form ammonium and other forms of sulphate and nitrate compounds that condense and form new particles in the air, called secondary inorganic aerosol (SIA). Certain VOC are oxidised to less volatile compounds, which form secondary organic aerosol (SOA).

Sources: Particulate matter is either of natural origin, e.g. sea salt, naturally suspended dust, pollen, volcanic ash (see EEA, 2012e) or from anthropogenic sources, mainly from fuel combustion in thermal power generation, incineration, households for domestic heating and vehicles, amongst others. In cities vehicle exhaust, road dust re-suspension and burning of wood, fuel or coal for domestic heating are important local sources.

OZONE

O_3

Ground-level (tropospheric) O3 is not directly emitted into the atmosphere but formed from a chain of chemical reactions following emissions of the precursor gases NOX, VOC and CO. Nitrogen oxides are emitted during fuel combustion, for example by industrial facilities and road transport.

Nitrogen oxides play a complex role in O3 chemistry: close to its source NOX will deplete O3 due to the reaction between the freshly emitted NO and O3. Areas downwind of major sources of VOC and NOX may experience O3 peaks after wind has carried O3 and its precursors far from their sources. Thus, high O3 concentrations can occur in remote areas.

Volatile organic compounds are emitted from a large number of sources including paint, road transport, refineries, dry-cleaning and other solvent uses. Volatile organic compounds are also emitted by vegetation, with amounts dependent on temperature. Methane (CH4), also a VOC, is released from coal mining, natural gas extraction and distribution, landfills, wastewater, ruminants, rice cultivation and biomass burning. Fire plumes from wild forest and other biomass fires contain CO and can contribute to O3 formation.

The chemistry of O3 formation and its decay are complex and are also driven by energy from the sun. Therefore, O3 is labelled as **photochemical pollutant**. The main features of this can be summarized as follows: NO2 can efficiently absorb sunlight and dissociate, producing atomic oxygen (O) and NO. The atomic oxygen in turn reacts rapidly with molecular oxygen (O2) to form O3 (provided a third molecule such as molecular oxygen or nitrogen absorbs the excess energy released in this reaction). On the other hand, NO, typically emitted by combustion processes, reacts rapidly in the air with O3 to form NO2 and O2 and therefore contributing to the decay of O3 concentrations. However, the polluted air however contains also VOC. Nitrogen oxides and VOC are taking part in hundreds of chemical reactions. Through the action of the hydroxyl radical formed by the action of sunlight, VOC are degraded to produce substances that react with NO to produce NO2 without consuming O3. The net result of these reactions is that more than one O3 molecule is formed for each VOC molecule degraded.

NITROGEN DIOXIDE

NOx

Nitrogen dioxide is a reactive gas that is mainly formed by oxidation of NO. High temperature combustion processes (e.g. those occurring in car engines and power plants) are the major sources of NOX, the term used to describe the sum of NO and NO2. Nitrogen monoxide makes up the majority of NOX emissions. A small part is directly emitted as NO2, typically 5–10 % for most combustion sources, with the exception of diesel vehicles.

SULPHUR DIOXIDE

SOx

Sulphur dioxide is emitted when fuels containing sulphur are burned. The key manmade contributions to ambient SO2 derive from sulphurcontaining fossil fuels and biofuels used for domestic heating, stationary power generation and transport. Volcanoes are the most important natural source.

CARBON MONOXIDE

CO

Carbon monoxide is a gas emitted due to incomplete combustion of fossil fuels and biofuels. Sources: Road transport used to emit significant amounts of CO but the introduction of catalytic converters reduced these emissions significantly. CO concentrations tend to vary with traffic patterns during the day. The highest CO levels are found in urban areas, typically during rush hours at traffic locations.

HEAVY METAL

The heavy metals arsenic (As), cadmium (Cd), lead (Pb) and nickel (Ni) are common air pollutants, mainly emitted as a result of various industrial activities and combustion of coal. Although the atmospheric levels are low, they contribute to the deposition and build-up of heavy metal contents in soils, sediments and organisms. Heavy metals are persistent in the environment and some bioaccumulate in food chains.
Air pollution is only one source of exposure to these metals but their persistence and potential for long-range atmospheric transport means that atmospheric emissions of heavy metals affect even the most remote regions (WHO, 2007).

As

Arsenic is released into the atmosphere from both natural and anthropogenic sources. Most man-made emissions are released from metal smelters and the combustion of fuels. Pesticides used to be an important source, but their importance declined as a result of restrictions in various countries. Tobacco smoke may contain arsenic, thereby being a source of exposure in ambient air.
Arsenic in air is usually a mixture of arsenite and arsenate, with organic varieties of negligible importance except in areas of where there is substantial application of methylatedarsenic pesticides. Most As in the air is found in the fine particle fraction.

Cd

Cadmium is released into the atmosphere from natural and anthropogenic sources. Volcanoes, windborne particles and biogenic emissions are considered the main natural sources of cadmium in the atmosphere.
The anthropogenic sources of cadmium include non-ferrous metal production, stationary fossil fuel combustion, waste incineration, iron and steel production and cement production.

Ld

Lead is released into the atmosphere from natural emissions, which are soil suspension by wind, sea salt, volcanoes, forest fires and biogenic sources. These emissions are not entirely natural but contain some contributions from past depositions of anthropogenic lead. Major anthropogenic emission sources of lead on a global scale include the combustion of fossil fuels from, for example, traffic, waste disposal and production of non-ferrous metals, iron, steel and cement.

Ni

Nickel is a ubiquitous trace metal, which occurs in soil, water, air and in the biosphere. Nickel emissions to the atmosphere may occur from natural sources such as wind-blown dust, volcanoes and vegetation. The main anthropogenic sources of nickel emissions into the air are combustion of oil for heat or power generation, nickel mining and primary production, incineration of waste and sewage sludge, steel manufacture, electroplating and coal combustion.

BENZENE C6H6

Incomplete combustion of fuels is the largest source of benzene. Benzene is an additive to petrol and 80–85 % of benzene emissions are due to vehicular traffic in Europe. Other sources are domestic heating, oil refining and petrol handling, distribution and storage. In general, the contributions from domestic heating are small (about 5 %) but with sharp geographic patterns. Wood combustion can be an important local source of benzene where wood burning can account for more than half of the domestic energy needs.
Removal of benzene from the atmosphere mainly occurs through the reaction of benzene with the hydroxyl (OH) radical. Photo-oxidation contributes to ozone formation, although benzene reactivity is relatively low. A lifetime of several days is sufficient for benzene to be transported over long distances.

BENZO (a) PYRENE

BaP

Benzo(a)pyrene (BaP) is a five-ring polycyclic aromatic hydrocarbon (PAH) and is found in fine particulate matter originating from combustion.

A main source of BaP in Europe is domestic home heating, in particular wood burning. Other sources include road traffic, outdoor burning and rubber tyre wear.

POLLUTANTS SCHEME

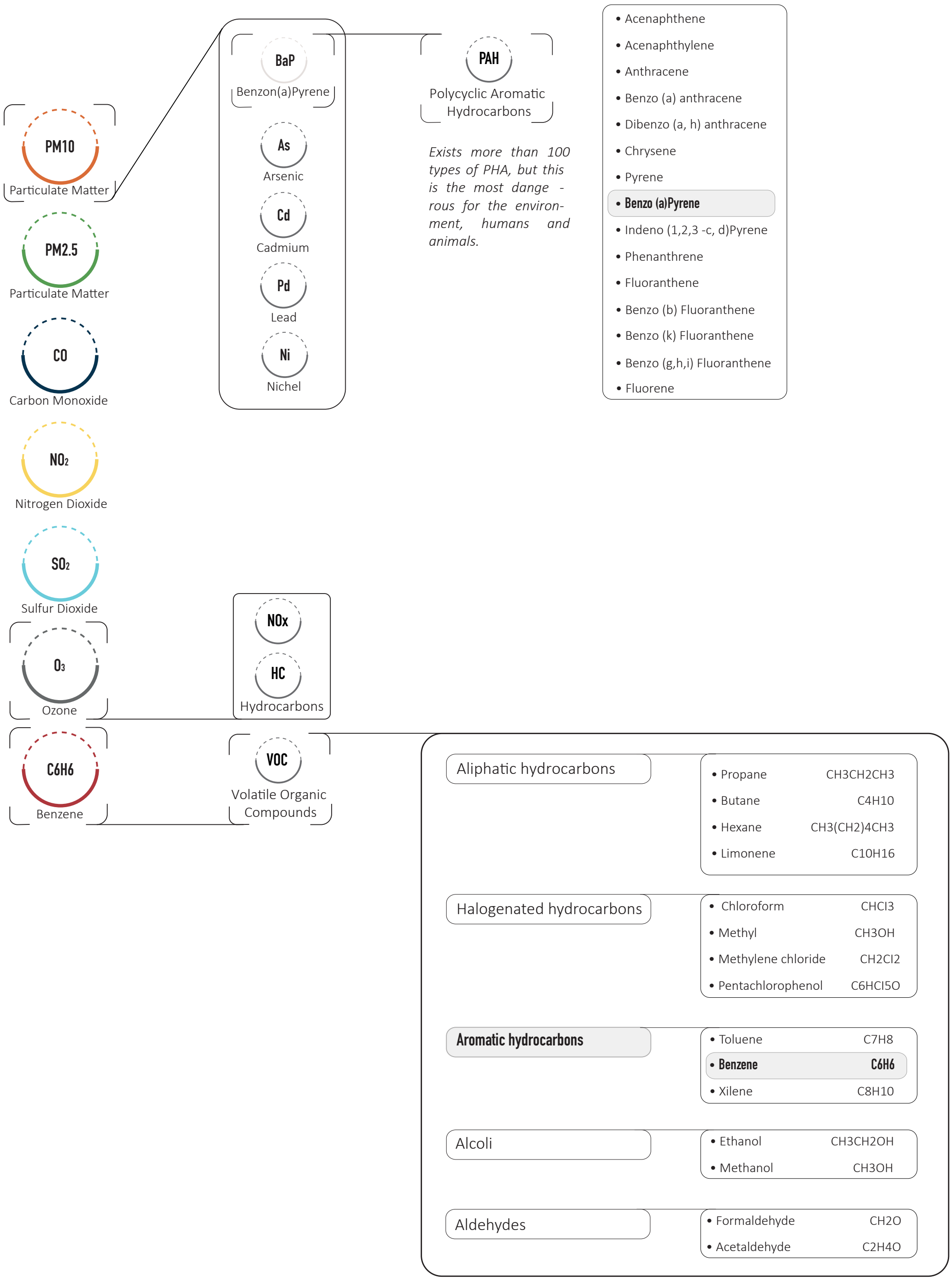


Fig. 3 Scheme which represetn themain pollutants and derivations.

POLLUTANTS EMISSONS FOR SECTOR

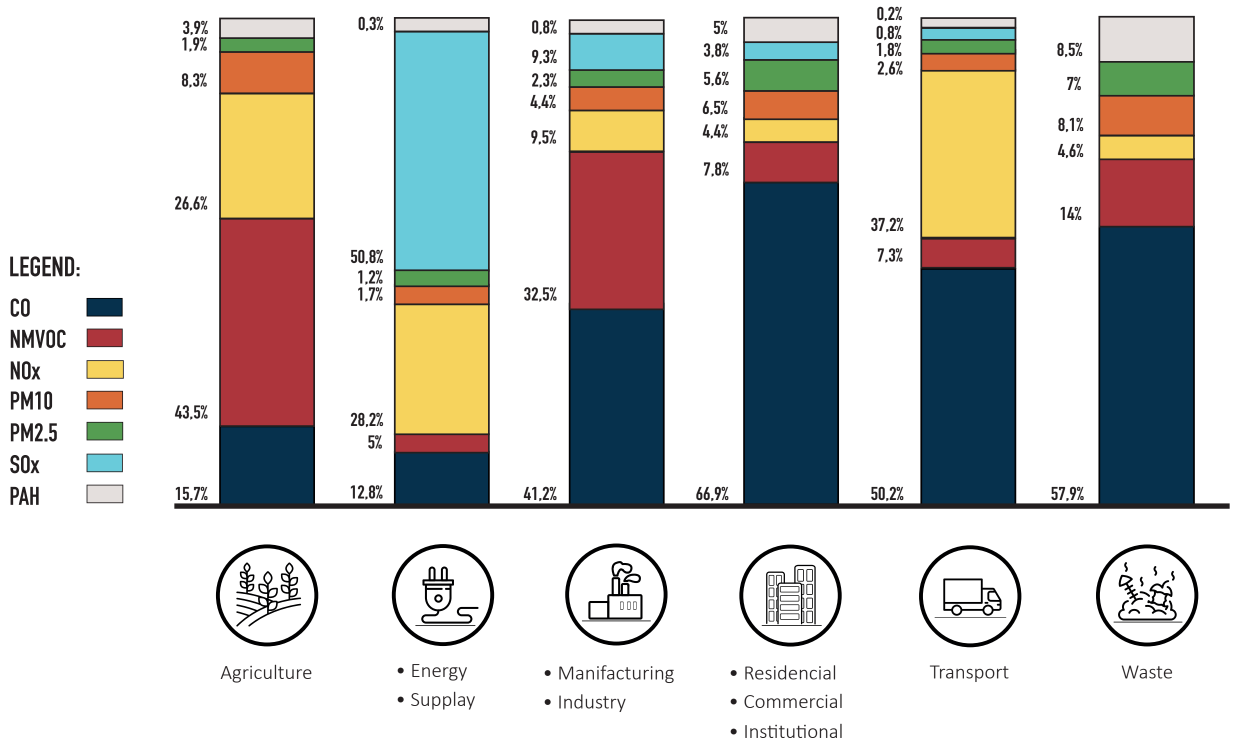


Fig. 4 Scheme of sources, produced from EU Air Quality 2019 report data.

2.3. THE EFFECT OF AIR POLLUTION

Air pollution is a local, regional and transboundary problem caused by the emission of specific pollutants, which either directly or through chemical reactions lead to negative impacts. As explained in more detail below, these include:

- effects on human health caused by exposure to air pollutants or intake of pollutants transported through the air, deposited and accumulated in the food chain;
- acidification of ecosystems, both terrestrial and aquatic, which leads to loss of flora and fauna;
- eutrophication in ecosystems on land and in water, which can lead to changes in species diversity; odamage and yield losses affecting agricultural crops, forests and other plants due to exposure to ground-level ozone;
- impacts of heavy metals and persistent organic pollutants on ecosystems, due to their environmental toxicity and due to bioaccumulation;
- effects on climate forcing;
- reduction of atmospheric visibility;
- damage to materials and cultural heritage due to soiling and exposure to acidifying pollutants and ozone.

2.3.1 ECOSYSTEM IMPACT

Air pollution also damages the environment. For example, ozone can damage crops and other vegetation, impairing growth. These impacts can reduce the ability of plants to take up CO2 from the atmosphere and indirectly affect entire ecosystems and the planet's climate. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters. **Acidification** causes disturbances in the function and structure of ecosystems with harmful ecological effects, including biodiversity loss.
Acidification caused by deposition with the environment in wo ways: by **direct** mechanism, when deposited pollutants and/or their chemical derivatives interact chemically with the plants or building materials; with the term 'direct' damage to plants and trees means an injury caused by the direct interaction between gaseous pollutants with the foliage and other exposed parts of a plant. The other is by **indirect** mechanism, when deposited pollutants and/or their chemical derivatives cause such changes in soil and/or aquatic ecosystems which damage flora and fauna. The acid deposition leads to indirect damage through acidification of soil [5]. However anthropogenic acidification is only partly responsible for soil acidification. There are **natural** processes contributing to acidification of soil:

- introduction of carbonic acid from precipitation, microbiological and root respiration
- acidic decaying products, coming from vegetation decay
- nitrification from natural sources of nitrogen
- formation of sulphuric acid during oxidation of iron sulphides

The **anthropogenic** processes of soil acidification are caused by:

- pollution in form of acid precipitation
- agricultural practices

The acidification can effect as well the fresh water, causing a decrease of pH. Fortunately not all surface waters are sensitive to acidification caused by acid precipitation. In most cases buffering capacity prevents a decrease in pH.
The most sensitive waters are located in highlands with a thin soil layer covering granite bedrock. The buffering capacity of such soil is small.
(The acidification is caused principally by the emission of sulfur dioxide [SO2] and nitric oxide [NOx]). [6]
Likewise, deposition of nitrogen compounds can lead to **eutrophication** (from Greek eutrophos, "well-nourished"), which constitutes an oversupply of nutrient nitrogen in terres

trial and aquatic ecosystems. Consequences include changes in species diversity, invasions of new species and leaching of nitrate to groundwater.

The most commonly element which leads to overgrowth of plants and algae in aquatic ecosystems are, nitrogen or phosphorus. According to Ullmann's Encyclopedia, "The primary limiting factor for eutrophication is phosphate" [7]. The availability of phosphorus generally promotes excessive plant growth and decay, favouring simple algae and plankton over other more complicated plants and causes a severe reduction in water quality. Phosphorus is a necessary nutrient for plants to live and is the limiting factor for plant growth in many freshwater ecosystems. Phosphate adheres tightly to soil, so it is mainly transported by erosion. Once translocated to lakes, the extraction of phosphate into water is slow, hence the difficulty of reversing the effects of eutrophication. The human activities are the principal caused that speed up the natural eutrophication. Due to clearing of land and building of towns and cities, land runoff is accelerated and more nutrients such as phosphates and nitrate are supplied to lakes and rivers, and then to coastal estuaries and bays.[8]

2.3.2 CLIMATE IMPACT

The air pollution may also impact the Earth's climate. Some air pollutants interfere with the Earth's energy balance and are therefore known as 'climate forcers'. These can either be gases (e.g. ozone) or airborne particulate matter (aerosols). Some climate forcers reflect solar radiation (e.g. sulphate aerosols) leading to net cooling, while others (e.g. black carbon aerosols) absorb solar radiation, thereby warming the atmosphere. In addition, aerosols influence the formation, microphysics and optical properties of clouds, resulting in indirect climatological effects. Deposition of certain aerosols (e.g. black carbon) may also change the Earth's surface reflectivity (albedo), especially on ice- and snow-covered surfaces, thereby accelerating melting. In other words, the The air pollution may also impact the Earth's climate. Some air pollutants interfere with the Earth's energy balance and are therefore known as 'climate forcers'. These can either be gases (e.g. ozone) or airborne particulate matter (aerosols). Some climate forcers reflect solar radiation (e.g. sulphate aerosols) leading to net cooling, while others (e.g. black carbon aerosols) absorb solar radiation, thereby warming the atmosphere. In addition, aerosols influence the formation, microphysics and optical properties of clouds, resulting in indirect climatological effects. Deposition of certain aerosols (e.g. black carbon) may also change the Earth's surface reflectivity (albedo), especially on ice- and snow-covered surfaces, thereby accelerating melting. In other words, the Ground-level O3 and black carbon, a constituent of PM, contribute to global warming.

In fact, the ozone is a secondary pollutant formed in the troposphere from complex chemical reactions following emissions of precursor gases such as NOX and non-methane VOC (NMVOC). The ozone is a powerful and aggressive oxidising agent, elevated levels of which cause respiratory health problems and lead to premature mortality. High levels of O3 can also damage plants, leading to reduced agricultural crop yields and decreased forest growth. [8]

2.3.3 HUMAN HEALTH IMPACTS

Numerous scientific studies have linked air pollution to health effects including:

- harm to the respiratory system, leading to the development or aggravation of respiratory diseases, decreased lung function, increased frequency and severity of respiratory symptoms such as coughing and difficulty breathing, or increased susceptibility to respiratory infections;
- harm to the cardiovascular system;
- harm to the nervous system, affecting learning, memory and behavior;
- harm to the reproductive system;
- cancer.

The consequence is some of these impacts may result in premature death. Sensitive individuals, such as older adults and children and people with pre-existing heart and lung diseases or diabetes, appear to be at greater risk of air pollution-related health effects.

The Global Burden of Disease study estimates that 3.4 million premature deaths were attributed to outdoor air pollution 2017. This means that outdoor air pollution was respon sible for 6% of global deaths. [9]

In some countries, it accounts for 10% of deaths, or higher.

In the map here we see the share of annual deaths attributed to outdoor air pollution across the world. In 2017 this ranged from less than 2% across many countries in Sub-Saharan Africa; 2-3% across North America and Oceania; 4-6% across much of Europe and Latin America; and higher than 6% across many countries in Asia, North Africa and the Middle East.

At the highest end of the scale around 1-in-10 deaths were attributed to outdoor air pollution. In Egypt this share was 12%; in Turkey and China it was 10%; and in India it was 8%

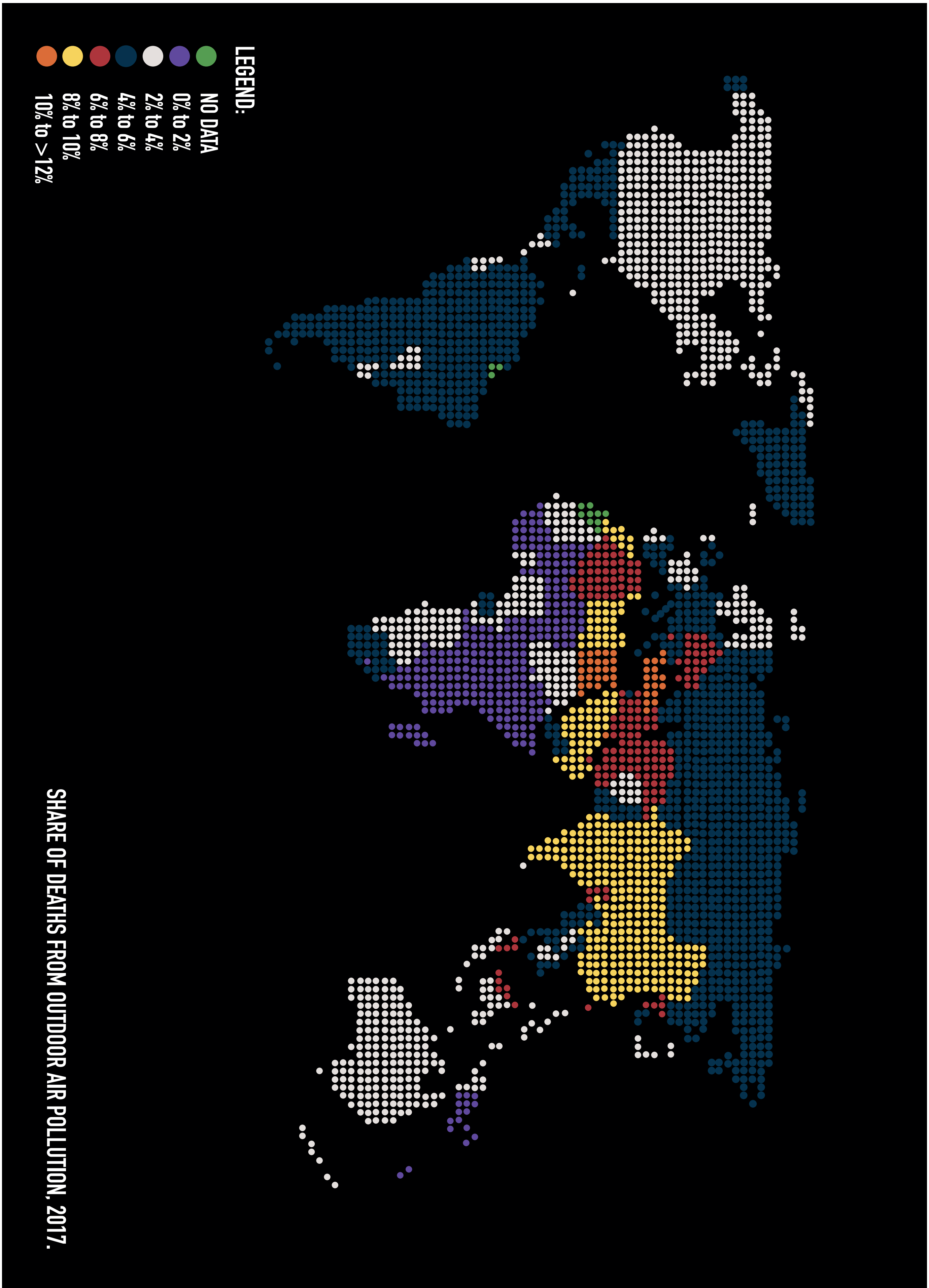


Fig. 5. Map: number of death from outdoor air pollution, World, 2017, source: IHME, Global Burden of Disease [OurWorldInData.org/outdoor-air-pollution]

When we compare the share of deaths attributed to outdoor air pollution either over time or between countries, we are not only comparing the extent of outdoor air pollution, but its severity in the context of other risk factors for death. Air pollution's share does not only depend on how many dies prematurely from it, but what else people are dying from and how this is changing . [10]

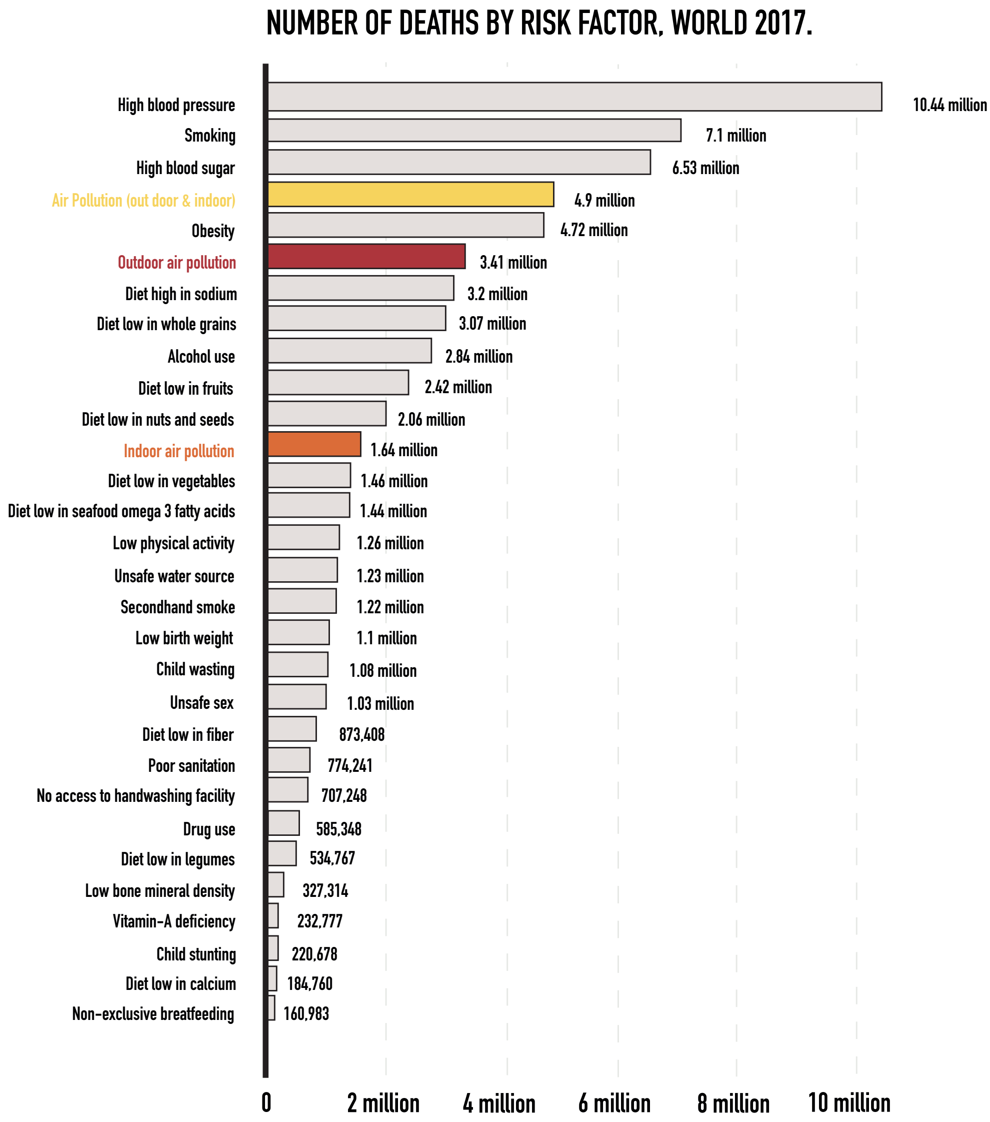


Fig. 6. Chart: number of deaths by risk factor, World, 2017, source: IHME, Global Burden of Disease (GBD)

Table 1. EFFECTS OF AIR POLLUTANTS ON HUMAN HEATH, THE ENVIROMENT AND CLIMATE

Polltant	Health effects	Environmental effects	Climate effects
PM2.5 PM10	Cardiovascular and lung diseases, heart attacks and arrhythmias. Can affect the central nervous system, the reproductive system and cause cancer. The outcome can be premature death.	Can affect animals in the same way as humans. Affects plant growth and ecosystem processes. Can cause damages and soiling of buildings, including monuments and objects of cultural heritage. Reduced visibility.	Climate effect varies depending on particle size and composition: some are reflective and lead to net cooling, while others absorb solar radiation leading to warming. Can lead to changed rainfall patterns. Deposition can lead to changes in surface albedo.
O_3	Irritates eyes, nose, throat and lungs. Can destroy throat and lung tissues, leading to decrease in lung function; respiratory symptoms, such as coughing and shortness of breath; aggravated asthma and other lung diseases. Can lead to premature mortality.	Damages vegetation by injuring leaves, reducing photosynthesis, impairing plant reproduction and growth, and decreasing crop yields. Ozone damage to plants can alter ecosystem structure, reduce biodiversity and decrease plant uptake of CO2.	Ozone is a greenhouse gas contributing to warming of the atmosphere.
NOx	NO2 can affect the liver, lung, spleen and blood. Can aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection.	Contributes to the acidification and eutrophication of soil and water, leading to changes in species diversity. Enhances sensitivity to secondary stress (such as drought) on vegetation. Acts as a precursor of ozone and, particulate matter, with associated environmental effects. Can form nitric acid and damage buildings by surface recession.	Contributes to the formation of ozone and particulate matter, with associated climate effects.
SOx	Aggravates asthma and can reduce lung function and inflame the respiratory tract. Can cause headache, general discomfort and anxiety.	Contributes to the acidification of soil and surface water. Contributes indirectly to the transformation of mercury to the bioaccumulative methyl- mercury, which is toxic. Causes injury to vegetation and local species losses in aquatic and terrestrial systems. Contributes to the formation of inorganic particulate matter with associated environmental effects. Damages building materials.	Contributes to the formation of sulphate particles, cooling the atmosphere.
CO	Can lead to heart disease and damage to the nervous system (e.g. personality and memory changes, mental confusion and loss of vision). Can cause headache, dizziness and fatigue.	May affect animals in the same way as humans, although concentrations capable of causing these effects are unlikely to occur in the natural environment, except in extreme events such as forest fires.	Contributes to the formation of greenhouse gases such as CO2 and ozone.

Polltant	Health effects	Environmental effects	Climate effects
As	Inorganic arsenic is a human carcinogen. May cause decreased production of red and white blood cells, damage to blood vessels, abnormal heart rhythms, and liver and kidney damage. May damage the peripheral nervous system.	Highly toxic to aquatic life, birds and land animals. Where soil has high arsenic content, plant growth and crop yields may be reduced. Organic arsenic compounds are very persistent in the environment and subject to bioaccumulation.	No specific effects.
Cd	Cadmium, especially cadmium oxide is likely to be a carcinogen. It may also cause reproductive damage and is toxic to the respiratory system. Exposure can cause permanent kidney damage, anaemia, fatigue and loss of the sense of smell. It can also cause lung damage, shortness of breath, chest pain and accumulation of fluid in the lungs.	Toxic to aquatic life, as it is absorbed by organisms directly in water. It interacts with cytoplasmatic components such as enzymes, causing toxic effects in cells. Cadmium is highly persistent in the environment and bioaccumulates.	No specific effects.
Ld	Can affect almost every organ and system, especially the nervous system. Can cause premature birth, impaired mental development and reduced growth. It can also have cardiovascular and renal effects in adults and effects related to anaemia.	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Effects on animal life include reproductive problems and changes in appearance or behaviour.	No specific effects.
Ni	Several nickel compounds are classified as human carcinogens. Non-cancer effects include allergic skin reactions, effects on the respiratory tract, the immune and defence system and on endocrine regulation.	Nickel and its compounds can have highly acute and chronic toxicity to aquatic life. Can affect animals in the same way as humans.	No specific effects.
C6H6	A human carcinogen, which can cause leukaemia and birth defects. Can affect the central nervous system and normal blood production, and can harm the immune system.	Has an acute toxic effect on aquatic life. It bioaccumulates, especially in invertebrates. Leads to reproductive problems and changes in appearance or behaviour. It can damage leaves of agricultural crops and cause death in plants.	Benzene is a greenhouse gas contributing to the warming of the atmosphere. It also contributes to the formation of ozone and secondary organic aerosols, which can act as climate forcers.
BaP	Carcinogenic. Other effects may be irritation of the eyes, nose, throat and bronchial tubes.	Is toxic to aquatic life and birds. Bioaccumulates, especially in invertebrates.	No specific effects.

Fig. 7, table 1, Effects of air pollutants on human health, the environment, and the climate, sources Air Quality in Europe-2018 Report. [13]

2.4. THE POLICIES

2.4.1 THE POLICIES GOVERNING ECOSYSTEM/CLIMATE CHANGE (international)

The UNECE, [United Nations Economic Commisions for Europe] member states have been working successfully to reduce air pollution in the region, identify EIGHT protocol. [11]

1984- Geneva Protocol (EMEP Protocol) Protocol on Long- term financing of the cooperative programme for monitoring and evaluation of the long-range transmission of air pollutants Europe (EMEP)
EMEP has three main components: collection of emission data for sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs) and other air pollutants; measurement of air and precipitation quality; and modelling of atmospheric dispersion.

1985- Helsinki Protocol- Reduction of Sulphur [SO_2] Emissions or their Transboundary Fluxes by at least 30 per cent

1988- Sofia Protocol- concerning the Control of Emissions of Nitrogen Oxides [NO_2] or their Transboundary Fluxes

1991- Geneva Protocol concerning the Control of Emissions of Volatile Organic Compounds [VOC]or their Transboundary Fluxes. The VOC's is major air pollutant responsible for the formation of ground-level ozone.

1994 Oslo Protocol on Further Reduction of Sulphur Emissions. The Executive Body adopted the Protocol on Further Reductions of Sulphur Emissions in Oslo on 14 June 1994.

1998 Aarhus Protocol on Heavy Metals. It targets three particularly harmful me tals: cadmium, lead and mercury. The Protocol aims to cut emissions from industrial sources (iron and steel industry, non-ferrous metal industry), combustion processes (power generation, road transport) and waste incineration. In addition, the Protocol requires Parties to phase out leaded petrol.

2012- to amend the Protocol to include more stringent controls of heavy metals emis sions and to introduce flexibilities to facilitate accession of new Parties.

1998 Aarhus Protocol on Persistent Organic Pollutants (POPs) It focuses on a list of 16 substances that have been singled out according to agreed risk criteria. The substances comprise eleven pesticides, two industrial chemicals and three by-products/contaminants. The Protocol includes provisions for dealing with the wastes of products that will be banned.

In **2001,** the Stockholm Convention on Persistent Organic Pollutants was adopted, a treaty negotiated under the auspices of the United Nations En vironment Programme (UNEP).

In **2009**, Parties to the Protocol on POPs adopted decisions to amend the Protocol to include seven new substances.

1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. The Protocol sets national emission ceilings for 2010 up to 2020 for four pollutants: sulphur (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH3). The Protocol also sets tight limit values for specific emission sources.

Parties have to report on their emissions once a year. In addition, the Protocol requires Parties to provide projections of their future emissions.

2.4.2 THE POLICIES GOVERNING HUMAN HEALTH (international)

The policies that protect people's health from pollutants and therefore disease is the **IARC** (International Agency for Research on Cancer).[13] Agency founded in May 20, 1965 and which is part of the WHO (World Health Organization) intergovernmental agency.

WHO (World Health Organization) [14] founded 1948 with headquarters in Geneva, is made up of 194 Member States divided into 6 regions (Europe, Americas, Africa, Eastern Mediterranean, Western Pacific and Southeast Asia).

WHO has been working on air quality since 1958, starting from indoor air quality (IAQ) and in the second moment to the Outdoor Air Quality (OAQ).

The report regarding the pollutants and the effect on the human health are:

1987: first edition of WHO AQGs (Air Qualtity Guidelines) in this first volume there were 28 air pollutants, classified as organic and inorganic, but they did not guarantee the absence of health effects.

2000: second publication, a different approach was taken to assess what is carcinogenic and non-carcinogenic, and was published based on the lower-limit range tests. In this edition, the exposure limit values have been included, based on the European air quality directive (EC 1996).

In this edition there were 35 air pollutants, also increasing indoor air quality pollutants and PM was included, but risk estimates for an increase in PM concentration were not provided and provided.

2006: the third and last edition, whit the update of the WHO AQGs "WHO Air Quality Guidelines, Global Update 2005" where the four air pollutants were included, PM, O3, NO2 and SO2, and also the objectives to try to improve the situation.

But Just in 30 October to 1 November 2018, it was the First WHO Global Conference on Air Pollution and Health took place at the WHO headquarters in Geneva, Switzerland. The conference participants emphasized the urgent need to act against air pollution, both ambient and household, as it is responsible for about 7 million deaths globally each year. It was emphasized that effective interventions are feasible and compatible with economic growth, but the economic part we will see in in the other chapter. [4]

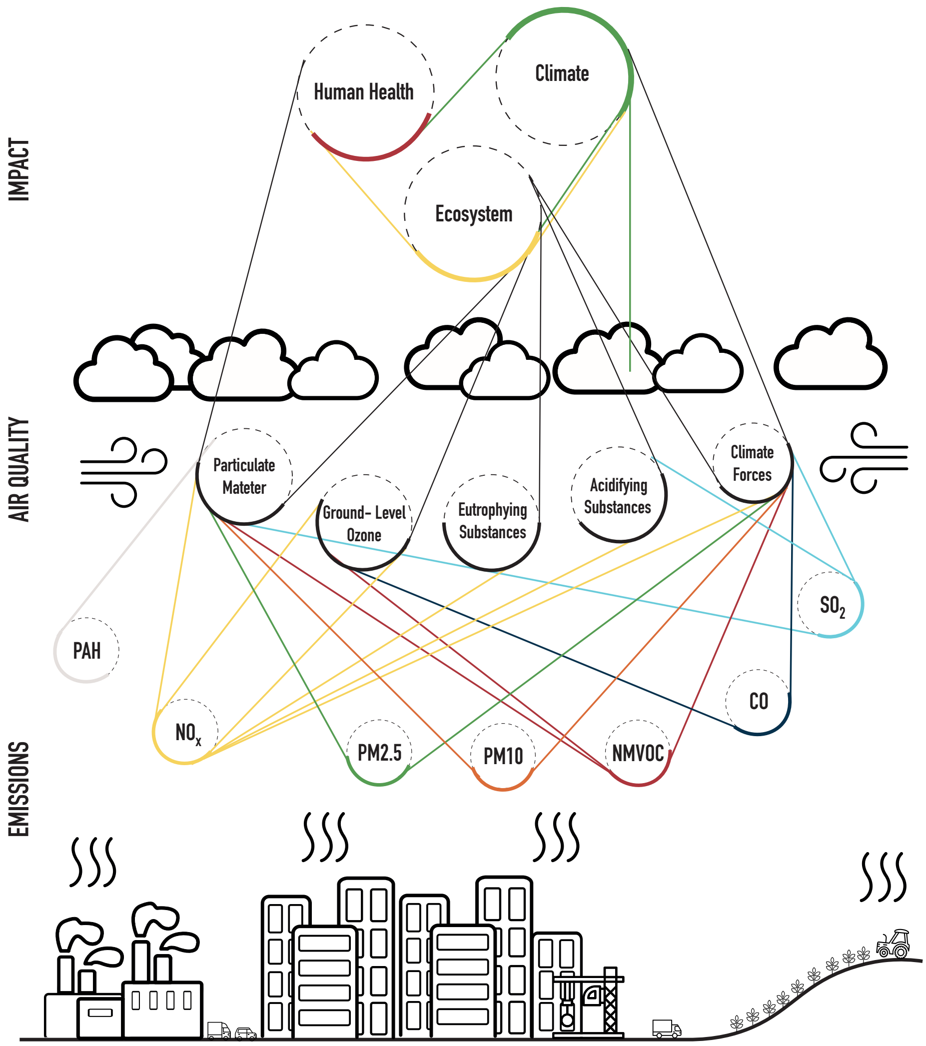


Fig.8.Scheme, regard the impact of the air quality of Human health, Ecosystem and climate. Sources, AEE.

2.4.3 THE POLICIES GOVERNING THE AIR QUALITY IN EU AND ITALY

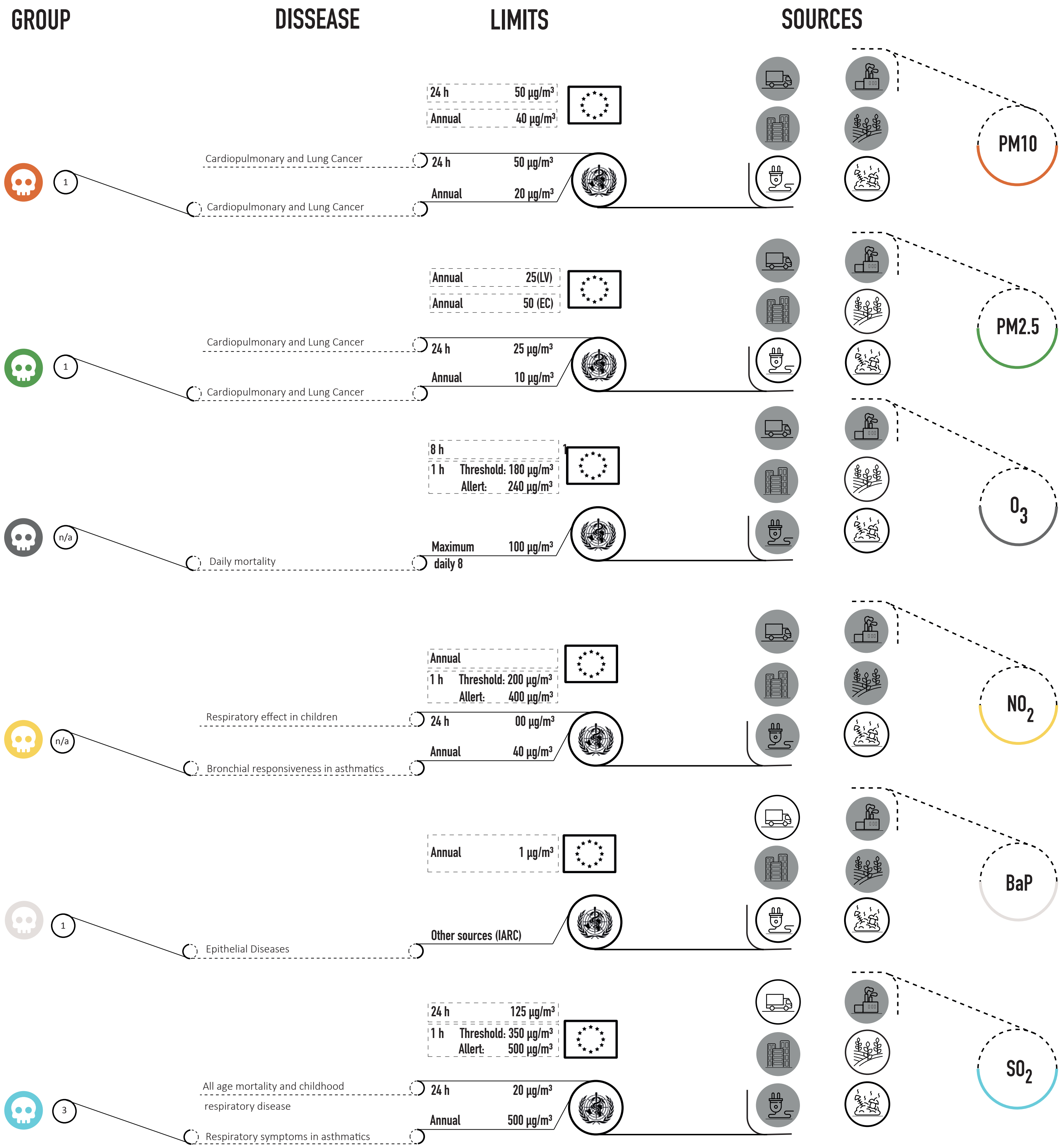
At an international level, the United Nations Economic Commission for Europe (UNECE), WHO and the United Nations Environment Programme, among others, have continued to decide on global actions to address the long-term challenges of air pollution. For the policy intervention of the UNECE, are already talked (in the section 2.4.1: The policies governing ecosystem/climate change) as well regard fot the WHO (in the section 2.4.2: The policies governing human health).

Instead for the European Union Legislation, the clean air policy is based on three main pillars (European Commission, 2018):

1. Ambient air quality standards set out in the Ambient Air Quality Directives (EU, 2004, 2008) to protect human health and the environment. The directives also require Member States to assess air quality in all their territories and to adopt and implement air quality plans to improve air quality where standards are not met and to maintain it where the air quality is good.
2. National emission reduction commitments established in the National Emission Ceilings (NEC) Directive (EU, 2016), which requires Member States to develop national air pollution control programmes, to comply with their emission reduction commitments.
3. Emission and energy efficiency standards for key sources of air pollution, from vehicle emissions to products and industry. These standards are set out in EU legislation targeting industrial emissions, emissions from power plants, vehicles and transport fuels, as well as the energy performance of products and non-road mobile machinery [15].

Air quality plans and measures to reduce air pollutant emissions and improve air quality National (Italian) and local measures is by the directive of DLGs155/2010, based on the Ambient Air Quality Directives (EU, 2004, 2008) set the obligation of developing and implementing air quality plans and measures for zones and agglomerations where concentrations of pollutants exceed the EU standards (and
of maintaining quality where it is good). These plans and measures should be consistent and integrated with those under the NEC Directive (EU, 2016). The integrated national energy and climate plans under the Regulation on the Governance of the Energy Union and Climate Action (EU, 2018b) should also be considered in terms of their capacity to reduce emissions of air pollutants.

SUMMARY of POLLUTANTS_ SO



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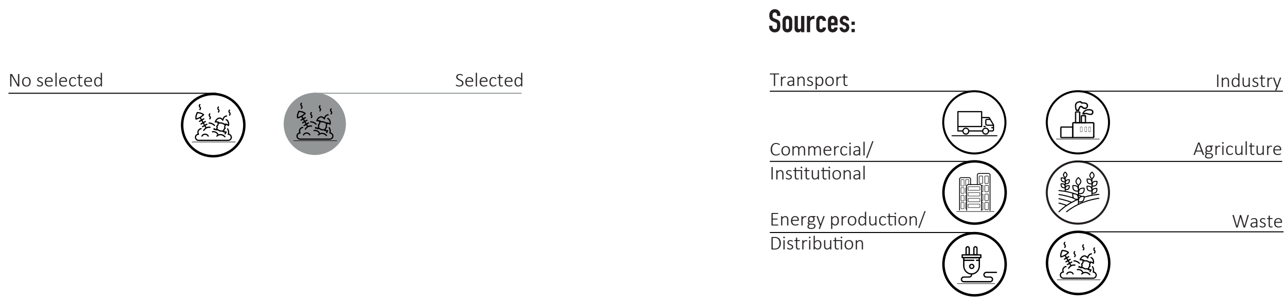


URCES and UE & WHO LIMITS

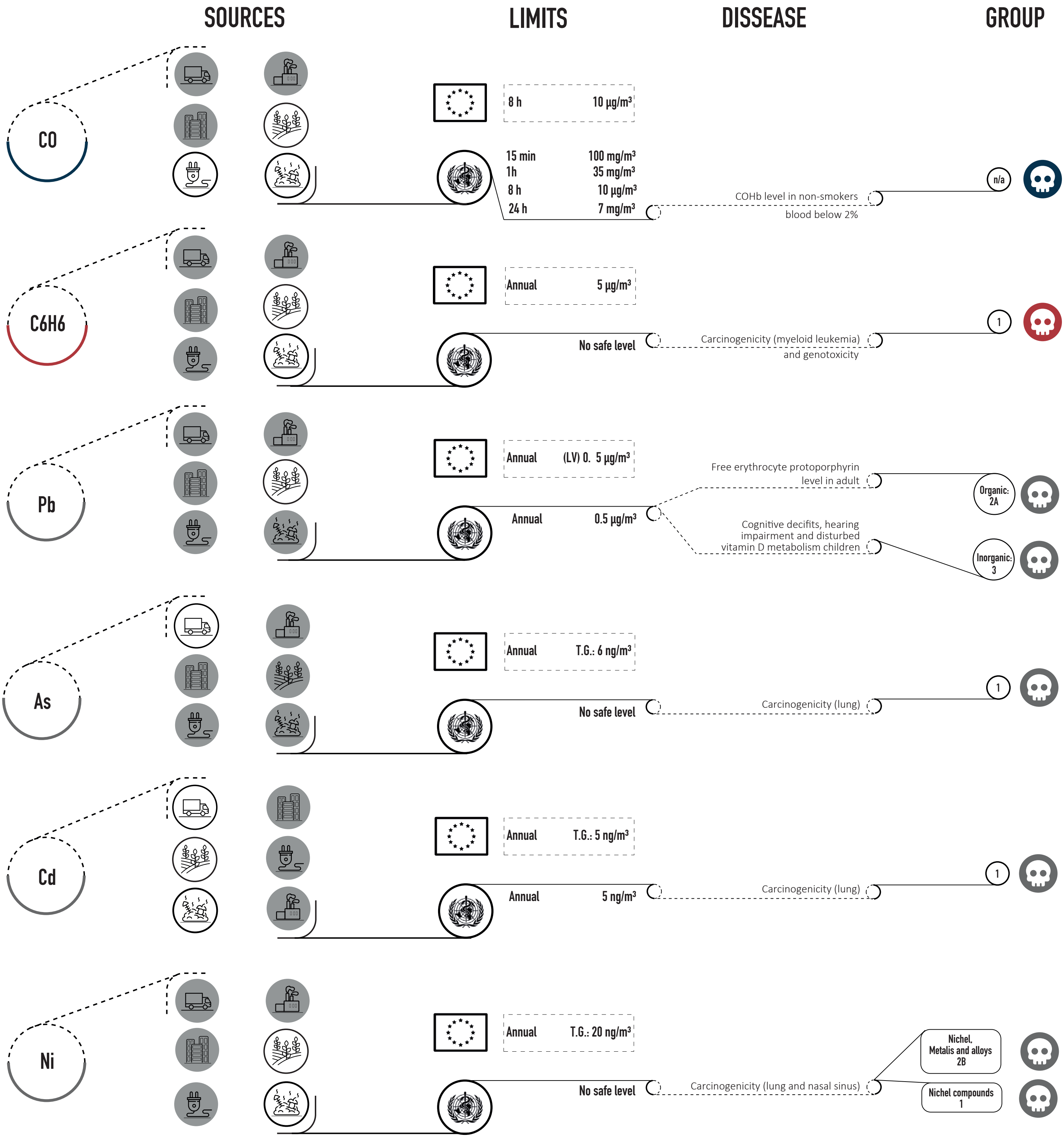
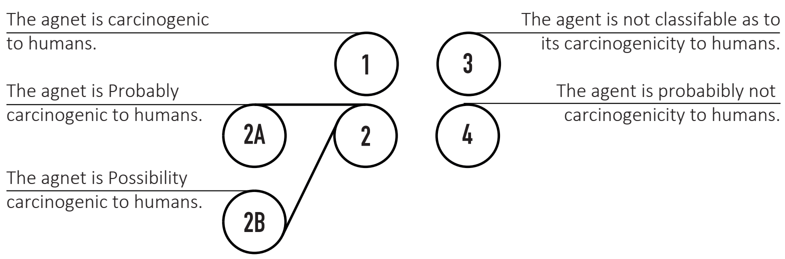


Fig.9. Auto Product scheme. It is a summary of the sources that create pollutions and the limits of the air quality and the human health of the European Union and the World Health Organization.

IARC* carcinogen classification :



Note:

*IARC *(International Agency for research on Cancer)*

PART
THREE

3.0 SOCIO-ECONOMIC EVALUATION

3.0. SOCIO-ECONOMIC EVALUATION

This chapter is based on two litterature review, the first to quantify the number of sickness and mortality caused by the pollutants in paticolar the particulate matter (PM). Another literature review was carried out to identify the most appropriate method to evaluate the weight and the effect of the illness in the economic field.
Thanks to this research we found a method that allowed us to calculate the impact of air pollutants, for the city of Turin.
At the same time, this work has given us the possibility to publish an article based on the work done in this chapter, about the different methodologies present in literature to calculate the costs deriving by air pollution. [ANNEX 1_p.167]

3. 1. EPIDEMIOLOGY STUDY

Until now we have seen that the main causes of pollutants come from the burning of fossil earth, and the principal sources the industry, household, and motor vehicles. We have seen different approaches to reduce these, focusing on used alternative energy and increasing the performance of the building.
As we have already talked in the previous chapters the air pollution is a worldwide problem with broadly known harmful effects on human health and on the environment, creating disease. Unfortunately, the illness does not manifest itself immediately, but during time, in particular with the constant contact of emission pollutants.[1] For this reason, the air quality limits have been created, in order to protect people's health and the environment. Specially to safeguard people's health, because pollution mainly affects us. In chapter 2, we showed all the diseases caused by each polluted, as WHO (world health organization) report, the pollutants create diseases which affect in particular the respiratory and cardiovascular systems. [2]

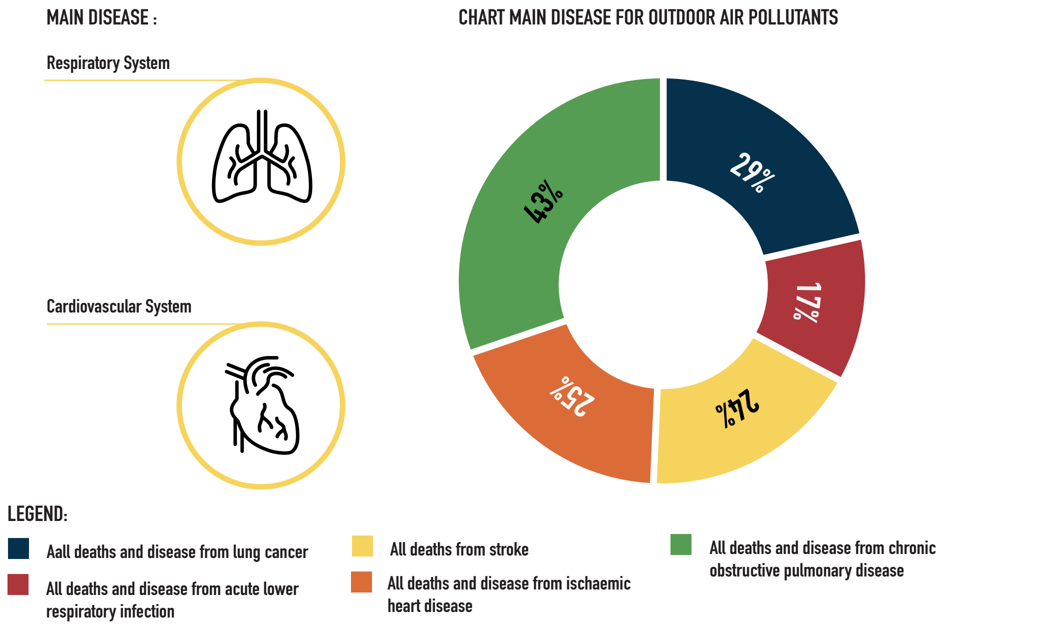


Fig. 1 Chart main disease from outdoor air pollutants, produced from WHO report 2019

But the polluters are not the only cause of these diseases, there are other triggers that create lung tumors, such as the smoking. In fact, from the WHO report to 2019 emerged that 90% of lung cancers, and the 27% cancer deaths attributed to use of tobacco. For this reason, emerge the questions: How we can recognize the disease caused by the effects of pollution? [3] And, how do we know which are the deaths or the diseases caused by the polluter?

For give an answer about these questions, the first it's to identifying the main metrics most used to quantify the physical health impacts caused by air pollutants exposure, through a review of epidemiological studies.

On the specific of the case study, it's important to give a definition of epidemiology. Epidemiology (from the Greek επι δη ος λογοσ (epi demos logos) = study on the population) is the branch of medicine which deals with the incidence, distribution, and possible control of diseases and other factors relating to health, and as early as 2000 years ago, Hippocrates and others claim that environmental factors can influence the occurrence of the disease.[4]
Recent studies did in 2000, the American Thoracic Society (ATS) exhaustively listed the effects of air pollution on health, from the most severe to the least severe.

The health effects of air pollution are traditionally distinct into **short-term** when the ef fects are observed a few days later, such as irritation of the respiratory tract, or **long-term** effects, when effects are observed after long-term exposure and years after the start of exposure, such as chronic bronchitis or lung cancer.

How we said the epidemiology studied the population and the effect of the disease, but we have to take into account that human being has a different way to react. This factor is called **susceptible**, or individual **susceptible individuals**, which express a member of population who have the risk to becoming infected by a disease. In our case by the atmosphere pollutant. From the studies emerge that the age's phase has more risk to meet the disease are the child, the elderly, and individual's whit cardiovascular and respiratory diseases.

Another classification that Epidemiological studies did is the difference between:, **observational studies** (they evaluate the distribution of diseases in the population and the determinants of disease) and **intervention studies** (experimental studies as the exposure of each participant, or each community, is assigned by the researcher with a randomized procedure, which also guarantees the control of other risk factors not known at the time of the study).

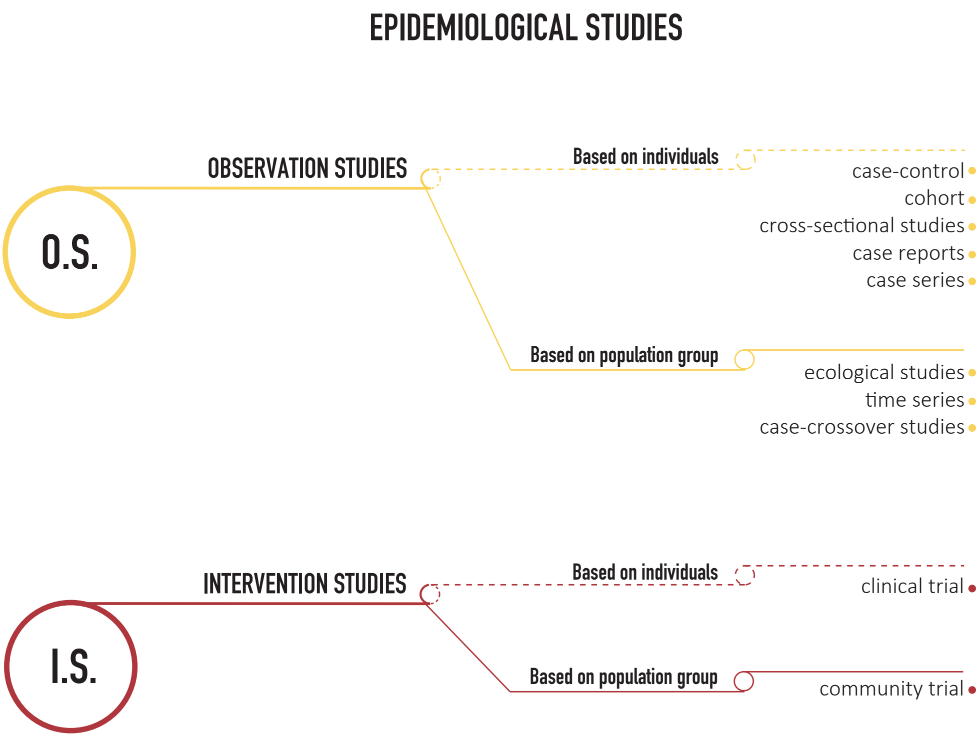


Fig. 2. Scheme of epidemiology studies, produced from EPI 2013.

Observational epidemiological studies are divided into:

- The **case-control** study starts from the definition of a group of people with the disease of interest and a control group without the disease and compares the proportions of exposed to the factor studied in the two groups.
- The **cohort study** starts from the definition of subjects exposed and not exposed to the factor of interest and follows these groups through time to determine the development of disease in each group.
- The **cross-sectional** study is based on the observation of the disease and exposure to the factor of interest at the same instant in time or in a very short interval.

The studies most used to analyze the effects of air pollution on human health are **time-series studies**, and **ecological studies**, which are correlation studies, in which exposure is not attributed to the individual level but is evaluated the variation of data at an average at the group level. These studies add the time lien: the exposure must precede the event and the latter must follow the exposure in a relatively short time. The association between exposure and effect in observational studies is estimated by calculating the **relative risk** (RR) or probability ratios(Odds Ratio).
The most used studies to analyse the **short-term effects** of air pollution on human health are time series and **case-crossover studies.**
The case-crossover design, a particular type of case-control studies, is used to study the existence of an association between short-term exposure and the presence of a specific event that you want to investigate.
These case studies are an association between two phenomena based on a **dose-response** relationship that must take place following an accepted method, that is by verifying compliance with specific causality criteria.
The randomness criteria approved by the scientific community are nine:

- Strength of the association
- Timing sequences
- Dose response relationship
- Specificity of the effect
- Biological plausibility
- Not contradicting the knowledge of other disciplines
- Consistency with other studies
- Analogy
- Reversibility of the effect.

3. 1.1. Association Measures

To evaluate the association, or the degree of statistical dependence, between **risk factors** and the onset of a disease based on observational studies, four categories of subjects can be identified, as represented in the table (fig.3) below.

	SICK	NO SICK	TOTAL
EXPOSED	A	B	A + B
NO EXPOSED	C	D	C + D
TOTAL	A + C	B + D	A + B ; C + D

Fig. 3. Categories of subjects analyzed to evaluate the association between exposure and disease.

From this scheme it is possible to found the **absolute risk** (RAs), defined as the ratio between those exposed to the risk factor who became ill and the total of those exposed, it is equal to the incidence of the disease among those exposed:

$$RAs = \frac{a}{(a + b)}$$

Equation 1

Another index is the **relative risk** (RR), equal to the ratio between the incidence in the exposed and the incidence in the unexposed considering the same risk factor:

$$RR = \frac{(RAs\ exposed)}{(RAs\ NO\ exposed)} = \left[\frac{\frac{(a)}{(a + b)}}{\frac{(c)}{(c + d)}} \right]$$

Equation 2

This ratio is equal to 1 if the factor considered has no influence on the development of the disease; it is higher than 1 when the risk factor plays a role in determining the disease; it is less than 1 if the factor under consideration is protective, i.e. it reduces the probability of contracting the disease.

A further index of association is **attributable risk** (AR), which represents the share of patients among the exposed that could be avoided if the risk factor were completely remo ved. The RA corresponds to the difference between the incidence in the exposed and the incidence in the no-exposed:

$$RA = (RAs\ exposed) - (RAs\ NO\ exposed) = \left[\frac{(a)}{(a+b)} - \frac{(c)}{(c+d)} \right]$$ *Equation 3*

In addition, a confidence interval can be calculated for the **risk estimate**, which, with a certain probability, includes the value of the parameter in the general population. The 95% confidence interval (95% CI) represents the range of values that has a 95% probability of including the true value of the population.

3. 1.2. Relative Risck (RR) associated to pollutants

After this small explanation about epidemiology, we can go more in deep.
From a literature review, we found the cases studies associated on the pollutant of particulate matter. In particular, we will focus on the pollution in PM10, which will be the pollutant of our case study.

In epidemiological studies, we have to do a distinction between the index of mortality and morbidity, to describe the progression and severity of a given health event.
These are useful tools to distinguish the risk factors of diseases and the incidence on the society. As follow there is a definition regarding mortality and morbidity.

Mortality is related to the number of deaths caused by the health event under investigation. It can be communicated as a rate or as an absolute number. The mortality index, usually gets represented as a rate per 1000 individuals, also called the death rate. The calculation for this rate is to divide the number of deaths for a period of time for a part of the population by the total population. To keep these values concise and for ease of comparison to other health events, this number can be multiplied by 1000 to reflect the "per 1000" rate of the target population.[5]

Morbidity, on the other hand, is the state of being symptomatic or unhealthy for a disease or condition. It is usually represented or estimated using prevalence or incidence. Prevalence describes the proportion of the population with a given symptom.

It is calculated by dividing the number of affected individuals by the total number of individuals within a specific population. It is usually presented as a ratio or as a percentage. [5]

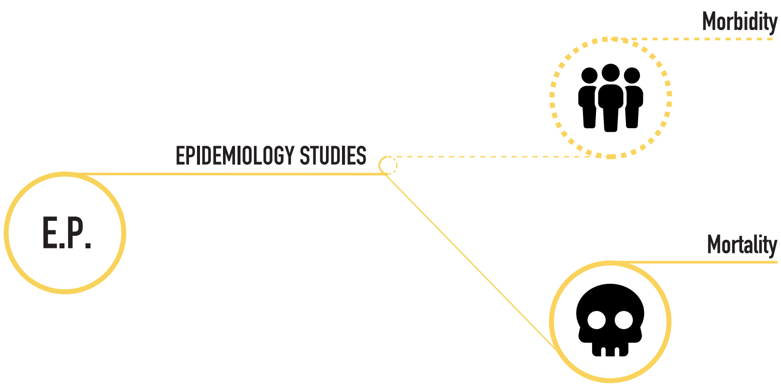


Fig. 4. Scheme which represents the two main measures on the epidemiology studies.

In the folow table, (table 1) we have report as in literature of the epidemiological studies there is a distinction betwen the chronic effects and the acute effect, for the mortality outcomes, and like they classify by the age.
Instead in the table 2 are report the Morbidity Outcomes for the different age related for the different cases.
From the litterature emerge that the mayority of the acute effects, are calculate on the PM2.5 because more dangerous, so there is a formula to convers this value in PM10.

$$PM_{2.5} = 0.7 * PM_{10}$$ *Equation 4*

Mortality Outocomes	Age
Chronic Effects	
• All Causes (exluding accidents)	> 30
• Lung Cancer	> 30
Acute Effects	
• All Causes (exluding accidents)	All
• Cardiovascular diseases	All
• Respiratory diseases	All

Table 1. Causes of death selected for the health impact assessment. The cases written in red are those considered in the case study

	Morbidity Outocomes	Age
Morbidity	• Hospital admissions for cadiac diseases	All
	• Hospital admissions for respiratory diseases	All
	• RADs (restricted activity days lower respiratory)	15-64
	• WLDs (work loss days)	15-64

Table 2. Morbidity outcomes selected for health impact assessment. The cases written in red are those considered in the case study

In table 3, is reports the literature review for the epidemiological studies, in which specific health diseases associated to air pollution are identified into **short-term**, i.e. the effects are observed in few days, and **long-term**, i. e. the effects are observed after years of exposure. In this table, the diseases are put in relation with the main metrics used, where as we saw the most common are mortality and morbidity, which allow estimating the disease risk.

	Reference	Exposure	Pollutants	Disease
Mortality	Anderson et al., 2004 [6]	Short term	PM10	All causes, respiratory, cardiovascular
	Biggeri et al., 2004 [7]	Short term	PM10	All causes
	Ostro et al., 2007 [8]	Short term	PM2.5	All causes, respiratory, cardiovascular
	Brunekreef et al., 2009 [9]	Long term	PM2.5	All causes, respiratory, lung cancer, cardiovascular
	Dong et al., 2012 [10]	Long term	PM2.5	All causes, respiratory, cardiovascular
	Pope et al., 2002 [11]	Long term	PM2.5	All causes, cardiovascular, lung cancer
Morbidity	Biggeri et al., 2004 [7]	-	PM10	Chronic obstructive pulmonary disease
	Dominici et al., 2004 [12]	-	PM2.5	Chronic obstructive pulmonary disease, heart failure, ischemic heart disease

*Table 3. Literature review: epidemiological studies and metrics.*Article referement (annex-1).*

Firstly, before seeing the different approaches for monetary the air quality, we have to explain which there is an index that permitting morbidity and mortality to be simultaneously described within a single number which is the **Health-adjusted life years** (HALYs). This value has “increasingly relevant to both public health and medical decision-makers” and of late, HALYs have gained higher visibility in policy circles, both domestically and internationally. [2]

The HALYs in compose by two family of measures which are, the **disability-adjusted life years** (DALY) and **quality-adjusted life years** (QALYs).

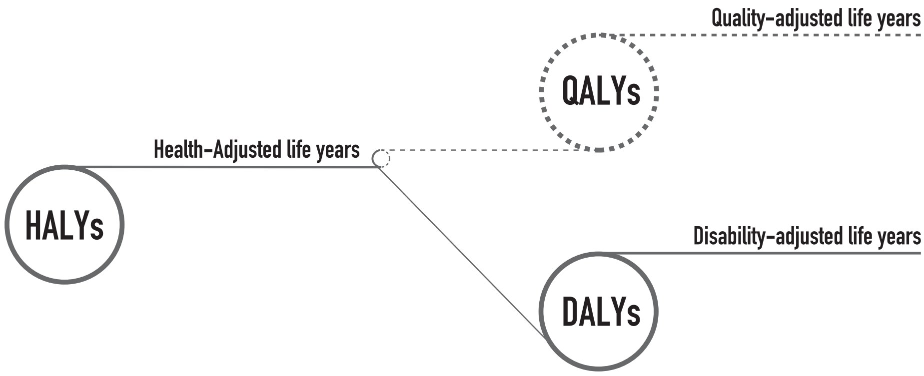


Fig. 5. Scheme rappresentaitive about the HALYs components.

QALYs were developed in the late 1960s by economists, operations researchers, and psychologists, primarily for use in cost-effectiveness analysis. The QALY, (quality-adjusted life-year or quality-adjusted year) shows the benefit which could be realized if we reduce for our case the pollutant. In fact, a case study conducted by Schmitt, in 2016, showed QALY gain and health care resource impacts of air pollution control. [2]
The QALY, combines morbidity and mortality effects into a single index and is obtained by multiplying the period of time spent in a given health state by health-related quality of life (HRQoL), (and is captured on a scale from 0 to 1.0, representing the extremes of death and full health.) weights associated with that state.

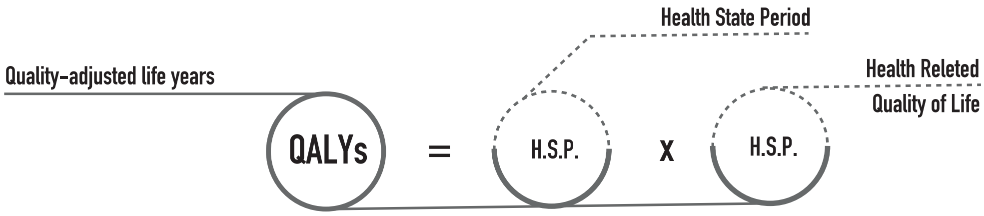


Fig. 6. Formula of QALYs

In 1993, a World Bank and World Health Organization collaboration resulted in the publication of a volume that sought to quantify the global burden of premature death, disease, and injury and to make recommendations that would improve health, particularly in developing nations. [2] In 1996 the WHO introduced the methodology for calculating the DALY, which is composed of the proportions and number of deaths attributable to exposure to PM were complemented by the number of Year of Life Lost (YLL) due to premature morta-

lity, multiply by a second component, years of life lived with disability (YLDs).
As show the folow figure (figure 6.)

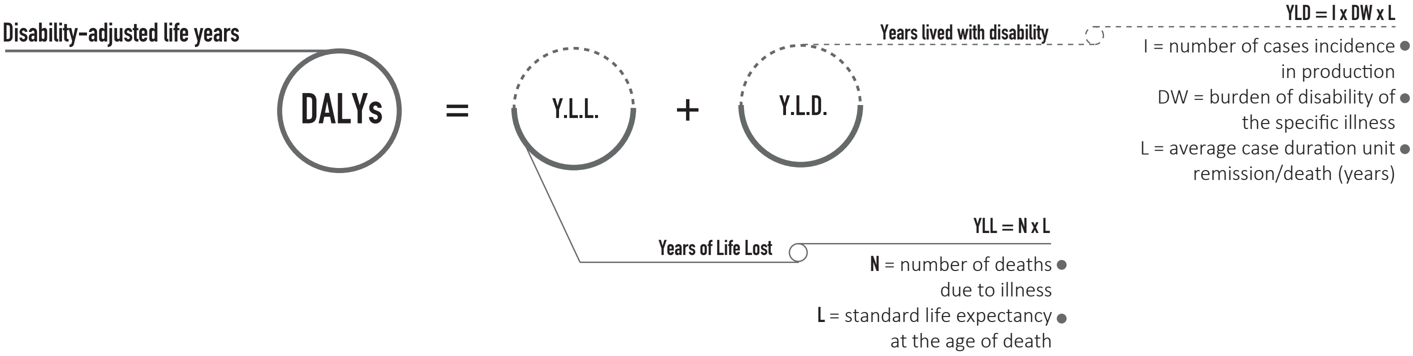


Fig. 7. Formula of DALYS

For this master thesis was calculate the YLL, because the aim of this research was to do an analysis to see the strong impact of the pollutant on the population, in the way to have the based to understand how may years are lost cased by the pollutant.
For this reason, YLL component was estimated.
The calculation of YLL (for this case study) is as follows:

$$YLL_x = E_x * e_x$$

Equation 5

where E_x are the deaths attributable to exposure to PM by age class x and sex (see Equation 1) and e_x, are the life expectancies.

3. 2. ECONOMIC METHODS

In this second part of the chapter, the effort was put in order to classify the available methods for economic valuation. The aim is to found a method which assign monetary values to non-marketed goods or services, among the health impacts of air pollution, with the use of appropriate methodological approaches.

3. 2.1. External costs

In heath economics, it is rather common to use the cost-of-illness (COI) approach, known as burden of disease (BOD), to evaluate the economic burden that illness imposes on society as a whole. In other words, the COI estimate the burden of diseases and other adverse condition or events on society or parts of society. The aim of COI is descriptive: to itemize, value, and sum the costs of a particular problem with the aim of giving an idea of its economic burden. [5]

The costs related to the COI are estimated in four steps: firstly, the relevant resources are identified, secondly, these resources are quantified (e.g. days in hospital, visits to the doctor, etc.) thirdly, the quantified resources are monetized at their opportunity cost, and finally, costs not occurring in the same period of time are discounted. [13]

The COI studies traditionally stratify into three categories: **direct** costs, **indirect** cost and the **intangible** costs. [5], [13]

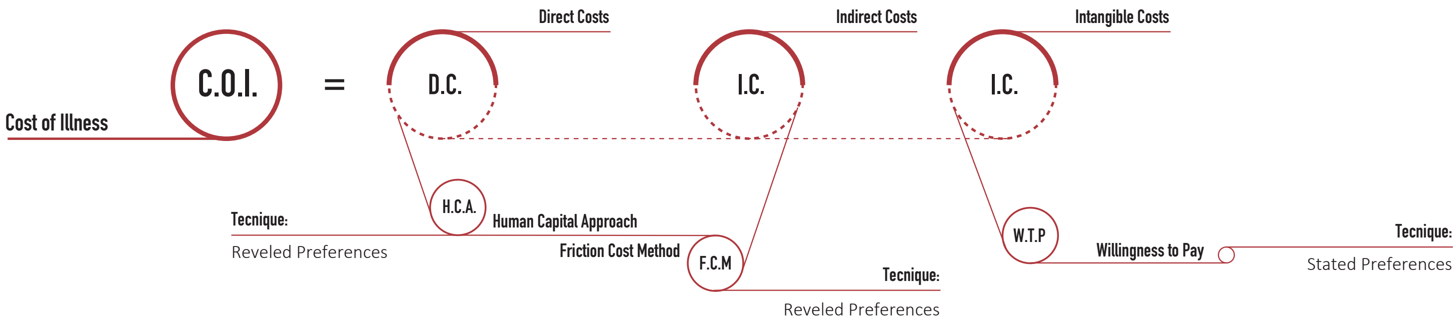


Fig. 8. Scheme rappresente the COI, and how is compose.

The **direct cost** mainly consists of cost relating to the prevention diagnosis, and treatment of patients; these costs are estimated on market value, by multiplying the epidemiological data related to the disease with the cost of hospitalization for i.e. medical staff, examinations, laboratory test, and non-healthcare resources like transportation, household expenditure, relocating. (Joe in at 2014, Silvera at in 2015). [1] The direct cost are estimated using bottom-up or top down accounting methods (Silvera at in 2015).

The top-down approach, known as attribute risk approach," measures the proportion of disease that is due to exposure to the disease or the risk factors."

The **indirect costs** identify the value of the loss of productivity due to morbidity as well loss of production due to morbidity or mortality. These costs are based on market value for e.g., wages, incomes and earnings. The most using methods for estimating the indirect cost are the Human Capital Approach (HCA) and the Friction Cost Method (FCM). [1], [12]

The **intangible costs** include non-market cost attempt to quantify subjective factors such as quality of life, leisure and pain. These costs are based on non-market values for pain and suffering from morbidity and mortality and are estimated using quality-adjusted-life-year (QALY) by the methods Willingness to Pay (WTP). [13]

The main methods used for the calculation of the indirect cost are the Human Capital approach (HCA) and the Friction Cost Method (FCM).

Human Capital Approach (HCA)

Based on this method, the loss of productivity is calculated for the period between the moment of the pathological event and the return to work (or, in the case of chronic diseases, the achievement of retirement age), while the optimal monetization parameter is represented by the income received by the patient before the onset of the disease. In fact, in the absence of accurate data, the income normally considered is the national average, relative, at most, to professional categories.[14] The weakness of this approach is the overestimation of real productivity losses. In fact, the short period of absence the work can be done by the colleagues, instead the long period is possible to assume another person, in this way the effective losses of production as well from the social point of view.

Friction cost method (FCM)

This method is more sophisticate respect the previous, the basic concept is that the value of the non-production associated with a disease depends on the period necessary to recover the original level of production (defined as the friction period).In fact, take in account that during the long term of illness, it is not verify the loss of productivity because there is a new hired person. Is different as well the approach for the short term, in fact, study had demonstrated that a reduced the hours of work, decrease the productivity. In particular

the reduction of cost has been estimated that a day of absence from work is equal to 80% of productivity work daily of the sick worker. (M.A. Koopmanschap, p.178) [15]. Therefore, the value of friction period is equal to the 80% of the daily income of the sick worker.
Although, as well this method that is an evolution of the Human Capital Approach has been a criticized, in particular the empirical difficulties related to the estimate of elasticity values and the friction period. [16]

There is other method, less used for calculating the indirect cos, which is the Hedonic Price (HP).

The Hedonic Price (HP)

It is another approach to monetize of the air pollutant, that is not strictly connected to the health of the people but is a factor the characterizes the value of the property, in the "real estate market". This is another method to monetize the air quality, that how we said at the beginning of this paragraph is very difficult to monetarize goods that don't have a value in the market.
The hedonic price model is based on Lancaster's theory (1966), where the people attribute a value to the good according to the different characteristics it possesses.
The hedonic price method aims to determine the extent of air pollution effect on the value of the real estate market.
This method is used to examine the constituent characteristics and estimate the value of each characteristic.
Normally, to estimate the price of the housing it takes into consideration different elements, such as structural components, environmental factors, public services, urban form, and other.
In the fields of environmental economics, studies show that levels of pollution have a significant impact on the price of housing. In particular a case conducted in Seoul metropolitan area, Kim, Phipps and Anselin (2003) developed an econometric model of spatial hedonic housing price to estimate the value of a marginal increase in the concentration of SO_2 and NO_x. They found that levels of SO_2 pollution has a significant impact on the price of housing whilst NO_x pollution is not. [17]
Hedonic price models are also used to check the capitalization of public services. Edel and Sclar (1974) indicated the need to include the size of the public service and tax is paid in the hedonic price analysis. [18]

In other words, this method highlights as the differences in the value of the residential property may arise as a result of a variety of sources such as the number and quality of accommodation available, the accessibility of the business center, the level and quality of public facilities, the level of taxes paid on the property, and the characteristics of the surrounding environment, as measured by the level of air pollution, congestion and noise aircraft, and access to the garden and water facilities. as a good producer or as a consumer good. [19]

The equation to calculate the hedonic property value is:

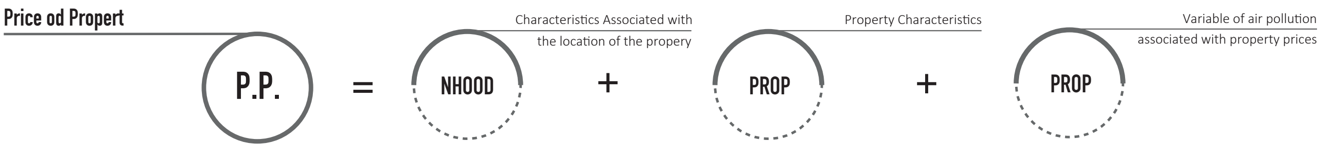


Fig. 9. Formula to calulate the Hendoic Property value

Where:

PP= price of property

PROP= property characteristics

HOOD= characteristics associated with the location of the property

ENV= variable risk of air pollution associated with property prices.

Instead for the **intangible cost**, are used the method Willingness to pay, (WTP).

Willingness to pay (WTP)

This method is derived to the economic theory of well-being, this method requires you to estimate yourself this method requires you to estimate how much an individual would be willing to pay in order to receive a certain health treatment. The difference of this method to the other two, that don't take into consideration just the indirect costs, but the intangible cost as well, and so the human being as individual.

There are various empirical methods in the literature to calculate the WTP:

- wage risk, in this case the value is achieved by estimating the extra wage paid to wage risk, in this case the value is achieved by estimating the extra wage paid to induce workers to accept the risk at work. This rating normally takes into account the income differentials between the different professions. In this case, it is not really a question of willingness to pay a reduction in risk, but a willingness to accept (WTA) [20]

The Willingness to pay is based on a contingent valuation method. The technique most used are the **Contingent Valuation Method (CVM)** and the **Choice Experiment (CE).** As follow we will explain these two methods.

Contingent valuation methodology (CVM)

The contingent valuation methodology (CVM) is deeply rooted in the neo-classical welfare economic theory, in fact, "the contingent valuation represents the most promising approach yet developed for determining the public's willingness to pay for public good". (Mitchell & Carson, 1989) [20]

This method uses survey questions to ask respondents to directly value the good or service of interest in a hypothetical market. A CV survey usually has three main parts. The first part is a detailed description of the good being valued and the hypothetical market in which the good is provided to the respondents. The second part is the core part in a CV survey, the Willingness-to-Pay (WTP) or Willingness-to-Accept (WTA) question. The third part usually asks demographic questions and debriefing questions to respondents.
The CV method is very flexible as researchers can construct a hypothetical market with a desired provision structure and payment vehicle for a very wide range of public or private goods. The goods that have been valued by the CV method include environmental amenities, resources, new private commodities and health risks.
The limitation of the CV method is the hypothetical nature of the CV survey; people's stated preferences may deviate from their true preferences because of the hypothetical scenario. Therefore, despite its apparent simplicity, CV requires the researcher to make multiple decisions to ensure valid and reliable responses from survey subjects. [21],[22]

The choice experiment (CE)

The choice experiment (CE) encompasses a variety of multi-attribute preference elicitation techniques widely used by market researchers to evaluate potential new products and new markets for existing products (Garrod and Willis, 1997) [23]. Recently, this approach was employed as an alternative to contingent valuation method (CVM) and to complement other preferred methods such as the hedonic price model (HP).

This method has a number of advantages. First all, it is easier than other valuation methods in estimating the value of each attribute that makes up an environmental good. This is useful because many policies are more concerned with changing attribute levels, rather than losing or gaining the environmental good as a whole.

It allows respondents to systematically evaluate trade-offs among multiple environmental attributes or among environmental and non-environmental attributes. [24]
The selection of attributes heavily depends on literature, focus group discussion (FGD), and pilot study. [24] [25]

The theoretical framework of CE has been developed based on the theory of Alberini et al. [26]. The utility function of an individual is decided by good consumed (X), leisure time (L), individual's characteristics (Z), and the individual's health status (S).

$$U = U(X, L, Z, S)$$

Equation 6

The health status or NSD of an individual depends on certain biological factors, environmental quality, medical expenditures (ME), and socio-economic factors. This model considers the biological factors as constant. Environmental quality refers to the air pollution index (API) The ME is also an important factor to determine an individual's health status. It is shown in the follow Equation :

$$S = S(Q, M, Z)$$

Equation 7

Where Q is the API, M is ME (refers to the individual's cost for medicines), and Z is the socio-economic factors. Socio-economic factors such as individual's household income (HIC), age (AGE), gender (GEN), number of dependent members and city (CITY), and environmental variables such as RS, outdoor activities (OA), and environmental consciousness (EC) were included in the model. Then, the respondent's utility function becomes Random Utility Theory (RUT) as follows in Equation:

$$U_{ij} = V_{ij}\ (X, L, Z, S) + \varepsilon_{ij}$$

Equation 8

The indirect utility function under the random utility model can be illustrated by observable (Vij) and unobservable (εij) components on individual choice.

Since CE is developed based on random utility theory, the purpose of this method is to present the respondents with the task of selecting one choice from many alternatives. In CE, there will be more than one alternative in the choice set and the respondent will be asked to choose one choice from the set of alternatives. In CE, the probability of any household respondent prefers the option j, in the choice set to any alternative options k.

The utility level depends on a particular choice is a combination of the weighted attributes based on the relative importance of each of them. The easiest model is the linear model as in Equation:

$$V_{ij} = ASC + \beta_1 NSD_{ij} + \beta_2 ME_{ij} + \beta_3 API_{ij} + \beta_4 BID_{ij} + \varepsilon$$

Equation 9

Where, Vij is utility associated with the air quality option, β is a vector of marginal utility parameters and X is a vector of attributes (k) from a choice set.

ASC is (alternative specific constant) in order to capture any variation in choices that cannot be explained by either socio-economic variables or attributes. NDS are the number of sick days, BID is the extra payment for fuel price.

A multinomial logit interaction model (MLIM) with interaction was used to capture insight into the sources of heterogeneity and to identify the social, economic and demographic characteristics, equation:

$$V_{ij} = ASC + \beta_1 NSD_{ij} + \beta_2 ME_{ij} + \beta_3 API_{ij} + \beta_4 BID_{ij} + BID * EDU * BID * HIC + BID * CITY + BID * AGE + BID * ETH + BID * OA * BID * RS + \varepsilon$$

Equation 10

Life Quality Index (LQI)

There is others method used to evaluate the impact of air pollution. This is a method developed in Canada, which is the Life Quality Index. The application explication and the use of this method we can see, in the study conduct by Pandey and Natwani (2003), where, to

evaluate the standard for the particulate matter and ozone by the Canada Wide Standard (CWS) the calculated the cost-benefit using the Life Quality Index.
The Life Quality Index (LQI), is a compound social indicator comprising societal wealth and longevity, as a tool to guide the selection of optimal strategies for managing risk. In this article, they present a model to determine an acceptable level of expenditure that can be justifiably incurred on behalf of the public interest in exchange for a small reduction in the risk of death that results in improved. This value can be considered as the Societal Willingness to Pay (SWTP). Its estimation is based on a Life Quality Index (LQI) that is derived using the principles of welfare economics under uncertainty and expected utility theory. The LQI for society is derived as: [22]

$$L = G^{q}E$$

Equation 11

where G is the real gross domestic product (RGDP) per person/year, E is the life expectancy (LE) in the country, and q is the elasticity of utility of consumption. q is the ratio of average work to leisure time available to members of society.

In other words, the LQI consists of two major indicators: the real gross domestic product per person as a measure of resources and the quality of life and life expectancy, which has been validated time and again as a universal indicator of social development, environmental quality, and public health.

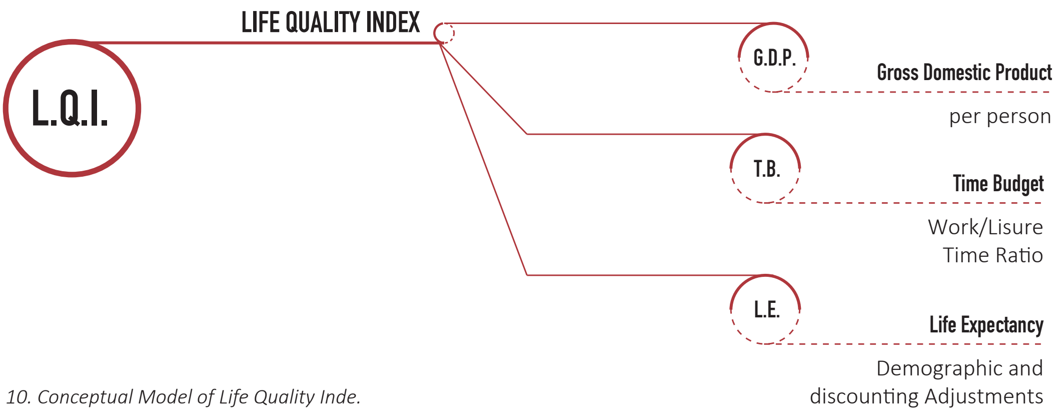


Fig. 10. Conceptual Model of Life Quality Inde.

The LQI leads to a necessary criterion that can determine the level of expenditure beyond which it is no longer justifiable to spend resources in the name of safety.

3. 2.2. Techniques for the valuation of indirect and intangible costs

Economic valuation refers to the assignment of money values, which have a particular and precise meaning, to non-marketed assets, goods and services. A variety of techniques are available, the main methodological approaches of economic valuation can be broadly classified into revealed and stated preferences techniques. [4]

- **Revealed preferences (RP)** techniques rely on market observations to capture the value of an environmental good that it is not itself traded in any market but is in a way connected with other marketed goods. Revealed techniques included, Humana Capital Approach (HCA), Friction Cost Method (FCM) and Hedonic Pricing (HP).

- **Stated preferences (SP)** techniques: in this case, the market for the good is beings constructed the use of questionnaire. In this hypothetical market, individuals have the opportunity to pay for an environmental improvement that will increase their utility or accept compensation for an environmental deterioration that will decrease their utility. The most common forms of SP techniques are the Contingent Valuation Method (CVM) and Choice Experiments (CE) [4].

Due to the high cost and time demands needed to perform an original valuation study **benefit transfers (BT)** technique have been developed.

- **Benefit transfers (BT)** is defined as the adaptation and use of existing economic information derived for specific sites under certain resources and policy conditions to new contexts or sites with similar resources and conditions. Kougea (2011) defines a typology of the most usual benefit transfer methods, namely the unit value transfer approach, unit transfers with adjustment to reflect site-specific features and the benefit function transfer.

After this first approach, we start to go more in deep and analyze some of these cases. In the table 4 are reports the reviewed techniques potentially used for the cost voices calculation, classified according to the belonging category and type of cost they contribute to compute.

Method	Category	Cost	Reference
Human Capital Approach	RP	Indirect	Garattini et al., 2000 [15]
Friction Cost Method	RP	Indirect	Garattini et al., 2000; [15] Koopmanshap et al., 1995 [16]
Hedonic Pricing	RP	Indirect/Intangible	Kim et al., 2003; [17] Saptutyningsih et al., 2015 [19]
Contingent Valuation Method	SP	Indirect/Intangible	Ndambiri et al., 2015[14] Guo et al., 2006; [22]
Choice Experiment	SP	Indirect/Intangible	Sarabdeen et al., 2020; [25] Yoo et al., 2008[24]

*Table 4. Literature review of main economic evaluation methods.*Article referement (annex-1.)*

3. 2.3. Advantages and Limitations about the Methods

The COI studies are not beyond criticism. Firstly, the COI studies are founded on a weak theoretical basis and cannot be used in the prioritization of resources, thus limiting their use as a health policy tool. For example, COI studies fail to evaluate the effectiveness of particular policies or programs and give no help in deciding how to divide resources efficiently between alternative interventions. Moreover, the use of different data and methods in different studies means that it may be difficult to compare findings across studies. Secondly the COI framework is that it generally presents conservative estimates because it often excludes certain cost dimensions associated with different risk factors. [3] [5]

Nevertheless, traditional COI studies are still valuable, in fact, they can identify any large gaps in the knowledge and data which would be required for a full accounting of costs, in this way they may stimulate new data collections and analyses aimed at filling these gaps. Moreover, COI studies can provide policymakers with potentially useful information for use in determining research and funding priorities for how healthcare money should be spent during a certain period, as well as assisting in budget planning decisions. Finally, by providing source-specific cost estimates for a particular risk factor (e.g. the costs associated with heating system of vehicle-induced air pollution), COI studies also give the way for cost-effectiveness analysis by identifying the main causes within a risk factor and can become useful sources for policy-relevant information.

As we have seen exist several methods that allow monetizing the health effects due to air pollution exposure.

PART

FOURTH

4.0. ENERGY & EMISSIONS

4.0. ENERGY & EMISSIONS

This chapter aims to show which are the principal pollutants that are produced by the energy performance of buildings, especially in the residential sector.

This chapter is divided in two part, in the first part we define which are the main goals, the tools and the methodology of the reference project that we are going to develop. The second part is related to apply the methodology on a case study. Starting from the investigation of the actual pollutants that the residential building sector emits, different scenarios of full and solely technological retrofit for residential buildings are explored, in order to study their capability in reducing the overall air pollutant emissions The main aim of the application is to explore different scenarios characterized by various policies to decrease the level of pollutants caused by the residential building. As we have already said the idea behind this master thesis is to found better solutions for having a more sustainable city and to improve urban life not just from the architecture point of view but also for the health of the citizen.

This chapter will be divided into three main parts: the first part regards the current energy and emissions assessment for the residential sector, while the second part consists in the calculation of the current situation for the city of Turin, in terms of pollutant emissions, as well as in socio-economic terms, allowing to estimate the actual costs associated to health effects due to people exposure to PM10 and PM2.5 emissions. Finally, the third part consists in the construction of different energy scenarios, resulting in different emissions forecasting for the city of Turin, which will be lately translated in economic terms, through the application of the HCA and WTP approaches, presented in chapter 5.

4. 1. METHODOLOGY

This section aims to describe the methodological steps used in order to characterize from the energy and environmental standpoints the residential sector of Torino. Section 4.1.1 focuses on the characterization of the residential building stock of Torino, using the Reference Building (RB) approach developed within TABULA European project (REF). Starting from the RB, we estimated the total consumption of energy and the principal pollutions emissions produced by them. The principal pollutant are : CO_2, CO, NO_2, SO_2, NMVOC, PM10, and PM2.5.

While in section 4.1.3 provides an explanation of the alternative retrofit scenarios developed in order to study their effects in energy and environmental terms, using two different approach.

Here below, in Figure 1, we list the main steps of the methodology followed to develop this project, regard the energy consumption of the residential building and the emission created by them.

MAINS STEPS of the METHODOLOGY

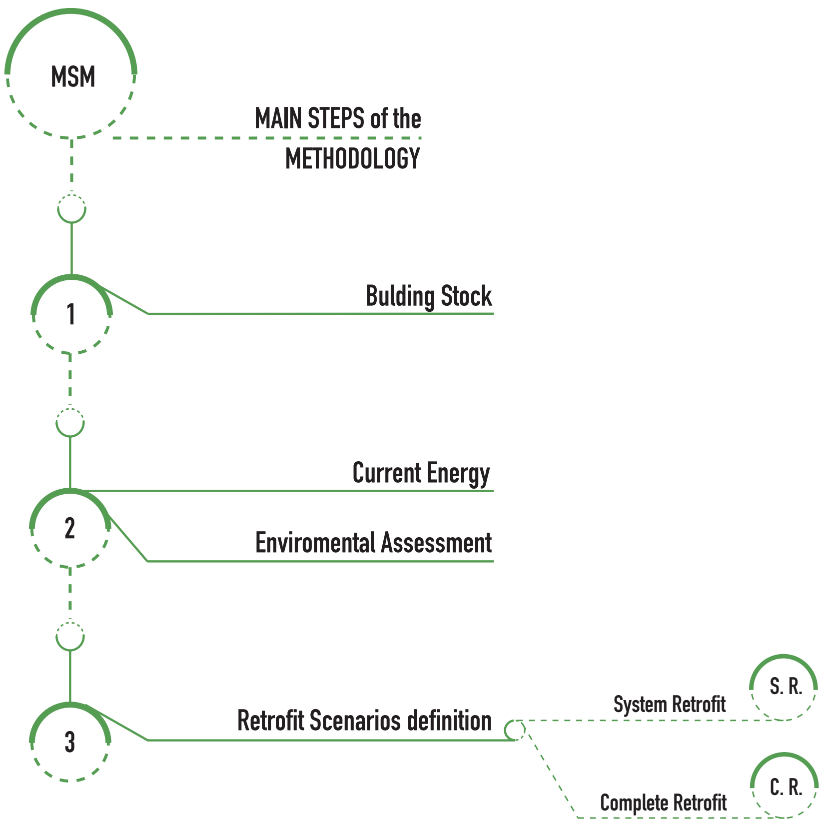


Fig. 1. Mains steps of the Methodology, for the part 1, Energy and Emissions

4. 1.1. Residential Building Stock Characterization

This section is dedicated to show the Reference Building (RF) concept, wich it was used to evaluate the current state of energy performance at an urban scale.

The concept of "referenced building type" was evolve with the European Project Tabula [1], which it was fundamental to determine the energy performance of building in the current situation and to calculate the emission of pollutants.

The project Tabula (Typology Approach for Building stock energy Assessment) [1] 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, among which Italy, and the Department of Energy of the Politecnico of Turin was involved in the assessment of the Italian case study.

For each country, a classification scheme, grouping buildings, has been developed and it's main goal was to create residential buildings prototypes (reference building) characterized by typical energetic features.

The aim of Tabula is that 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 the case of buildings retrofit.

Tabula give the guideline to create a referenced building type at European level.
The "**Typology building**" is based on the classification of common parameters related to the energy consumption of the building. There are three parameters that are taken into consideration to identify "building Typology", follow as:

1. Location regard the climate area
2. Construction period, which
3. Building size and shape

From this parametrer is create a matrix structure called "building typology matrix", which change by the region/climatic area (1), and in the axis x there is a "building ages class" (3), and on the axis y is present he "building size shape" (2).
In each cell of the matrix structure contain a "**Reference Building Type**" which it is a building considered representative in that specific condition.
The definition of building type in tabula was developed using three different methodologies, which are:

1. The "real example building" (ReEx): this method is used when the data is not present, in fact a group of experts identifies the building on the basis of the actual climatic context, the specific dimensions and age classes of construction.
2. The "real average building" (ReAv) instead of the previous method: this identifies

the typical building, which is identified through the statistical analysis of a large sample of existing buildings.

3. The "synthetical average building" (SyAv) identifies the type of building through an "archetype", which is not a real building, but a virtual building. For "archetype" is defined as "a statistical composite of the features found within a category of buildings in the stock" [2].

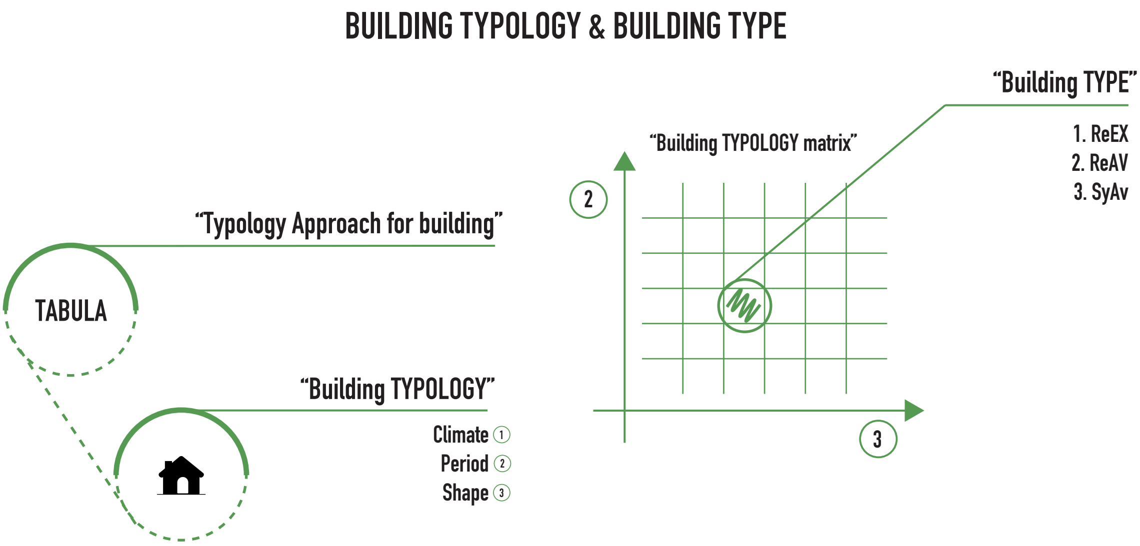


Fig. 2. Representation scheme about the difference between the "building Typology" and the "building Type".

Once the guidelines for the classification of the "preferred type of building" have been dictated, we can go into the specific Italian case, which will be taken for our case study.
The Italian matrix reports the feature of the climatic zone E, the average one in Italy, represents the 4.250 Italian municipality the total amount of 8.100. [3]
For the "Building Age class" was identify 8 construction period: class I, up to 1900, class II, from 1901 to 1920, class III from 1921 to 1945, class IV from 1946 to 1960, class V, from 1961 1975, class VI, from 1976 to 1990, class VII, from 1991 to 2005 and the class VIII after 2005.
The "Building size classes" is dived in four categories. The base of the division is related to the geometry, number of apartments etc, as follow: single family house (SFH), terrace House (TH), Multy-family house (MFH), Apartments block (AB).

The building types identified are 32. Specifically, the geometrical and technological characteristics of 14 out of 32 type 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 with 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 residential building typologies are published in a brochure (Building Typology Brochure-Italy) or on the internet by the site Webtool. [4] The Webtool is composed of the 21 countries of the UE that participated in the project, 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.

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.

The first step of the methodology is the creation of the current situation with the geometrical, technology, and energetic features, for the municipality of Turin at the residential sector.

As we have already said at the bigging of the chapter, this goal was possible thanks to the "references building" that give the geometrical, technology, structural and plant engineering feature and specific energetic performance, for the building categorized.

These phases, called "Building stock", creating the relationship between the 32 energy performance by Tabula, divided for category (SFH single-family house, TH terraced house, MFH multifamily house, AB apartment block) in the eight class of construction period (until 1900, 1901-1920, 1921-1945, 1946-1960, 1961-1975, 1976-1990, 1991-2005, after 2005). This are express in KWh/m2 and the meter square, the energetic reference was associate with the building of Turin, thank the last census (2011) by ISTAT, [4] it was possible to have the geometrical information.

An important hypothesis concerns the building sector is that 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.

Before moving on to the description of the next phase, it is necessary to open a bracket regarding the emission indices, “E”. These values are not reported in the Tabula brochure [3], but we can calculate starting from the data present in TABULA.

4. 1. 2. Current Energy and Enviromental Assessment

After having characterized the residential stock of Torino using the Reference Building approach, it is possible to evaluate its energy and environmental impact. Energy results are presented in the form of total primary energy consumption for space heating and water heating.

From an environmental standpoint, besides the traditional assessment of the CO2 emissions associated to energy use, emissions of main air pollutants are calculated CO, NO2, SO2, NMVOC, PM10 and PM2.5.

PRINCIPAL POLLUTANTS

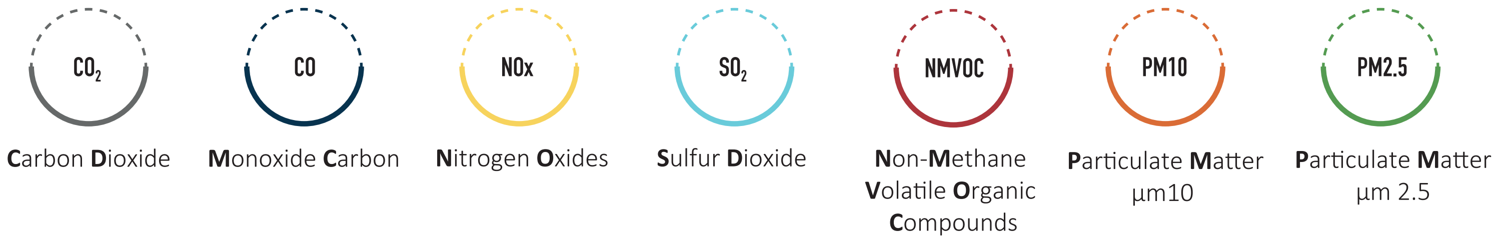


Fig. 3. Representation about principal pollutants emitted by buildings the we will take in consideration.

To calculate the emissions was take the value of emissions by EMEP (European Monitoring and evaluation programme) [5]. Moreover, we remark that all the consumptions and emissions are referred to an entire year. To be sure that the calculation was correct we compared our result whit the data by IREA (Inventario Regionale delle emissioni in Atmosfera)[6].

Before calculating the polluting emissions, it is necessary to calculate the energy consumption by the buildings.

Indeed, the emission indices “E” was associate at the building energy use Q_{use}, and the subsystems related to electrical auxiliaries Q_{aux}.

The data Q_{aux} was given by Tabula, instead, the $Q_{,use}$ was calculated starting from the data building energy need Q_{need} data and the efficiency factors of the plants $\eta_{s,ys}$, using the following formula:

$$Q_{use} = \frac{Q_{need}}{\eta_{s,ys}} \left[\frac{kWh}{m^2\,y}\right]$$

Equation 1

Where:

Q_{need} = buildings energy need [kWh/m^{2}y]

$\eta_{s,ys}$ = subsystem plat [-]

We know the Q_{need} (Building Energy Need) how this is covered by different energy sources. The main sources are natural gas and electricity but, in less portion, there are present as well as oil and biomass.

Thank tabula we know as well the coefficiency plat that composes the "Plat typology" for the heating system and for the production of the hot water.

In general, the subsystems plat (η_{sys}) is composed by generation (η_{gn}) emission (η_{e}), accumulation (η_{acc}) and distribution (η_{d}), but in Tabula the data of η_{e} is not present because in integrating into the η_{gn}.

For calculate the subsystem plat, we used the formula:

$$\eta_{s,ys} = \eta_{gn} * \eta_{acc} * \eta_{d} \quad [\,-\,]$$

Equation 2

Where:

η_{gn} = generation efficiency [-]

η_{acc}= accumulation efficiency [-]

η_{d} = distriution efficiency [-]

We have to specify that data like η_{acc} "accumulation", for the heating system and for the hot water and the η_{Wd} distribution, for just the hot water, they were in energy [kWh / m2]. In this case, we need to find the coefficient using the formula:

$$\eta_{H,acc} = \frac{Q_{H,need}}{Q_{H,need} + Q_{ls,Hs}} \quad [\,-\,]$$

Equation 3

Where:

$Q_{H,need}$ = buildings energy need for the heating systems, [kWh/m^{2}y]

$Q_{ls,H,s}$= building accumulation energy for the heating systems, [kWh/m^{2}y]

Instead for the calculation of the $\eta_{W,d}$ distribution, the formula is:

$$\eta_{W,acc} = \frac{Q_{W,need} + Q_{ls,Ws}}{(Q_{W,need} + Q_{ls,W,s} + Q_{ls,W,d})} \left[- \right]$$

Equation 4

Where:

$Q_{W,need}$ = buildings energy need for hot water, [kWh/m²y]

$Q_{ls,W,s}$= building accumulation energy for hot water, [kWh/m²y]

$Ql_{s,W,s}$= building distribution energy for hot water, [kWh/m^{2}y]

Knowing the total annual Q_{use} and the Q_{aux} for the heating and the hot water system, it is possible to calculate the pollutant emission "PE" for each different pollutant.

Multiplying the energy use by appropriate emission factors [7] of each pollutant, CO2, CO, NO2, SO2, NMVOC, PM10 and PM2.5 for different sources, it is possible to obtain the pollutant emissions. The unit of the emission factors considered is kg/kWh for the carbon dioxide, and g/kWh for the other pollutants.

The following formula show how to calculate the pollutant emissions produced by the sources, where the emission factor changes depending on the energy source and on the pollutants to be assessed (as shown in Table 1).

The basis for calculating the emission of pollutants comes from the guidelines of "the national agency for the protection of the environment", where in 2001 drafted a manual to calculate the emission of pollutants "Guidelines for local inventories of emissions into the atmosphere" [8], as follow, the formula for estimating emissions:

$$E / year = A * FE \quad \left[\frac{g}{y} \right]$$

Equation 5

Where:

E = emission [g di pollutant/year]

A = is an indicator of the activity whose sources of information can be: ISTAT censuses, various public and private bodies (Kg of product / year)

FE = is the emission factor per unit of activity and per specific pollutant (e.g. of pollutant/ kg of product)

With reference to the previous formula, we were able to calculate the emissions for our case study, where we associate the emissions of pollutants with energy consumption, as follow the formula to calculate the **Pollutant Emission (PE)**:

$$PE = (Q_{use} * ef) + (Q_{aux} * ef) \left[\frac{kg}{y}\right]$$

Equation 6

Where:

Q_{use} *ef = total emissions from the sources [kg]

Q_{aux}* ef = total emissions from the electricity [kg]

ef= emission factors of each pollutant [kg/kWh]

TABLE EMISSIN FACTOR (ef)

	CO_2 [Kg/kWh]	CO [g/kWh]	NOx [g/kWh]	SOx [g/kWh]	NMVOC [g/kWh]	PM10 [g/kWh]	PM2.5 [g/kWh]
Natural Gas	0.19	0.0792	0.1512	0.0011	0.0065	0.0007	0.0007
Oil	0.24	0.0133	0.2484	0.2844	0.0006	0.0054	0.0054
Biomass	0.025	1.080	0.288	0.040	0.036	0.216	2.917
Electricity	0.28	0.0626	0.0886	0.0277	0.0079	0.00016	0.0001

Table 1. Emission factor for residential building, from EMEP/EEA air pollutant emission Inventory Guidebook 2019

The data to the emission factors regard the different sources (natural gas, oil, and biomass) were taken from EMEP / EEA air pollutant emission Inventory Guidebook 2019, [7] instead the emission factor of electricity were taken from ISPRA data, (emission factors for stationary combustion sources) [9], [10].

We have to remark that EP was calculate for each typology building (AB, MFH, TH and SFH) for each eight "class of age" (until 1900, 1901-1920, 1921-1945, 1946-1960, 1961-1975, 1976-1990, 1991-2005, after 2005). As follow, the formula to calculate the Pollutant Emission for the different typology and class of period:

Apartament Blocks (AB) | Multi-Family House(MFH) | Terraced House (TH) | Single-Family House (SFH)

$(Q_{use,n} * ef_n) + (Q_{aux,n} * ef_n)$ | $(Q_{use,n} * ef_n) + (Q_{aux,n} * ef_n)$ | $(Q_{use,n} * ef_n) + (Q_{aux,n} * ef_n)$ | $(Q_{use,n} * ef_n) + (Q_{aux,n} * ef_n)$

$$\text{POLLUTANT EMISSION} \left[\frac{kg}{m^2 y}\right]$$

Equation 7

The last step was to associate the total emission to the surfaces for the different typology (AB, MFH, TH and SFH) of building, in this way it will be possible to have the total amount of pollutant emission associated at the city of Turin.

As follow, the formula for calculate the Total Pollutant Emissions:

Apartament Blocks (AB) | Multi-Family House(MFH) | Terraced House (TH) | Single-Family House (SFH)

$(PE_{,n} * S_n)$ | $(PE_{,n} * S_n)$ | $(PE_{,n} * S_n)$ | $(PE_{,n} * S_n)$

$$\text{TOTAL P.E.} \left[\frac{kg}{y}\right]$$

Equation 8

4.1.3. Retrofit Scenarios Definition

This step consists in the definition of different retrofit scenarios for the residential sector of Turin, in order to evaluate their capability in reducing the overall pollutants emissions for the entire city. Per each scenario, energy savings, as well as CO2, CO, NOx, Sox, NVOC, PM10, PM2.5 emissions reductions were assessed, using the current state of the city of Turin as benchmark for comparison.

Starting from the current characterization of the residential stock of Turin, different as sumptions were done, and can be considered valid for all scenarios.

No retrofit measures were considered for the reference buildings built before 1945 and for those built after 2005. Indeed, it is possible to consider buildings before 1945 as protected for their historical-artistical value, and thus retrofit actions could be restricted; as regards the buildings built after 2005, instead, they can be considered still new and well performing from an energy point of view, assuming that their construction already respects the current Italian regulations on energy efficiency. For these two reasons, only reference buildings built between 1945 and 2005 are considered for retrofit measures, for each scenario considered.

Two approaches were considered for the definition of scenarios; specifically, the first approach considers to renovate only the thermal generators of the reference buildings, without acting on the envelope; the second approach, instead, consider a full retrofit of the buildings, coupling envelope interventions (e.g application of insulation material to the walls, application of insulation material to the floors and roofs, replacement of windows) with technological substitutions (e.g substitution of thermal generators with more efficient solutions, installation of solar thermal collectors, etc.).

The first case, call "**system retrofit**" (SR), is based on evaluating the effective improvement of energy performance and the reduction of pollutant emissions by improving the efficiency of the system. In fact, the European Union aiming to save energy in all sectors, including the buildings sector. To encourage the people to invest by increasing energy savings, incentives are issued, called "white certificates", interventions can be of two types, at the beginning of the production process or at the user, for example by favoring the replacement of household appliances and boilers in favor of more efficient appliances. [11] In other words, this retrofit is based on modifying only the energy system, checking if there is an improvement intervening only in the technology system without intervening on the building envelope. This case is composed of two scenarios called S.R.-0.1 which is with biomass, and S.R.-0.2 which will be without biomass.

The second approach, called "**complete retrofit**" (CR), is more complete because takes into consideration also possible interventions on the envelope. Surely, a complete retrofit is more expensive and more time consuming, with respect to a solely technological retrofit. However, this scenario could provide more benefits on the long-term, especially in terms of emissions reductions, allowing to reduce the energy demand of the building itself and to install appropriate technological solutions to respond to heating needs. This scenario was built based on TABULA project [ref], and in particular, the complete retrofit approach is divided into two main scenarios: "standard complete retrofit"(SCR), built in order to achieve the standard regulations in terms of generators efficiency and envelope thermal characteristics, and "advanced complete retrofit" (ACR), in which more alternative technologies are used, among which renewable energy sources to partly satisfy building energy needs. As mentioned, both scenarios are built based on TABULA results.

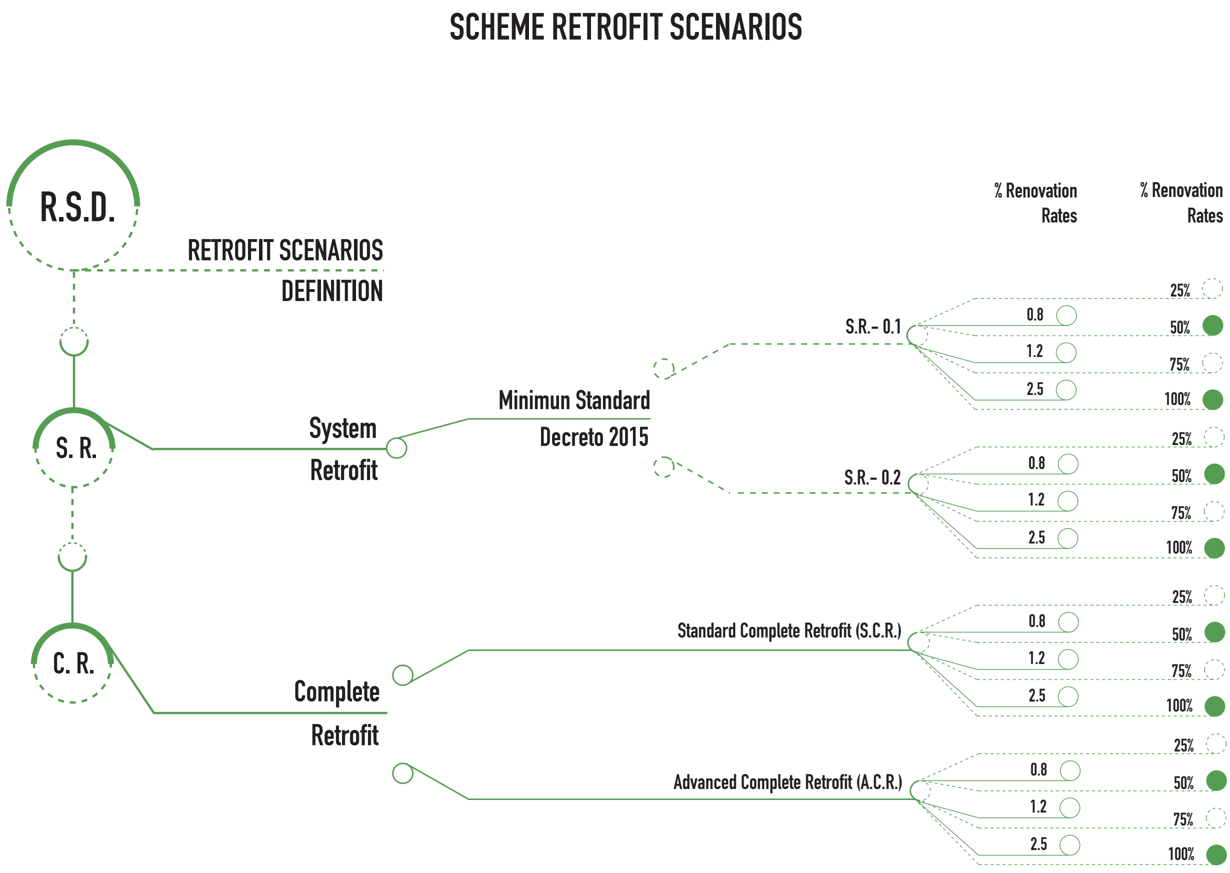


Fig. 4. Representation scheme about the Retrofit Scenarios Definition .

For the intervention, so for creation of the scenario, to try to find a better solution we used different values of renovation rate, in one hand, values that coming from the report of the renovation rate by the preview years. On the other hand, we assumed the renovation rate based on the historical moment that we are living. In fact, from the 27 of October 2020, there are incentives, ECOBONUS 110%, to increase the energy performance of the building. The value of renovation rate is used for both the scenarios, the SR and CR.

The value that we take from the latest energy efficiency report of 2019 [11] are 0.8% as a value to change the scenarios, which is the renovation rate on energy efficiency for the Piedmont region [11]. However, in order to carry out a sensitivity analysis, three other values were taken as the renovation rate, specifically,1.2% refers to the average Italian national renewable rate [12], and the other value is 2.5% refers to the average European Union renewable rate, as such the renewable rate it's between 0.5% to 2.5%. [12]

Indeed, the values that we assumed, based on the incentive ECOBONUS 110%, are four, 25%, 50%, 75% and 100%, based on the idea to create different possibility to see as it will be if we renovate all the residential sector (100%). This choice came from two reason, the first, that we explain before that is based for the historical moment, the other reason it is to see as it will be the effect if we intervention on all the residential sector (which is the 75% of all the building sector, because we are not interevent on all the class of period as we have already explained before).
For the technologies, we took the different percentage of intervention values as well, the number is given by certificates of Eco bus. From the report emerge the main interventions, for the Piedmont Region are, new boiler (condensing boiler, 60,39%), biomass generators (10,68%), and the heat pump (28,93%) [9].

EcoBonus INTERVENTIONS TABLE

	Number of Interventions	%
Condensing boiler, space heating	889	
Condensing boiler, space heating + H.W.	10.196	
Condensing boiler, centralized heating H.W.	59	
TOTAL Condensing boiler	**11.144**	**60,39**
Biomass generators, space heating	1.694	
Biomass generators, space heating + H.W.	276	
Biomass generators, centralized heating H.W.	-	
TOTAL Biomass Generator	**1.970**	**10,68**
Vapor compression heat pump	**5.339**	**28,93**

Table 2. Percentage of interventions distribution, source of the annual Energy Efficiency report, year 2019.

4. 2. APPLICATION TO THE TORINO CASE STUDY

After eving expalin the methodology that will be used and the aim of this master thesis, which is to evaluate the effect of the air pollution on the peoples health and wich are the strategy to reduce the emission of pollutant caused by the buildings residencial. The next step was to apply the methodology in a real case study, the city that we took in consideration is Turin.

Turin (886.837 inhabitant) covers an area of about 130 km2 in the western area of the Po valley, is surrounded by the Alps to the north and hills to the south and is crossed by four rivers including the Po which is the largest.

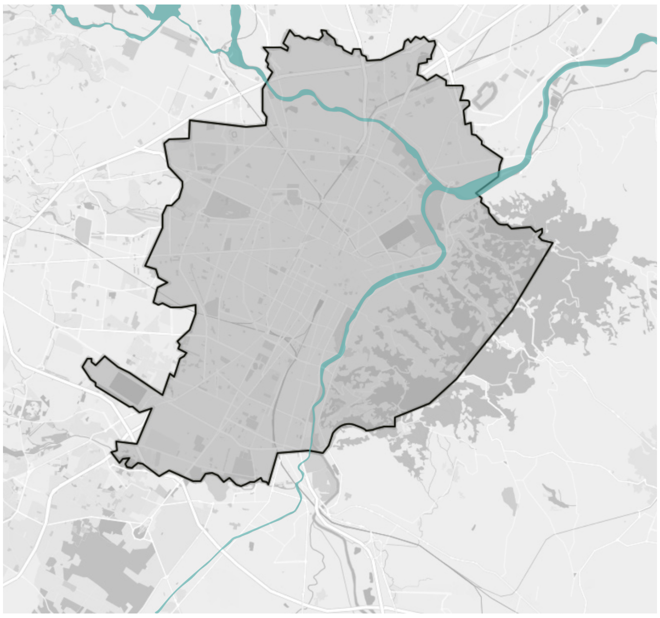


Fig.5. Map of the City of Turin

The city of Turin is considered one of the "greenest" Italian cities, in fact, the 2015 data showed that the municipality of Turin has 19,569,000 square meters of total area of green areas and public management, of which about 12,733,000 are parks and gardens. The data also showed that 21.93 square meters of greenery can be attributed to each inhabitant. [13]

From the Historical point of view, the city of Turin was born in the second half of the 1st century BC under Roman dominion, as a military camp, called Roman "castrum" (fig.6), dictating the shape of the city.

The structure remains unvaried for 1500 years. The first change in the shape of the city began to verify in 1600 until the French occupation in 1803.

The main changes that are made are three, the axis (still present) of the Via Roma is created, an axis is created that starts from the center and goes towards the river Po (via Po) , another major modification is the extension on the west side of the city, after Porta Susa. The city is protected by the creation of a new rings of wall (fig. 7). In a second moment, thanks to the French dominion, the walls will be removed, and the city will be enlarged according to the regular grid plan, with tree-lined courses that still characterize the city today.

Maps of Turin

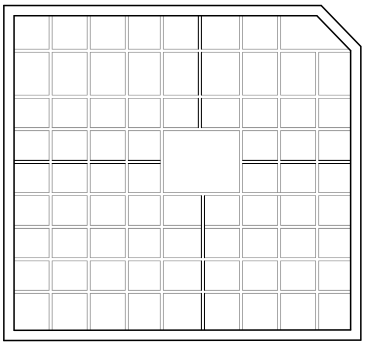


Fig.6. Map of Turin, in 1st century BC, "CASTRUM"

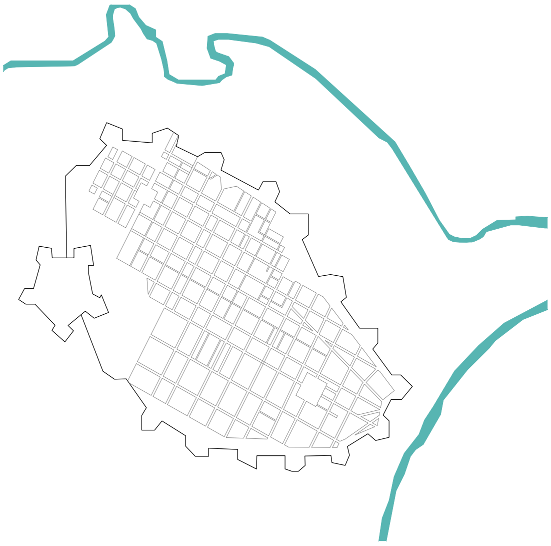


Fig. 7. Map of Turin, in 1780.

The other important expansion is in the end of the 19th century (fig. 8) in this moment the expansion is verify in two area, in the north of the city, in the Dora area, with the construction of the Barrier of Milan, and in the south of the city beyond the Valentino's park, towards Lingotto.
In the 1900s there was an important modification of the city, because the people move from the countryside to the city for the strong demand of work that has come with the birth of the "Fiat" industry. This phenomenon has increased the housing demand and consequently the construction of new workers' districts and social housing. In particular, during the period of fascism the population grew, that were registered 9,000 new inhabitant per year.
Instead, during the course of the Second World War the population will decrease, but in the end of the war will occur an economic boom, in fact, the demographic level will be reaching one million inhabitants between 1951 and 1962. This situation is given mainly be effect, which create a further expansion of the city (fig. 9).
However, due to the deindustrialization and the increase of the service industry, large gaps are created in the city. The crisis gives the opportunity in the modification of the structure and productivity, and in the redevelopment of the former industrial areas, with events of the Winter Olympics of 150, gives new inputs and identification of the city.

Maps of Turin

Fig.8. Map of Turin, in 1881

Fig. 9. Map of Turin, in 1941

From this brief historical overview of the urban expansion of the city, it is not unexpected that most of the construction of the building heritage dates back to the second half of the nineteenth century, and increasing in the twentieth century.
Based on the most updated ISTAT census [4], which refers to 2011 data, Turin presents 63,764 Buildings, where 62,643 are occupied, 57.7% of which are residential buildings. From ISTAT statistics it emerges also that the 94% of the residential buildings in the city are privately owned.

BUILDING SCHEME

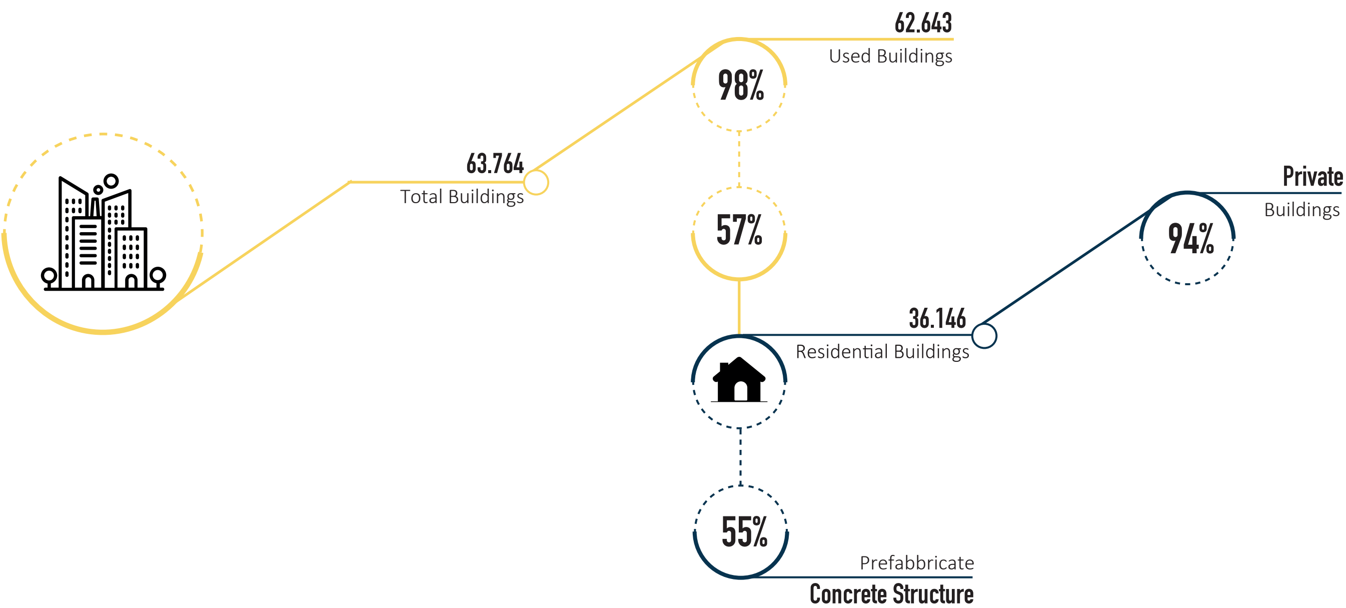


Fig.10. Rappresentation about the distribution of buildings in the city of Turin, by last census Istat 2011

More than 90% of buildings were built before 1980. Specifically, 70% were built between 1919 and 1970 and the greatest construction activity occurred between 1946 and 1960, where almost 30% of all residential buildings were built.[4]
During 1980 the activity of construction and restoration decrease.

60% of residential buildings have more than 4 floors above ground and about 26% have more than 16 apartments.
The 1946 and 1960 is characterized by a high number of building construction compared to other period, most of the buildings that were built in this ages, them are in good condition and mediocre conversation, while the buildings built earlier are of worse conditions.
The city's greatest building activity took place during the spread of heavy prefabrication systems based on concrete, which makes up 55.16% of Turin's buildings.
Coming to building services, more than 99% of homes have domestic hot water, and almost 96% of those that have a heating system. Around 74% of residential buildings present a centralized heating system, while almost 26% have an autonomous system and 4% have other fixed heating appliances (it worth mentioning that the sum does not make 100%, since it is possible that some apartment presents more than one system).
As regards the energy sources, approximately 80% of buildings make use of natural gas and methane for heating purposes, 5% is by diesel fuel 2% electric energy, 1% solid fuel, 1% gpl other sources 11% , and less than 1% of buildings are equipped with renewable energy systems (e.g. solar thermal collectors, photovoltaic systems, etc.). [4]

ENERGY SOURCES

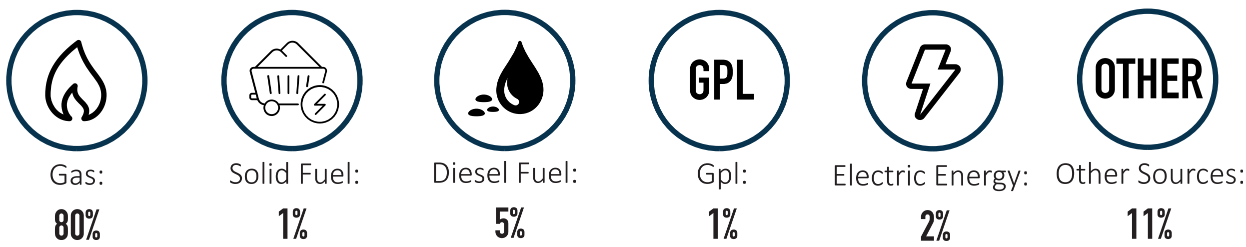


Fig.11. Different energy flue, present in the city of Turin, Data from Dati ISTAT, last census, 2011.

4. 2. 1. Residential building stock characterization

1. Geometry

After having defined Turin as the city as case study, was important to define the building stocks of our city. As already describe at the beginning of the chapter, Tabula [1] was used to define the building stock.

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 differ-buildings. 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.

We then had to compare the information in [14], that we will call as "Turin Data" with the one available in Tabula [1]. In the " Turin Data"[14] and [15] the typologies of buildings are 40, same 4 categories of Tabula but 10 building age- classes, (-1900, 1900-1918, 1919-1945, 1946-1960, 1961-1970, 1971-1080, 1981-1990, 1991-200, 2001-2005, 2006) while in Tabula [1] there are respectively 4 and 8 classes. This difference is given by the fact that in "Data Turin" [14],[15], the analysis of the Turin building stock is adapted to the building age-classes used for the census, while the subdivision in Tabula [1] represents the energetic building performance system techniques [16].

As already done and explain in the master thesis by Giulia Vergerio [16], 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 3.

CORRESPONDENCE BETWEEN THE TWO BUILDING AGE-CLASSES SUBDIVISION.

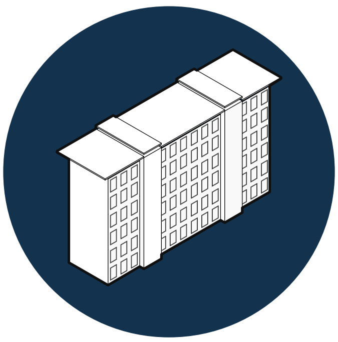
TURIN DATA	TABULA	CLASSES
-1900	until 1900	1
1900-1918	1901-1920	2
1919-1945	1921-1945	3
1946-1960	1946-1960	4
1961-1970		
	1961-1975	5
1971-1980		
	1976-1990	6
1981-1990		
1991- 2000	1991-2005	7
2001-2005		
2006	after 2005	8

Table 3. Table took from the master thesis by 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. The next step was to use the data from Tabula and Tabula web tool and brochure [3], [1] to define the energy models and building consumptions of each building typology in kWh/m2, associating this value for the total square meters of each building typologies of Turin.[4]

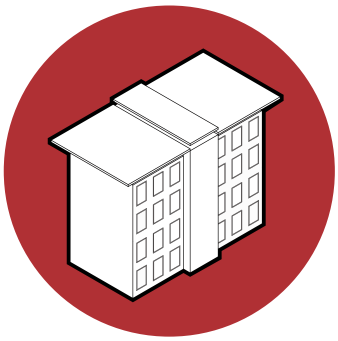
BUILDINGS AND SURFACES SCHEME

APARTAMENT BLOCKS (AB)



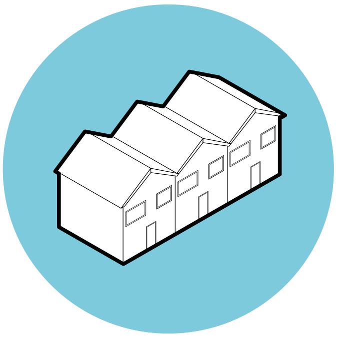
Period	m^2
1	172.701,90
2	2.655.095,10
3	3.101.422,40
4	5.126.430,20
5	10.391.830
6	4.566.914,70
7	1.518.604,20
8	201.147,90

MULTI-FAMILY HOUSES (MFH)



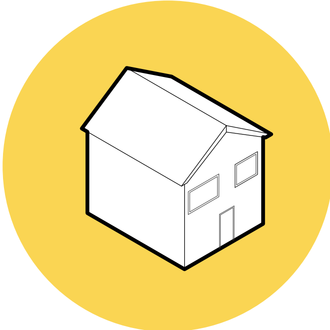
Period	m^2
1	34.571,20
2	390.743,40
3	840.095,80
4	1.197.748,20
5	861.994,40
6	211.052,30
7	143.518,40
8	36.385,50

TERRACED HOUSES (TH)



Period	m²
1	62.541,10
2	286.604,60
3	438.978,20
4	590.853,20
5	424.606,00
6	153.079,30
7	84.318,60
8	13.291,20

SINGLE-FAMILY HOUSES (SFH)



Period	m²
1	19.980,10
2	83.132,60
3	113.239,80
4	152.911,10
5	119.867,60
6	36.770,70
7	10.950,70
8	3.064,90

Table 4. Classification of the square meter by the four categories for the eight class of the period.

2. TYPE of FUEL

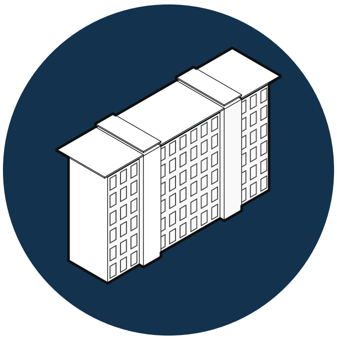
The second step was to estimate the consumption for each energy source, both for space heating and domestic hot water services, for each reference building.

The first step was to define the type of fuel used for each typology of the building. In this phase, we decided to use the information given by Tabula [1], where, the type of fuel and the typologies of boilers are illustrated for all the 32 types of building.

The subdivision in Tabula are prevalent between gas oil, natural gas boiler, biomass, eclectic boiler, and only a small part of the buildings (buildings built after 2005) use the alternative sources like the solar thermal panel.

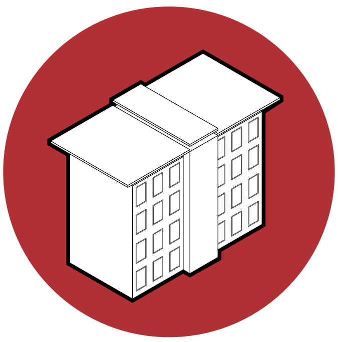
ENERGY SURCES BUILDING

APARTAMENT BLOCKS (AB)



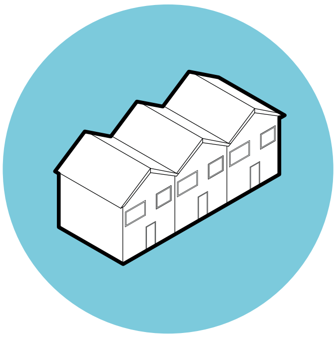
Period	HEATING	HOT WATER
1	Natural Gas	Natural Gas
2	Gas Oil	Natural Gas
3	Natural Gas	Natural Gas
4	Natural Gas	Electric Boiler
5	Natural Gas	Natural Gas
6	Natural Gas	Natural Gas
7	Natural Gas	Natural Gas
8	Natural Gas	T.P. 50%, N.G. 50%

MULTI-FAMILY HOUSES (MFH)



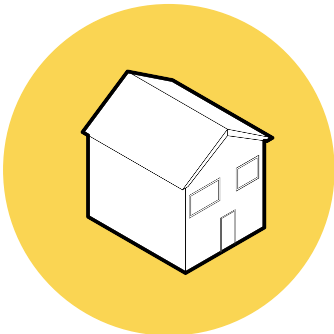
Period	HEATING	HOT WATER
1	Natural Gas	Natural Gas
2	Natural Gas	Electric Boiler
3	Natural Gas	Natural Gas
4	Gas Oil	Electric Boiler
5	Natural Gas	Natural Gas
6	Natural Gas	Natural Gas
7	Natural Gas	Natural Gas
8	Natural Gas	T.P. 50%, N.G. 50%

TERRACED HOUSES (TH)



Period	HEATING	HOT WATER
1	Natural Gas	Electric Boiler
2	Gas Oil	Gas Oil
3	Natural Gas	Natural Gas
4	Natural Gas	Natural Gas
5	Natural Gas	Natural Gas
6	Natural Gas	Electric Boiler
7	Natural Gas	Natural Gas
8	Biomass	T.P. 50%, B. 50%

SINGLE-FAMILY HOUSES (SFH)



Period	HEATING	HOT WATER
1	Natural Gas	Natural Gas
2	Natural Gas	Electric Boiler
3	Natural Gas	Natural Gas
4	Gas Oil	Gas Oil
5	Natural Gas	Natural Gas
6	Natural Gas	Natural Gas
7	Natural Gas	Natural Gas
8	Natural Gas	T.P. 50%, N.G. 50%

Table 5. Classification distribution Energy Sources for the each building Typology

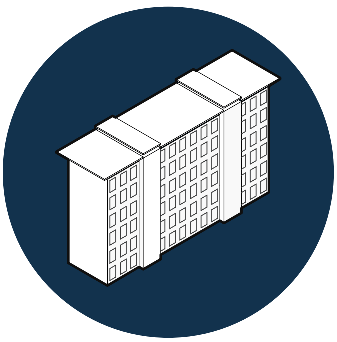
3. BUILDING ENERGY CONSUMPTION

Afterwards, the next step was to estimate the consumption for reference building. In Tabula the energy need Qnd and primary energy need P.E. (primary energy) for both heating and domestic hot water are enumerated.

To achieve the total energy consumption, we have to multiple the energy which is express in kWh/m2y for the total surface, for each four typologies.

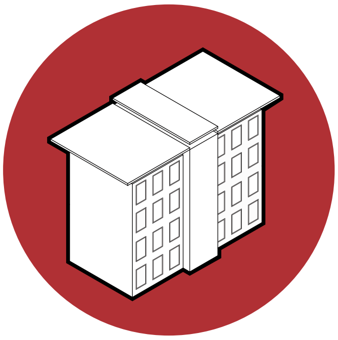
BUILDINGS ENERGY CONSUMPTION

APARTAMENT BLOCKS (AB)



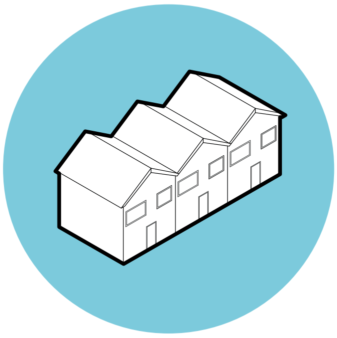
	HEATING		HOT WATER	
Period	P.E. [kWh/m²]	Q_{need} [kWh/m²]	P.E. [kWh/m²]	Q_{need} [kWh/m²]
1	226	133	58.5	18,8
2	284	194	25	18,1
3	275	162	52,2	18,1
4	233	157	55,2	17,9
5	224	134	52,6	18,2
6	97,5	67,6	22,7	17,4
7	79	62,9	23,2	17,1
8	43,1	36	16,2	17,7

MULTI-FAMILY HOUSES (MFH)



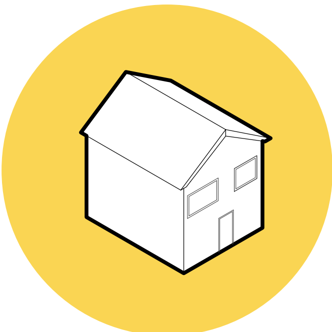
Period	P.E. [kWh/m²]	Q_{need} [kWh/m²]	P.E. [kWh/m²]	Q_{need} [kWh/m²]
1	438	250	22,2	16,1
2	349	199	55,1	17,9
3	293	200	46,7	19,1
4	253	170	54,3	17,7
5	198	153	25,5	16,9
6	132	105	22,6	16,6
7	105	70,3	23,3	17,9
8	48,1	40,5	16,4	18

TERRACED HOUSES (TH)



Period	P.E.	Q_{need}	P.E.	Q_{need}
1	474	197	42,30	15,40
2	505	253	48,20	15,70
3	496	250	21,60	15,70
4	409	173	53,70	15,80
5	481	241	41,80	16,60
6	224	113	40,00	15,30
7	127	85,10	18,60	15,80
8	83,10	65,80	18,40	15,30

SINGLE-FAMILY HOUSES (SFH)



	HEATING		HOT WATER	
Period	P.E. [kWh/m²]	Q_{need} [kWh/m²]	P.E. [kWh/m²]	Q_{need} [kWh/m²]
1	474	335	42,30	15
2	505	357	48,20	15,70
3	496	335	21,60	15,60
4	409	275	53,70	14,40
5	481	344	41,80	14,60
6	224	136	40,00	13,80
7	127	92	18,60	14,20
8	83,10	67	18,40	14,20

Table 6. Classification about the energy costruction , Primary energy and Energy need .

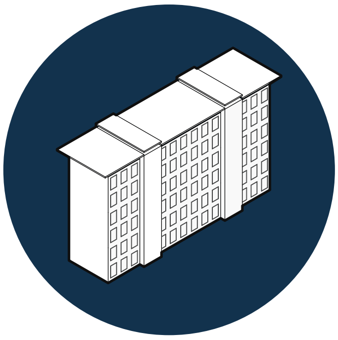
4. 2. 2. Current energy and environmental assessment

In this section, we will report the results of the calculations carried out using the method that was explained in the previous paragraph 4.1.2 (current energy and environmental assessment).

A method used to of how the energy used by buildings was calculated, and the emissions of pollutants.

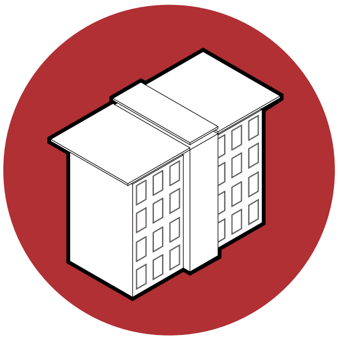
BUILDINGS ENERGY CONSUMPTION

APARTAMENT BLOCKS (AB)



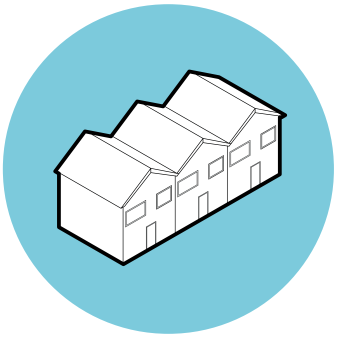
HEATING Q_{use} [kWh/m²]	HEATING Q_{aux} [kWh/m²]	HEATING $\eta_{s,ys}$ [-]	HOT WATER Q_{use} [kWh/m²]	HOT WATER Q_{aux} [kWh/m²]	HOT WATER $\eta_{s,ys}$ [-]
223	1,70	0,60	53,85	2,1	0,35
281,22	2,60	0,69	24,99	-	0,72
271,63	1,70	0,60	47,67	2,1	0,38
228,77	2,60	0,69	25,37	-	0,71
219,46	1,70	0,61	48,08	2,1	0,38
92,27	2,60	0,73	22,66	-	0,77
75,24	1,60	0,84	23,24	-	0,74
39,48	1,70	0,91	11,41	2,2	0,78

MULTI-FAMILY HOUSES (MFH)



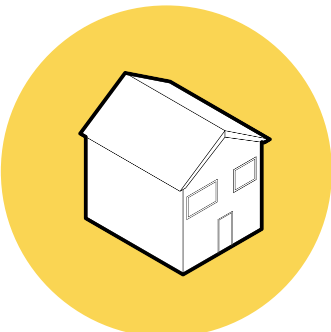
HEATING Q_{use} [kWh/m²]	HEATING Q_{aux} [kWh/m²]	HEATING $\eta_{s,ys}$ [-]	HOT WATER Q_{use} [kWh/m²]	HOT WATER Q_{aux} [kWh/m²]	HOT WATER $\eta_{s,ys}$ [-]
434,71	1,70	0,58	22,23	-	0,72
346,03	1,70	0,58	25,37	-	0,71
289,72	2,60	0,69	40,65	2,8	0,47
250,22	2,60	0,68	25,09	-	0,71
193,18	1,60	0,79	25,44	-	0,66
128,30	1,60	0,82	22,62	-	0,73
101,44	1,70	0,69	23,31	-	0,77
44,42	1,70	0,91	11,59	2,2	0,78

TERRACED HOUSES (TH)



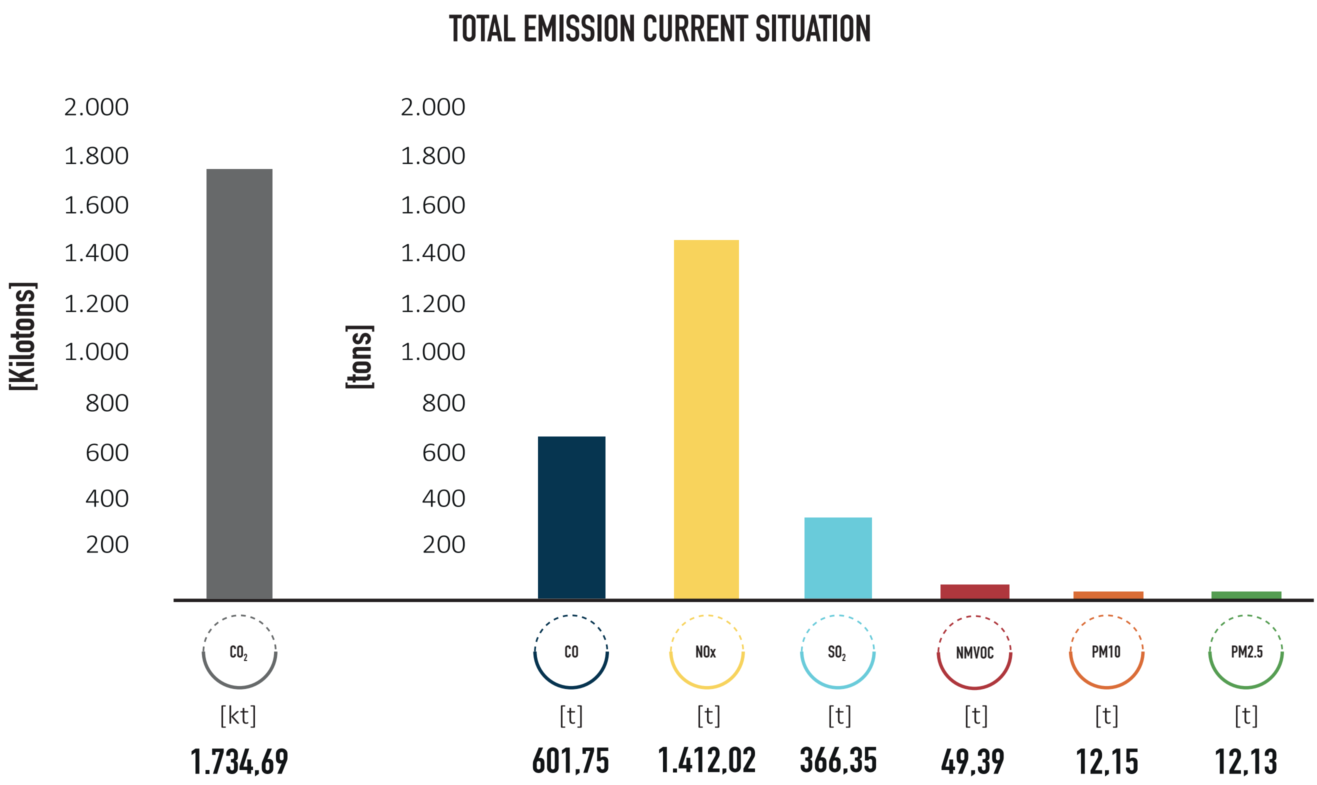
HEATING Q_{use} [kWh/m²]	HEATING Q_{aux} [kWh/m²]	HEATING $\eta_{s,ys}$ [-]	HOT WATER Q_{use} [kWh/m²]	HOT WATER Q_{aux} [kWh/m²]	HOT WATER $\eta_{s,ys}$ [-]
333,16	3,70	0,59	21,83	-	0,71
367,47	4,40	0,69	45,18	4,60	0,35
346,45	3,70	0,72	21,68	-	0,72
251,27	4,40	0,69	45,30	4,60	0,35
330,23	3,70	0,73	35,88	3,90	0,46
152,79	4,40	0,74	21,27	-	0,72
122,41	3,70	0,70	30,26	3,90	0,52
93,62	3,70	0,70	12,43	4,10	0,62

SINGLE-FAMILY HOUSES (SFH)



HEATING Q_{use} [kWh/m²]	HEATING Q_{aux} [kWh/m²]	HEATING $\eta_{s,ys}$ [-]	HOT WATER Q_{use} [kWh/m²]	HOT WATER Q_{aux} [kWh/m²]	HOT WATER $\eta_{s,ys}$ [-]
464,25	3,70	0,72	33,88	3,90	0,44
494,73	3,70	0,72	22,25	-	0,71
486,56	4,40	0,69	21,55	-	0,72
399,42	4,40	0,69	43,61	4,60	0,33
471,36	3,70	0,73	33,38	3,90	0,44
216,63	3,70	0,63	31,47	3,90	0,44
117,85	4,40	0,78	18,50	-	0,77
75,08	3,70	0,89	9,51	4,10	0,75

Table 7. Classification of Energy use, Energy auxiliar, for the Referenced building



Graph 1. Representation total pollutant emission for the residencial building sector for the city of Turin.

4. 2. 3. Retrofit Scenarios Definition

This paragraph presents the assumptions behind the scenario definitions, as well as the main outcomes in terms of energy consumption and pollutants emissions reduction achieved.

As reported in the methodological section, (4.13. Retrofit Scenarios Definition) two approaches of retrofit interventions were defined, allowing the definition of three scenarios: system retrofit (SR) scenario (S.R.-0.1,S.R.-0.2), standard complete retrofit (SCR) scenario and advanced complete retrofit (ACR) scenario.

As previously mentioned, SR assumes to intervene only on thermal generators, while both SCR and ACR scenarios couple envelope retrofit solutions with technological interventions, starting from TABULA scenarios, and aiming to NZEB standards. The value of renovation rates that we took is 0,8 because is the Piedmont region value of renovation. Hence, once we have established which renovation rates are to be applied to our scenarios, it has had to be distributed over different surfaces.

Assuming to intervene only on buildings built between 1945 and 2005, the considered renovation rate was applied only to this portion of buildings. As previously reported, the classes of buildings built before 1945 were not taken into consideration, as they are already part of the historical period that results as protected buildings, as well as those of buildings built after 2005, as they are already equipped with technologies that reflect the current energy standards for buildings.

From here, once it was understood which are the classes of interest, where to apply the renewal rate (1946-1960, 1961-1975, 1976-1990, 1991-2005) we created a table to weigh the renewal rate based on to the built for the different classes. In other words, we created a table with all the surfaces that we took in consideration and added together. (Table 8)

SURFACES

Period	(AB) [m^2]	(MFH) [m^2]	(TH) [m^2]	(SFH) [m^2]
1946 - 1960	5.126.430,20	1.197.748,20	590.853,20	152.911,10
1961 - 1975	10.391.830,80	861.994,40	424.606,00	119.867,60
1976 -1990	4.566.914,70	211.052,30	153.079,30	36.770,70
1991 - 2005	1.518.604,20	143.518,40	84.318,60	10.950,70
TOT.	**21.603.779,90**	**2.414.313,30**	**1.252.857,10**	**320.500,10**

Table 8. Table which represents the surface of the references buildings that we intervene in the specific class of the period.

PERCENTAGE

Period	(AB) [%]	(MFH) [%]	(TH) [%]	(SFH) [%]
1946 - 1960	20,03	5,93	2,31	0,60
1961 - 1975	40,61	3,37	1,66	0,47
1976 -1990	17,85	0,82	0,60	0,14
1991 - 2005	5,93	0,56	0,33	0,14
TOT.	**84,42**	**9,43**	**4,90**	**1,25**

Table 9. Tabel represents the percentage of the intervention based on the totality surfaces in which we intervened.

Once the first step was concluded, which was to distribute the renewal rate in a weighted way on the different classes for the different historical period, and as we already said this approach was used for all scenarios, we were able to focus on how to act on the systems and technology.

4. 2. 3.1. System Retrofit (SR)

This section is dedicate to show the intervention on the technological system, we intervened using the minimum requirements by law (Requisiti minimi di prestazione Energetica del 2015) [17], without touching the envelope.

To do this we have maintained the current requirements $Q_{H,need}$, $Q_{W,need}$ and intervene on the efficiency system η_{hsys} for the heating system and the domestic hot water.

So to calculate the energy consumption, Q_{use}, both for heating $Q_{h,use}$ and for domestic hot water $Q_{w,use}$ using the formula that we used for the creation of the current situation (section 4.1.2. Current Energy and Environmental assessment, equation 1)

From the formula used for the calculation of the efficiency system, as follow:

$$\eta_{s,ys} = \eta_{gn} * \eta_{acc} * \eta_{d} \quad [-]$$

Equation 2

Where:

η_{gn} = generation efficiency [-]

η_{acc}= accumulation efficiency [-]

η_{d} = distriution efficiency [-]

We apply the η_{e} (emission) and η_{d} (distribution) used for the calculation of the referenced building, in the current situation and we changed the η_{gn} (generation) using the regulation [17], in the following table are report the new valued used.

Generation efficiency η_{gn} :	HEATING	HOT WATER
• Gasseous fuel generator	0,72	0,60
• Solid biomass generator	0,72	0,60
• Steam compressione heat pump with electric motor	3,00	0,47
• District heating	0,97	-

Table 10. Tabel represents the generation efficiency η_{gn} apply.

The other change was in modify the Qaux, for both the heating and hot water, the value is different regard the replacement system. The data were taken by the efficiency report of

2019 [7], thanks to the emission of the “white certificates” regarding the tax deductions about the energy-saving (BONUS CASA), It was possible to have the quantity and type of systems installed during the year 2018. The type of system replaced are, condensing Boiler, Boiler with biomass source, and heat pump.

The Data for the Q_{aux}, was taken by Tabula in the standard and advanced section, in the following table are report the value for the different systems and referenced buildings.

	HEATING		HOT WATER	
	η_{acc} [-]	Q_{aux} [kWh/m²]	η_{acc} [-]	Q_{aux} [kWh/m²]
• SFH - TH	0	4,4	0	3,9
• AB - MFH	0	2,6	2,1	2,2

	HEATING		HOT WATER	
	η_{acc} [-]	Q_{aux} [kWh/m²]	η_{acc} [-]	Q_{aux} [kWh/m²]
• SFH - TH	1,4	4,4	1,4	3,9
• AB - MFH	1,4	2,6	2,1	2,2

	HEATING		HOT WATER	
	η_{acc} [-]	Q_{aux} [kWh/m²]	η_{acc} [-]	Q_{aux} [kWh/m²]
• SFH - TH	1,4	2,7	1,4	3,2
• AB - MFH	0,8	1,6	2,1	2,2

Table 11.Representation of the value Q_{aux} and η_{acc} for the heating and hot water system, used

After the explanation to where we took the data, was calculated the new energy used (Q_{use}) for the heating and hot water, for the different typology.

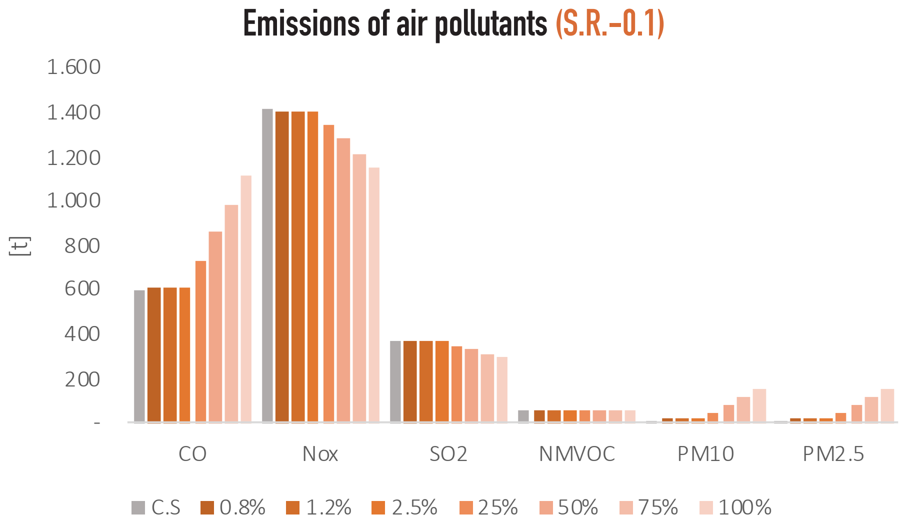
The following step was to distribute the percentage of new technologies on our class of intervention (1946-1960, 1961-1975, 1976-1990, 1991-2005) and renovation rate (0.8).

Percentege :

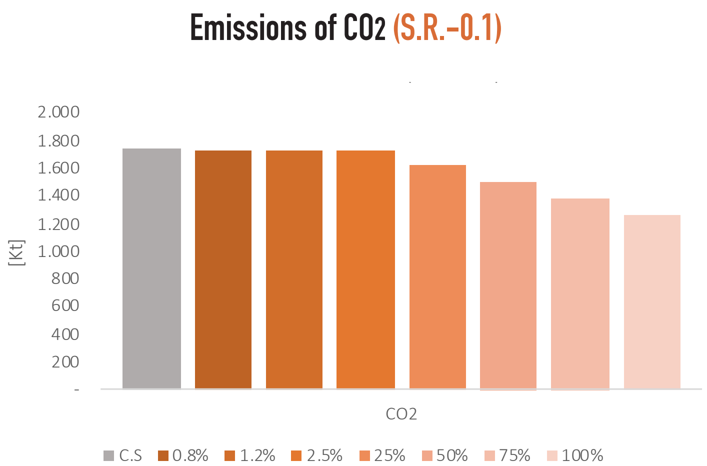
• Condensing Boiler	**60,39 %**
• Boiler with biomass generators	**10,68 %**
• Heat Pump	**28,93 %**

As well for this case, too, a weighted distribution was carried out (method previously used to distribute the renovation rate) for the different categories for the different historical periods.

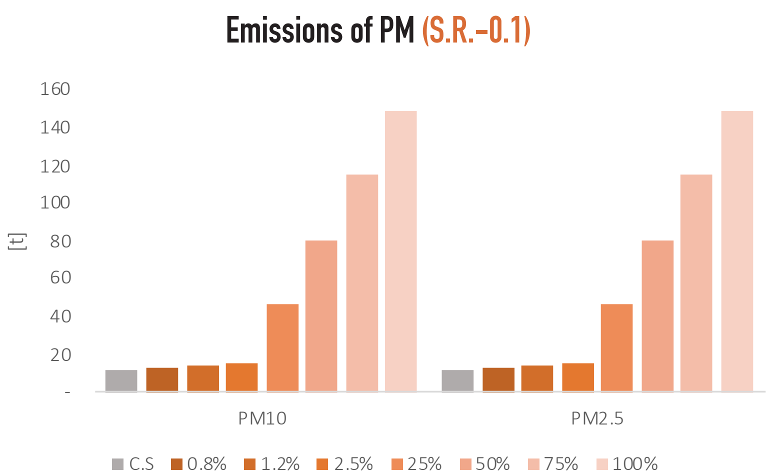
Each scenario is composed by all renovation rates wich we took in consideration. Also they are divide in two block, the first block represent the amount of emission for all the pollutans tones per year. The other chart block represent the avoided emission of pollutant. In the end of the thesis are reports the chartes with the number of the emissions. [ANNEX 2_ p.171].



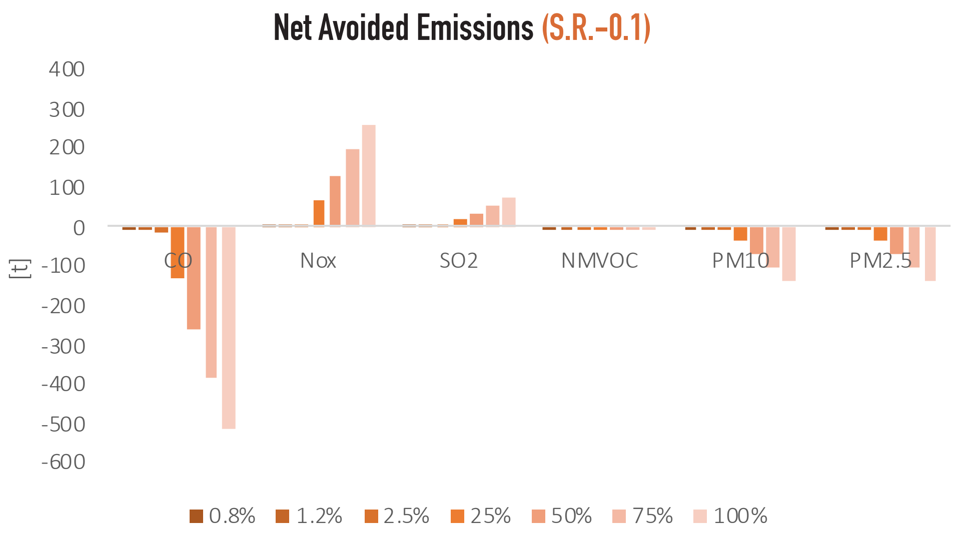
Graph 2. Representation of the total emissions in the S.R.-0.1 scenario, without the CO2 pollutant.



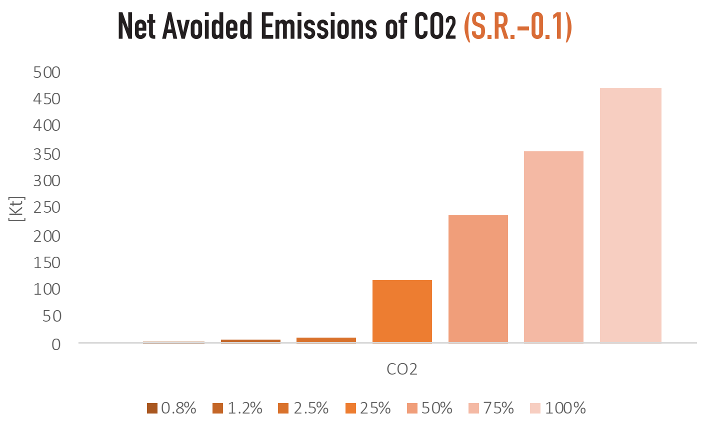
Graph 3. Representation of the total emissions of CO2 in the S.R.-0.1 scenario.



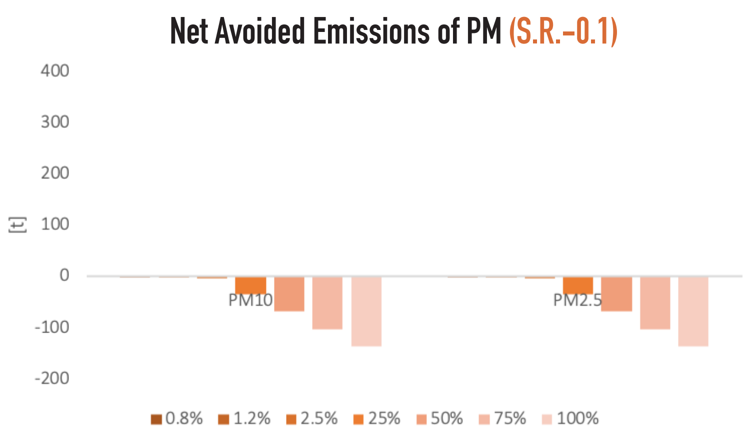
Graph 4. Representation of the total emissions of PM in the S.R.-0.1 scenario.



Graph 5. Representation of the Net Avoided Emissions in the S.R.-0.1 scenario, without the CO2 pollutant.



Graph 6. Representation of the Net Avoided Emissions of CO2 in the S.R.-0.1 scenario.



Graph 7. Representation of the Net Avoided Emissions of PM in the S.R.-0.1 scenario.

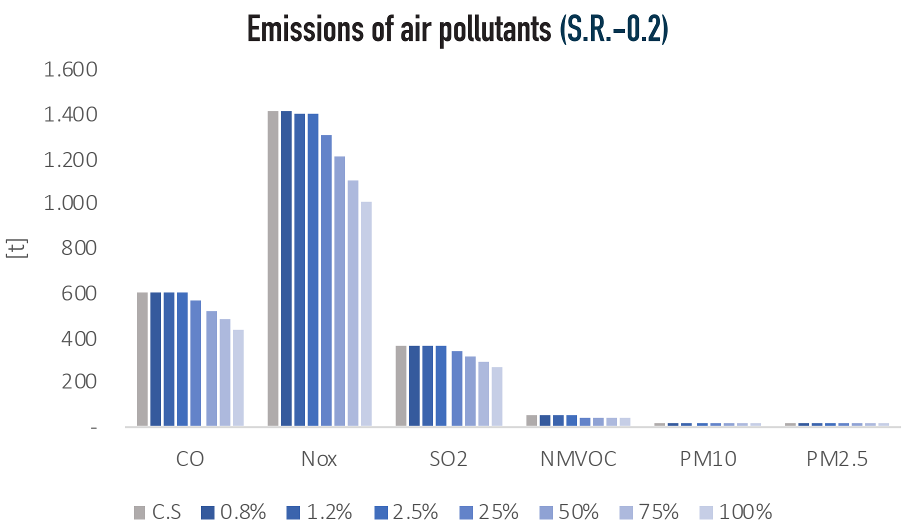
The result in this first scenario is negative, in fact, we have an increase in the emission of pollutants, especially for the pollutants CO, NMVOC, and PM. Especially regarding the PM 10 emissions, where with a renovation rate of 0.8%, there is an increase of 13,48%, which is equivalent a 13.24 [t]. The increase is huge with the renovation rate of 100% where there is an emission equal to 148,84 [t]. The reason for this result is because of the presence of biomass.

Indeed the biomasses are the ones that cause the most damage to pollution emission levels, especially as regards PM10, a topic that was considered by ENEA, which in 2017 drafted a report on the evaluation of fuels in residential heating [18], pointing out that the increase in pollution between 2000 and 2013 is due to the growth in biomass consumption for heating homes.

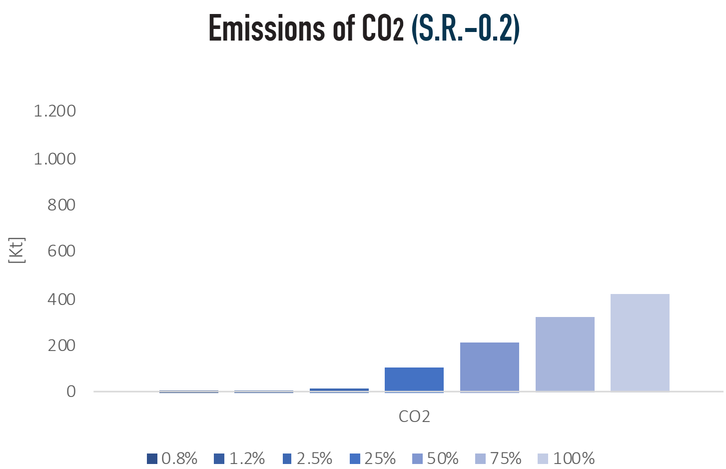
For this reason, even if there is only 10.68% of biomass boilers, they mean that there is a worsening in terms of emissions, instead to have an improvement.

We have created an alternative scenario (S.R.-0.2), without an intervention without Biomass.

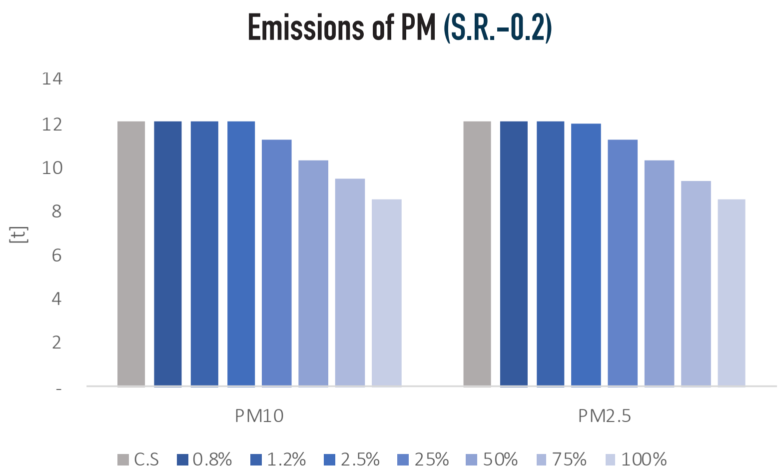
In this case, the intervention was installing the condensing boilers (65.73%) and heat pumps (34.27%).



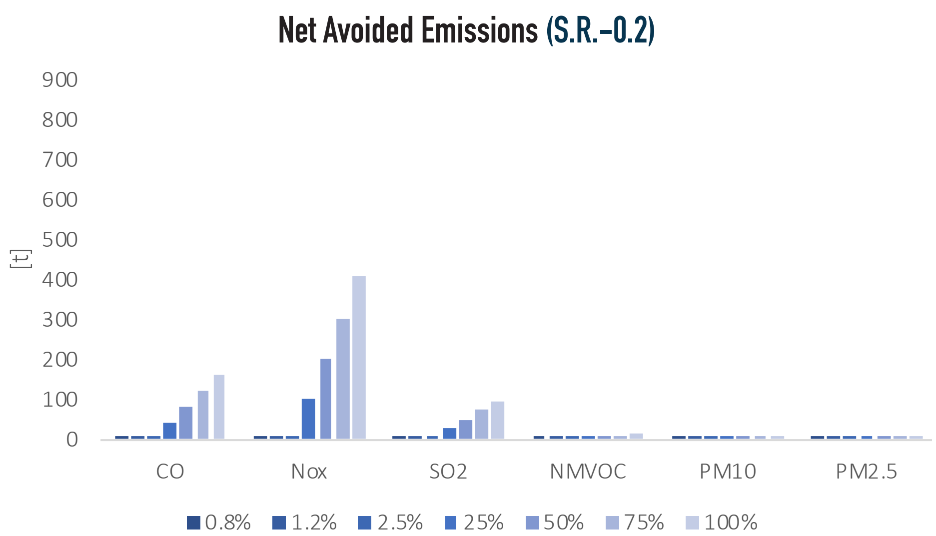
Graph 8. Representation of the total emissions in the S.R.-0.2 scenario, without the CO2 pollutant.



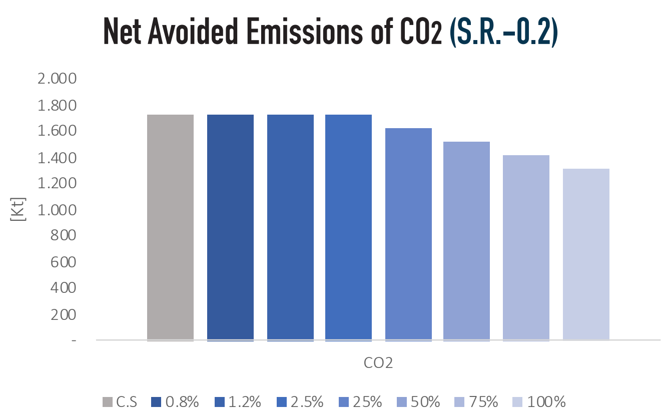
Graph 9. Representation of the total emissions of CO2 in the S.R.-0.2 scenario.



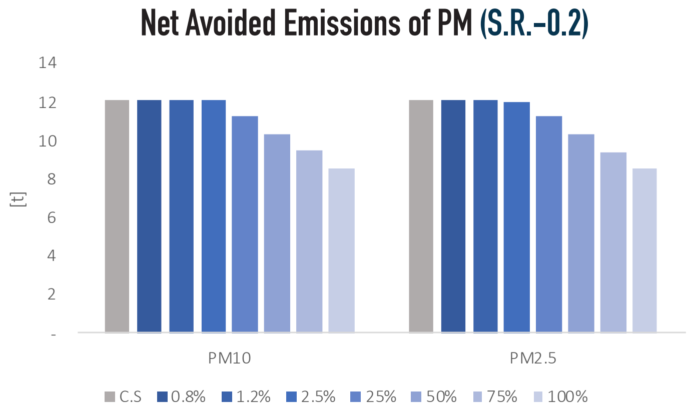
Graph 10. Representation of the total emissions of PM in the S.R.-0.2 scenario.



Graph 11. Representation of the Net Avoided Emissions in the S.R.-0.2 scenario, without the CO2 pollutant.



Graph 12. Representation of the Net Avoided Emissions of CO2 in the S.R.-0.2 scenario.



Graph 13. Representation of the Net Avoided Emissions of PM in the S.R.-0.1 scenario.

The results of this scenario show that by improving the efficiency system without the biomass energy source, there is a reduction in emissions.

We see a small reduction already in the renovation rate 0,8 where there is a decrease of 0,25% of the emission of PM10, 0,19% for the CO2. The percentage of reduction is higher for the NMOVC which has an emissions reduction equal to 0,33%.

Is visible a significant reduction of emission with the renovation rate of 100%. For the PM 10, which is uqually a 29,46% instead is not so strong the decrease of emissions for the CO2 pollutant which has only 7%.

4. 2. 3. 2. Complete Retrofit (CR)

The Complete Retrofit consists of intervention on improving the efficiency system and the envelope performance intervention. This type of intervention is based on a long-term perspective. This intervention is more difficult to apply because is quite an expensive intervention and it is necessary more time.

The approach we used is based on following the types of intervention presented by Tabula, which are two. One approach base on changed minimum efficiency system and change the envelope performance requirements, which we called “standard complete retrofit” (SCR) scenario. The other approach aims to create a nZeB building. In order to do this are used a hight technology performance and alternative sources, such as geothermal or solar energy, reducing the energy losses of the buildings, the scenario is “complete retrofit” (ACR) scenario.

The procedure for calculating the energy consumed and the emissions of pollutants is the same procedure that has been explained in the paragraph above (4.2.1 Definition Current situation) for the calculation of the current situation.

In other words, the required energy consumption is calculated based on the new Energy need (Q_{need}), and efficiency system ($\eta_{s,ys}$) data take, as we have already said, form tabula. This section can be seen as an extension of the tabula project, integrating not only energy improvement but also the possibility of the reduction of pollutants.

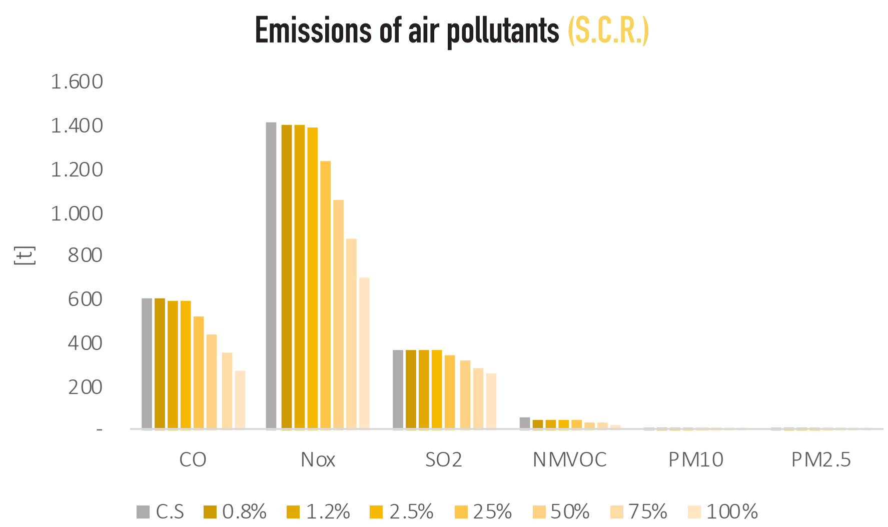
a. Standard Complete Retrofit (S.C.R.)

In the Standard Complete Retrofit (SCR) in present the district heating. District heating is not particular form of energy, but a compete system of production and distribution of heat, which can be generate by different energy sources. [19]

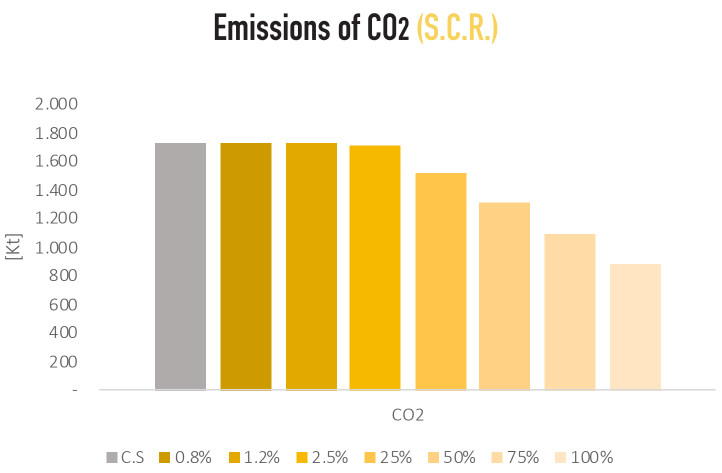
Study showed that thanks the district heating there is a reduction of greenhouse gas emission, and thanks the district heating, in 2010, Turin win the Award, KLIMAENERGY, an award which is based on the use of new technology, in a sustainable architecture, in energy saving and renewable energy in building sector. [20]

The district heating system in Turin is based on the use of natural gas as an energy source. [21], [22]

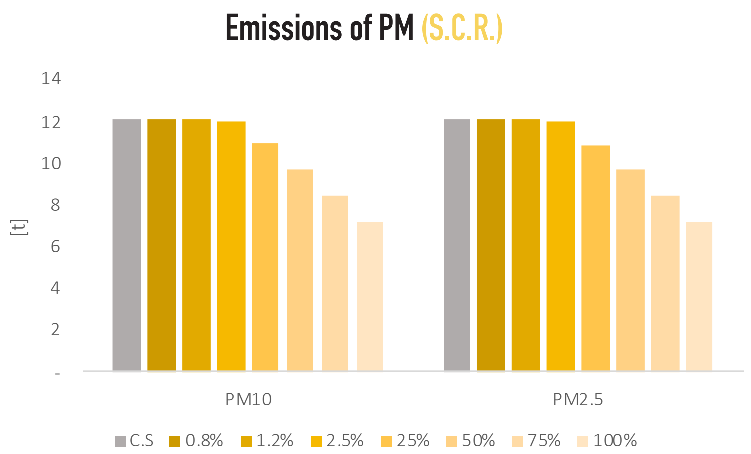
For this reason, the factor emission related to the district heating will be associated with the natural gas emission.



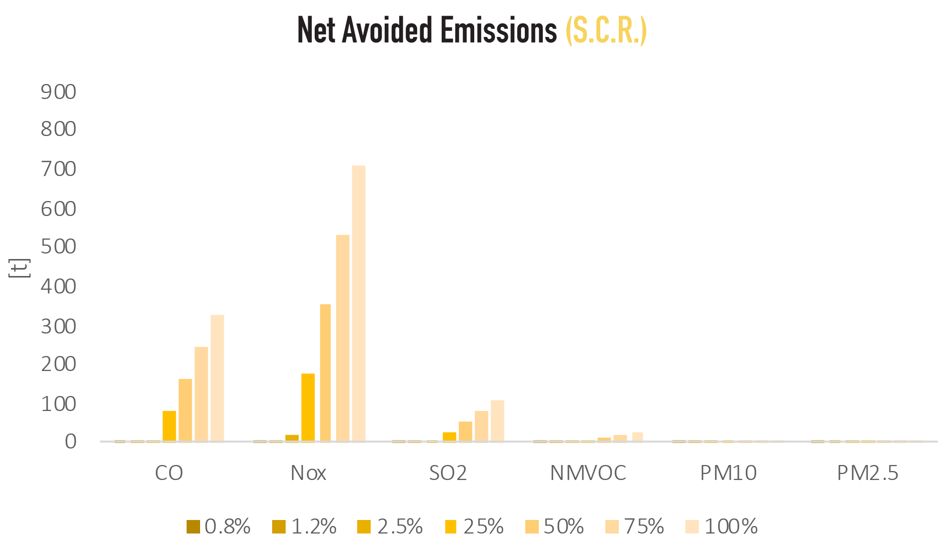
Graph 14. Representation of the total emissions in the S.C.R scenario, without the CO2 pollutant.



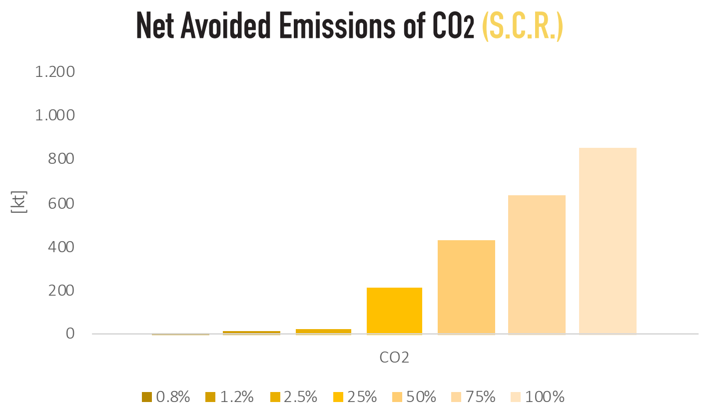
Graph 15. Representation of the total emissions of CO2 in the S.C.Rscenario.



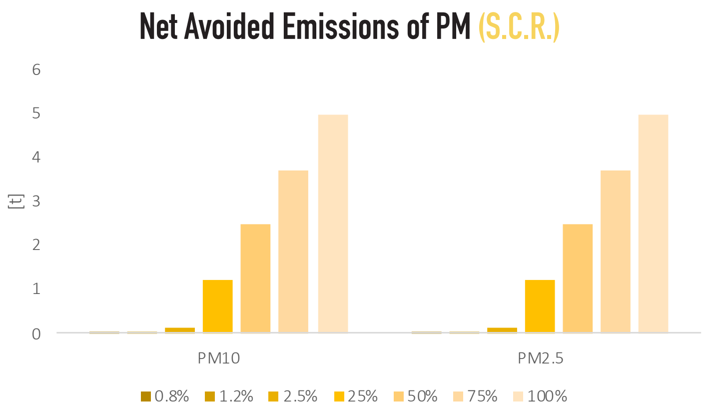
Graph 16. Representation of the total emissions of PM in the S.C.R. scenario.



Graph 17. Representation of the Net Avoided Emissions in the S.C.R. scenario, without the CO2 pollutant.



Graph 18. Representation of the Net Avoided Emissions of CO2 in the S.C.R. scenario.

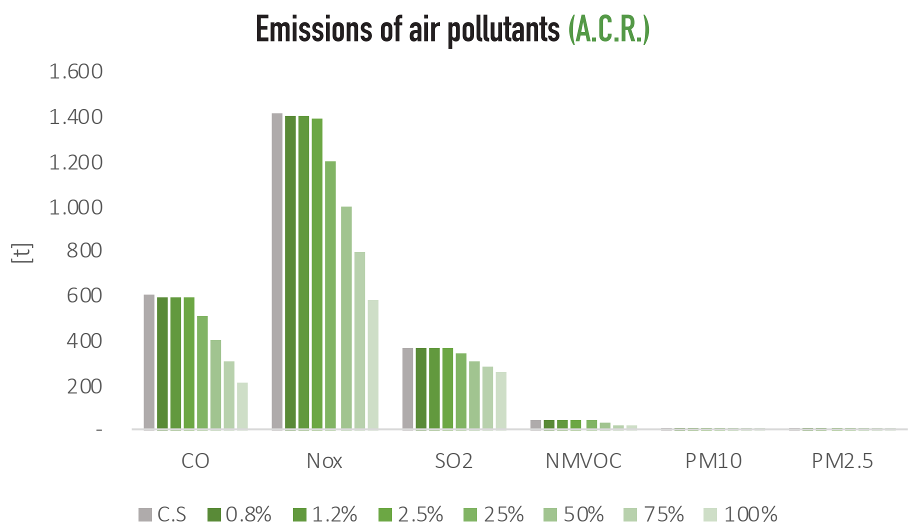


Graph 19. Representation of the Net Avoided Emissions of PM in the S.C.R. scenario.

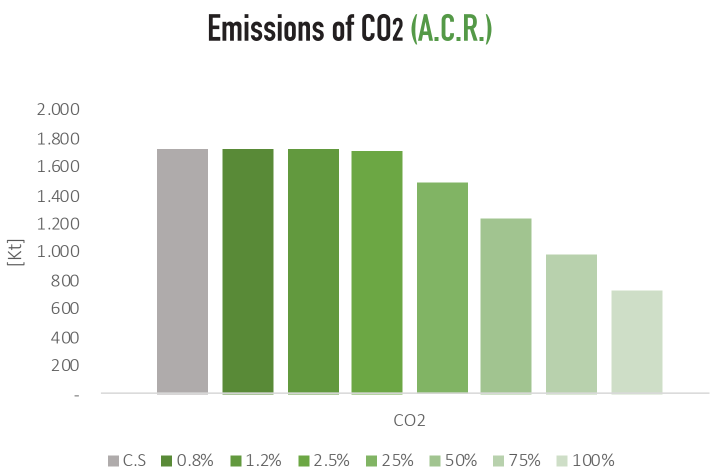
From this scenario emerge an important decrease in the emissions of pollutants. Therefore, it supports the thesis that intervening also in the envelope, increases the reduction of pollutants, in fact already at 50% of the renovation rate there is a reduction of pm10 emission equal to 20.5%. A nearly 50% reduction in CO_2 emissions by the 100% renovation rate.

b. Advanced Complete Retrofit (A.C.R.)

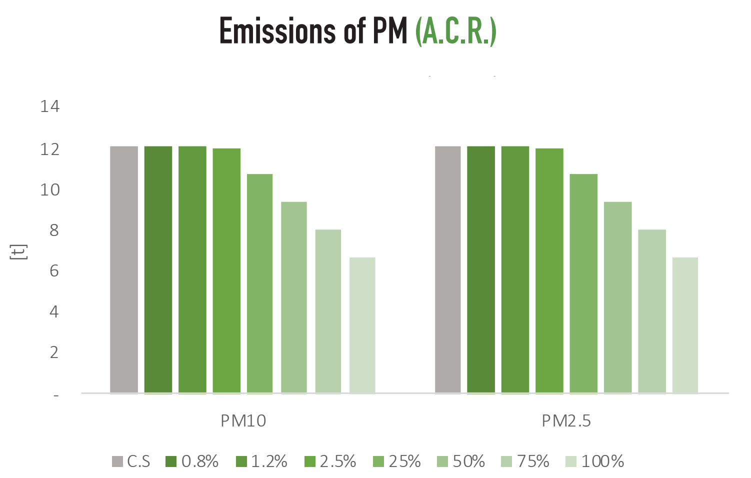
In this section, we will see the representation of the last scenario that we thought.
The ACR scenario is the most advanced because uses some renewable energy sources and technology more performances.



Graph 20. Representation of the total emissions in the A.C.R. scenario, without the CO2 pollutant.

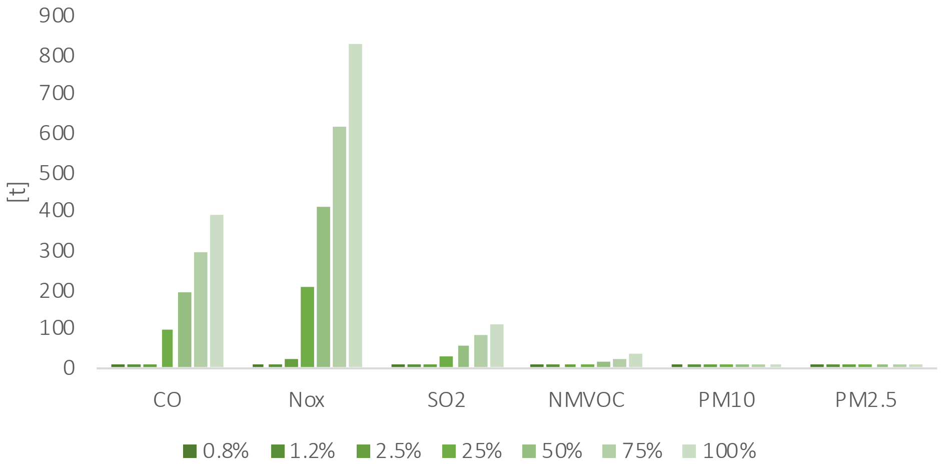


Graph 21. Representation of the total emissions of CO2 in the A.C.R. scenario.



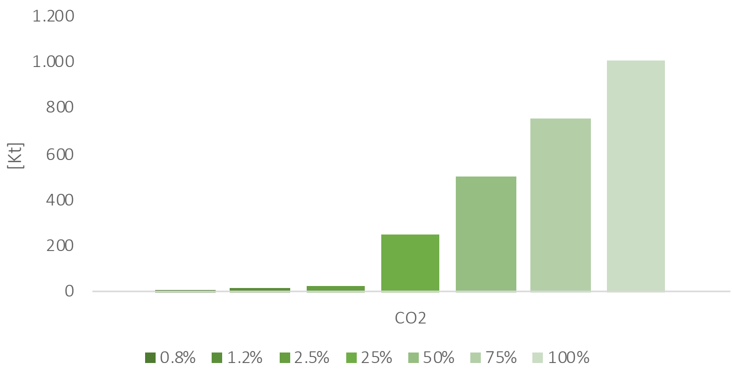
Graph 22.Representation of the total emissions of PM in the A.C.R. scenario.

Net Avoided Emissions (A.C.R.)



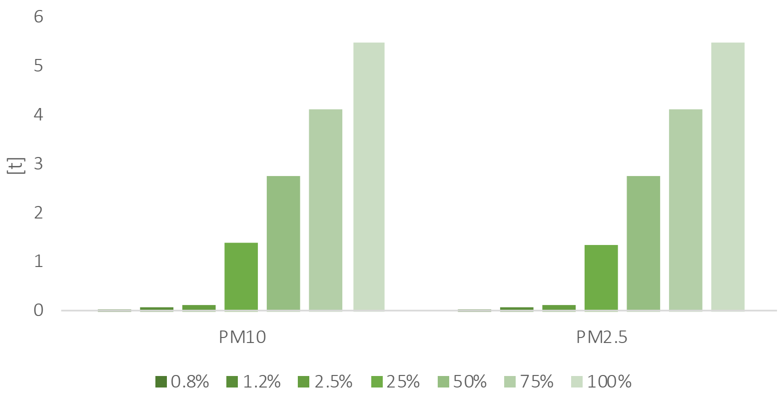
Graph 25. Representation of the Net Avoided Emissions in the A.C.R. scenario, without the CO2 pollutant.

Emissions of CO2 (A.C.R.)



Graph 26. Representation of the total emissions of CO2 in the A.C.R. scenario.

Emissions of PM (A.C.R.)



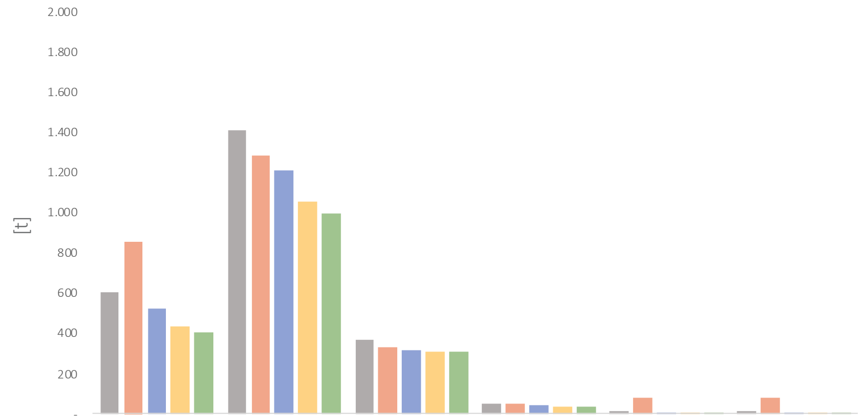
Graph 27. Representation of the total emissions of PM in the A.C.R. scenario.

As expected, the advanced scenario (A.C.R.) is the best scenario compared to the others, so much so that in the last renovation rate (100%) the CO_2 emission is halved, precisely a 58% reduction. This improvement can also visible for the other pollutants. Where there is a 65% CO reduction of 58% for NOx , 30% for SO_2, 64% for NMVOC, and a 45% reduction for PM.

For analyzing better the emissions in the different scenarios we took in consideration the most significant value which are 50% and the 100% renovations rates.

4. 2. 3. 3. Focus in the Renovation rate 50% and Renotation rate 100%

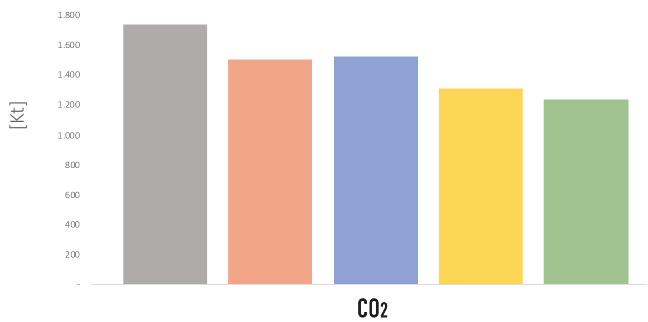
Emissions of air pollutants (50% renovation rate)



	CO [t]	NOX [t]	SO2 [t]	NMVOC [t]	PM 10 [t]	PM 2.5 [t]
C.S.	601,75	1.412,02	366,35	49,39	12,15	12,13
S.R.-0.1	859,11	1.281,04	329,56	53,88	80,49	80,47
S.R.-0.2	520,07	1.209,31	317,89	43,27	10,36	10,33
S.C.R.	437,97	1.057,17	312,94	36,18	9,67	9,65
A.C.R.	407,42	999,65	311,83	33,61	9,40	9,39

Graph 28. Representation of the total emissions in all the scenarios by the 50% renovation rate, without the CO2 pollutant.

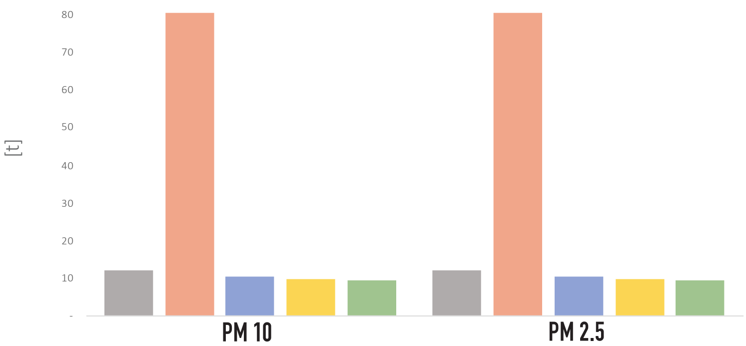
Emissions of CO2 (50% renovation rate)



	CO2 [t]
C.S.	1.734,69
S.R.-0.1	1.499,03
S.R.-0.2	1.525,03
S.C.R.	1.308,61
A.C.R.	1.231,95

Graph 29. Representation of the total emissions of CO2 in all the scenarios by the 50% renovation rate.

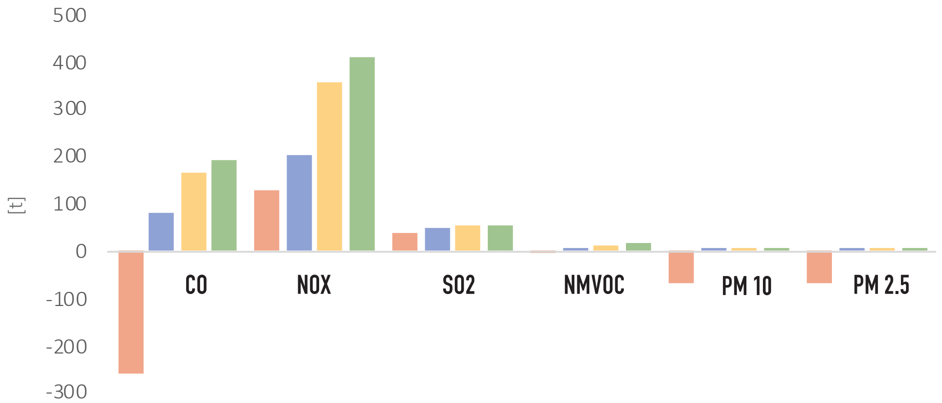
Emissions of PM (50% renovation rate)



	PM 10 [t]	PM 2.5 [t]
C.S.	12,15	12,13
S.R.-0.1	80,49	80,47
S.R.-0.2	10,36	10,33
S.C.R.	9,67	9,65
A.C.R.	9,40	9,39

Graph 30.Representation of the total emissions of PM in all the scenarios by the 50% renovation rate.

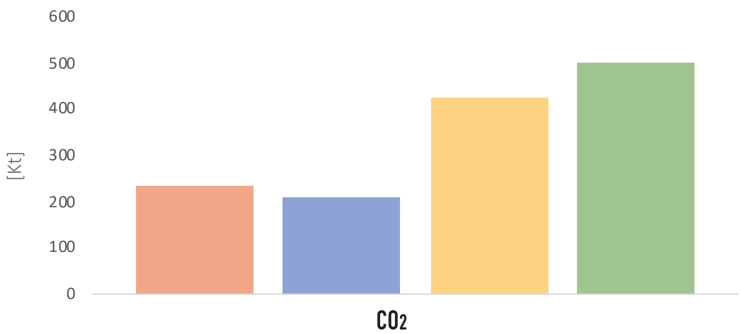
Net Avoided Emissions (50% renovation rate)



	CO [t]	NOX [t]	SO2 [t]	NMVOC [t]	PM 10 [t]	PM 2.5 [t]
S.R.-0.1	-257,36	130,98	36,80	-4,49	-68,35	-68,32
S.R.-0.2	81,68	202,70	48,46	6,12	1,79	1,80
S.C.R.	163,79	354,84	53,41	13,20	2,47	2,47
A.C.R.	194,34	412,37	54,52	15,78	2,74	2,74

Graph 31. Representation of the Net Avoided Emissions in all the scenarios by the 50% renovation rate, without the CO2 pollutant.

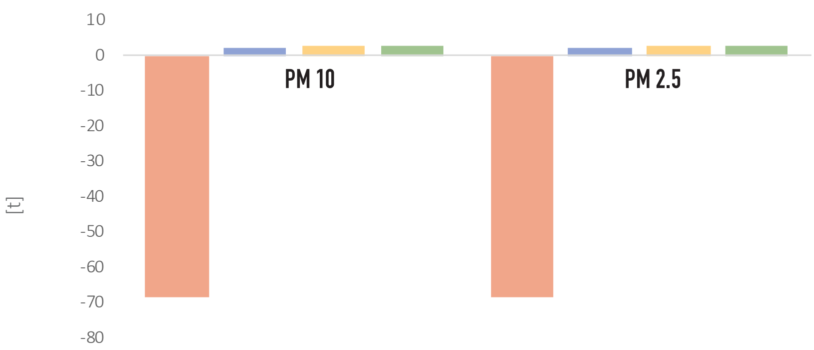
Emissions of CO2 (50% renovation rate)



	CO2 [t]
S.R.-0.1	235,66
S.R.-0.2	209,66
S.C.R.	426,08
A.C.R.	502,74

Graph 32. Representation of the Net Avoided Emissions of CO2 in all the scenarios by the 50% renovation rate.

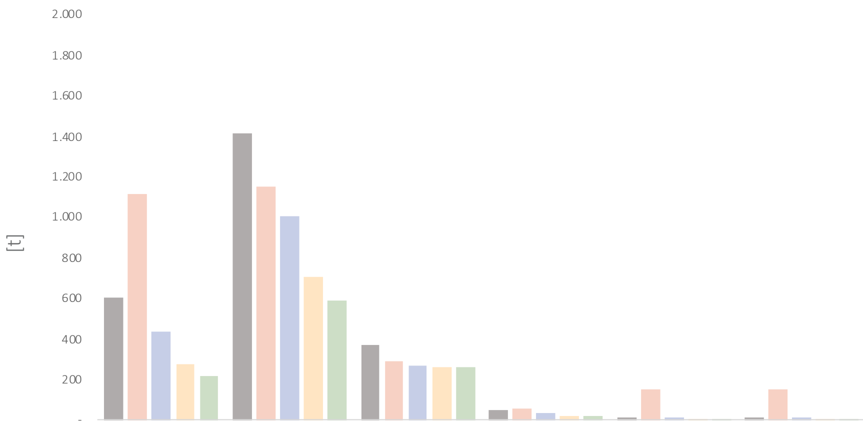
Emissions of PM (50% renovation rate)



	PM 10 [t]	PM 2.5 [t]
S.R.-0.1	-68,35	-68,32
S.R.-0.2	1,79	1,80
S.C.R.	2,47	2,47
A.C.R.	2,74	2,74

Graph 33. Representation of the Net Avoided Emissions of PM in all the scenarios by the 50% renovation rate.

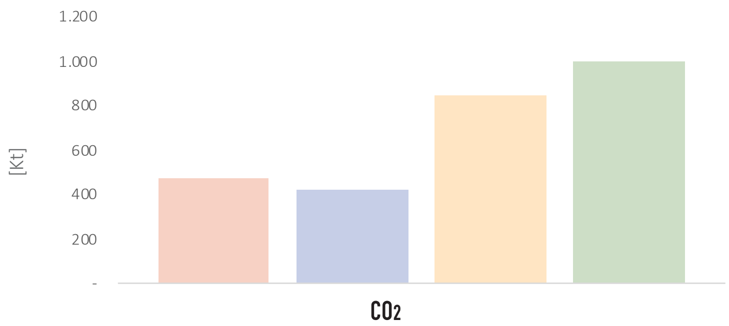
Emissions of air pollutants (100% renovation rate)



	CO [t]	NOX [t]	SO2 [t]	NMVOC [t]	PM 10 [t]	PM 2.5 [t]
C.S.	601,75	1.412,02	366,35	49,39	12,15	12,13
S.R.-0.1	1.116,46	1.150,06	292,99	58,43	148,84	148,80
S.R.-0.2	438,39	1.006,61	269,66	37,22	8,57	8,53
S.C.R.	274,18	702,33	259,53	22,98	7,20	7,18
A.C.R.	213,08	587,28	257,31	17,84	6,66	6,65

Graph 34. Representation of the total emissions in all the scenarios by the 100% renovation rate, without the CO2 pollutant.

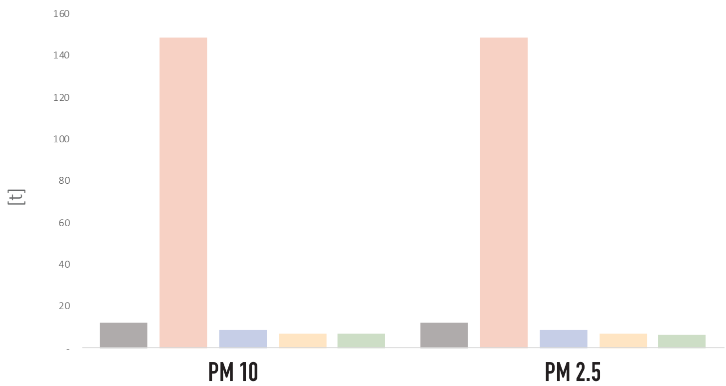
Emissions of CO_2 (100% renovation rate)



	CO_2 [t]
C.S.	1.734,69
S.R.-0.1	1.263,37
S.R.-0.2	1.315,37
S.C.R.	882,53
A.C.R.	729,21

Graph 35. Representation of the total emissions of CO2 in all the scenarios by the 100% renovation rate.

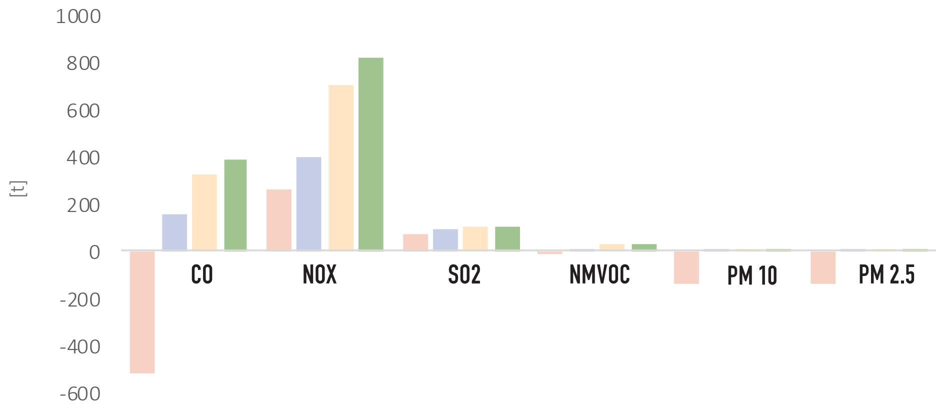
Emissions of PM (100% renovation rate)



	PM 10 [t]	PM 2.5 [t]
C.S.	12,15	12,13
S.R.-0.1	148,84	148,80
S.R.-0.2	8,57	8,53
S.C.R.	7,20	7,18
A.C.R.	6,66	6,65

Graph 36. Representation of the total emissions of PM in all the scenarios by the 100% renovation rate.

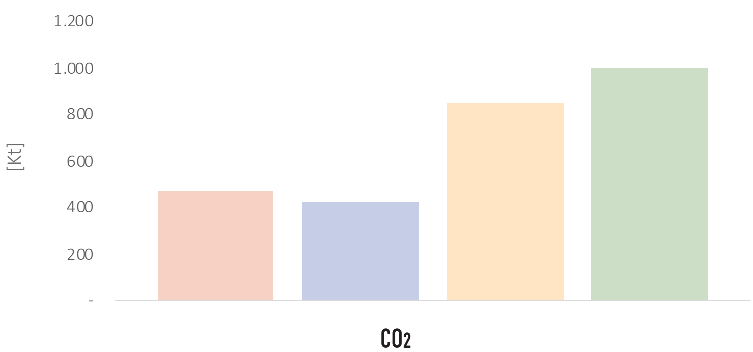
Net Avoided Emissions (100% renovation rate)



	CO [t]	NOX [t]	SO2 [t]	NMVOC [t]	PM 10 [t]	PM 2.5 [t]
S.R.-0.1	-514,71	261,95	73,37	-9,04	-136,69	-136,67
S.R.-0.2	163,36	405,40	96,70	12,17	3,58	3,60
S.C.R.	327,57	709,68	106,83	26,41	4,95	4,95
A.C.R.	388,67	824,74	109,04	31,55	5,48	5,48

Graph 37. Representation of the Net Avoided Emissions in all the scenarios by the 100% renovation rate, without the CO2 pollutant.

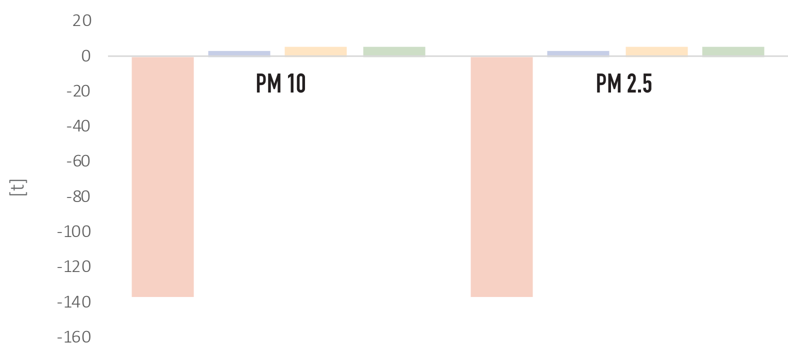
Emissions of CO2 (100% renovation rate)



	CO2 [t]
S.R.-0.1	471,32
S.R.-0.2	419,32
S.C.R.	852,16
A.C.R.	1.005,49

Graph 39. Representation of the Net Avoided Emissions of CO2 in all the scenarios by the 100% renovation rate.

Emissions of PM (100% renovation rate)



	PM 10 [t]	PM 2.5 [t]
S.R.-0.1	-136,69	-136,67
S.R.-0.2	3,58	3,60
S.C.R.	4,95	4,95
A.C.R.	5,48	5,48

Graph 40. Representation of the Net Avoided Emissions of PM in all the scenarios by the 100% renovation rate.

From this analysis, we can see that the first scenario S.R.-0.1 is the only that it has a negative effect, in fact there is an increase of emissions instead of a reduction. In the scenario with the 50% renovation rate, there is a significant reduction in emissions, especially in the last advance scenario (A.C.R.) which has a 23% reduction in PM emission compared to the second scenario SR.0.2- which has a reduction of 15%.
This analysis also shows that the 100% renovation rate is the best scenario, there is a significant reduction, despite not actually being renovated all the residential building sector.

4. 2. 3. 4. Discussion/Remark

In conclusion, these data show that, starting from the first System Retrofit Scenario (S.R.-0.1), where we intervened on the heating system, using the minimum efficiency requirements (by law), and we replacing the generators with a condensing boiler, biomass boiler, and heat pump, data took from the last report of 2019 on "energy efficiency".
There was a negative effect instead of an improvement. Indeed, with the 0.8% renovation rate there is an increase in emissions of pollutants, in particular CO, NMVOC, and PM. The PM has the highest emission per year which is 9%.

Starting from these first results, we decide to change the scenario by evaluating to remove the biomass as an energy source, in the prevision to have positive results.
Indeed, by making this change there is an improvement even with the 0,8% renovation rate which has created a reduction of emissions per year of 0.25% (average) for all pollutants (CO2, CO, NOx, SO2, NMVOC, PM10, PM2.5).
Data that starting to be significant with the 50% renovation rate, where there is an average reduction of 13% in pollution emissions per year.

As was to be expected, also intervening on the construction types, building envelope, with the most widespread technologies, using the minimum required energy performance (S.C.R. scenario), there is an average reduction of 23% emissions for all the pollutants, with a 50% renovation rate.
Intervening on all the buildings, 75%, because we have considered (period of intervention between 1946 and before 2005 of the residential building stock), we get almost half of the reduction of emissions, specifically 45.43% emissions per year.

These data are improved by using, from the point of view of the building envelope, thermal transmittance values that reflect the performance of a nearly zero energy building (NZEB project). Also, for the heating system, there were used values from the NZEB projects, in fact, as reported on the project Tabula, the heat pump (air and geothermal) is used for- most of the cases. With this type of intervention, there are significant reductions already with the 50% renovation rate, where the total emissions of all pollutants are reduced by 26% and intervening on the entire building stock there is a total reduction of 52.14% emissions per year.

The final result is generally positive, especially regard the data, because we use the values based on 2013 (tabula) and with the minimum requirements by law.
Anyway, it pushes us to increase the research field, especially based on the first scenario (S.R.-0.1) data, where the use of common technologies and efficiencies with minimum requirements, it has led to negative results. Therefore, a study based on the use of new technologies with greater efficiency could lead us to have positive results.

PART
FIVE

5.0. HEALTH & ECONOMY

5.0. HEALTH & ECONOMY

This chapter aims to show which are the effect of the pollutant on the people heath, in particular regard the particulate matters PM10, and to monetize the impact of the pollutant by using the different economic approaches.

In particular this chapter, as the previous chapter "energy and emissions", will be dived in two-part, the first part, is dedicated to the methodology, and the second part is dedicate to the application.

Specifically, the first part, as we have already said, describes the methodology which is basically dived in two mains areas, the first is dedicated to quantifying the disease which is associated with the concentration of PM10 emitted by the heating system. The diseases associated to the pollutant are on the cardiovascular and respiratory systems. The other main area of the methodologies is dedicated to monetizing a good the is not present on the market, in order to understand the weight of the social-economic impact of disease caused by pollutants. The methods which will be used are the Human Capital Approach (HCA) and Willingness to Pay (WTP).

Instead, the second part of the chapter is dedicated to the application of these methods, in particular on the population of the city of Turin.

5. 1. METHODOLOGY

In the following paragraph, we decided to illustrate which is the methodology used, and the main steps to quantify and monetization the effect of the air pollutants in the city of Turin (representing by the scheme below, figure 1).

Basically, the methodology is divided in two mains areas the first called "health", which is dedicated to explain where we found the "epidemiologic data", which are the relative risk (R.R.).

The second area, called "economy", is dedicated to the explanation of the two economic methods which we chose by the literature review explained in the chapter three, "socio-economic evaluation", which it is based on the different economic methods used for the calculation of the goods that are not present on the market, as the quality of the air.

The methods that we choose are, the Willingness to pay (WTP) and the Human Capital Approach (HCA), where together compose the Cost of Illness (C.O.I.).

We choose to use two approaches, in order to have a comparison of the two different approaches and to have a complete overview.

MAIN STEPS of the METHODOLOGY

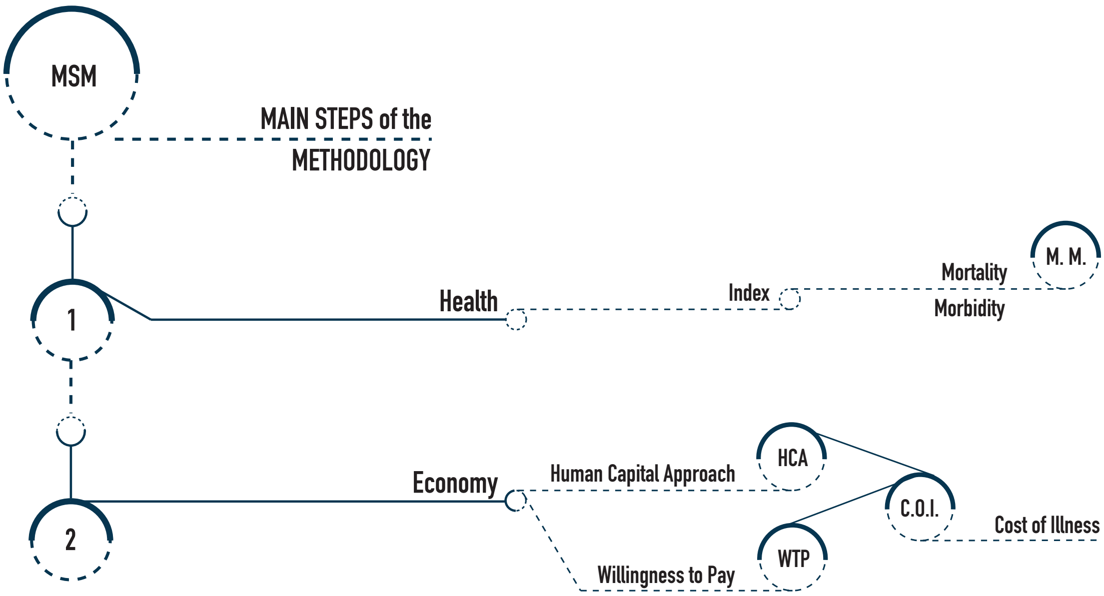


Fig. 1. This scheme represents the main steps of the Methodology.

5. 1.1. HEALTH Mortality & Morbidity

This section is dedicated to show where we found the data to quantify the diseases caused by the pollutant PM10.

From the epidemiologic literature review, we know that the pollutant PM10 hits the respiratory and cardiovascular system.

Thanks to the bibliography review was possible to quantify the morbidity and the mortality caused by the pollutants. Indeed, the epidemiological studies using the risk-based analysis, where the damage created by the presence of pollutants depends on the intensity of the phenomenon (dose/response approach), which is able to express the static relationship between the concentration of pollutants and the occurrence of a damage to health.

Thank the risk factors (RR), which is associate with the cardiovascular and respiratory diseases caused by PM10, it was possible to quantify the number of diseases and death on the population of Turin.

In the following table, we report, in a synthetic way, the bibliography reference associate to the relative risk that we will use on the application of our case study.

TABLE RELATIVE RISK (RR)

BIBLIOGRAPHY	HEALTH OUTCOMES	MEASURES (CI95%) [event/year]
	CHRONIC MORTALITY:	**RR for PM2.5 / PM10**
POPE et al. (2002)[1]	All(excluding accidents)	• 1.06 (1.02-1.11)
POPE et al. (2002)	Lung cancer	• 1.08 (1.03-1.16)
	ACUTE MORTALITY:	
Anderson et al. (2004)[2]	All (excluding accidents)	• 1.006 (1.004 -1.008)
Anderson et al. (2004)	cardiovascular causese	• 1.009 (1.005 - 1.013)
Anderson et al. (2004)	respiratory causese	• 1.013 (1.005 - 1.020)
Biggeri, Bellini & Terracini (2004)[3]	Hospital admissions for cardiac diseases	• 1.003 (1.000 -1.006)
Biggeri, Bellini & Terracini (2004)	Hospital admissions for respiratory diseases	• 1.006 (1.002 - 1.011)
	MORBIDITY:	
Anderson et al. (2004)	WLDs	• Turin specific impact functions (WLDs 4, per year per person 15-64)

Table 1. Summary of the literature reference about RR (CI 95%) by the PM10

In paragraph 5.2. , Application to the Population of Turin, we will see the application of this table, and so the association of the risk factor to the city of Turin data. The values regard the population of the city of Turin were taken from data ISTAT. [4]

5. 1.2. ECONOMY

This section is dedicating to the explanation of the two different approaches that we will use in our case study.

As follows, we will see, the two methods the human capital approach (H.C.A.) and the willingness to pay (W.T.P.) which compose the cost of illness (COI) that we used to estimate the cost of disease caused by the PM10 pollutant.

The COI is based on three types of cost, which are the direct cost, as the cost of hospitalization, or medical visit, the indirect cost, which is the loss of the working day, so the loss of money caused by the illness, calculated by the H.C.A. and the intangible cost that is related to the individual cost, like the pain of illness or the pain caused by the loss of people by the illness, calculated by the W.T.P..

The paragraph is dedicated to the explanation about where we took the data, to calculate the costs of the Human capital approach and the willingness to pay, which we will apply to the Turin Metropolitan.

5. 1.2.1. Human Capital Approach (H.C.A.)

As we have already said the methods that we used for the calculation of the economic impact by the emissions of pollutants are the Human capital approach and the Willingness to Pay.

The HCA takes in consideration the direct cost and the indirect cost.

DIRECT COSTS

The direct cost is given by the sum of the hospitalization cost and the costs of the medications (which are included as well the cost of medical visitation), for the respiratory and cardiovascular system. The costs of hospitalization were taken from the "Preziario della regione Piemonte di ospedalizzazione, 2018 "[5]. In this document, are present two columns, one where are the cost relates a just one day, and the other column related to more days. In order to have a more complete framework regarding the costs, we decided to take the second column.

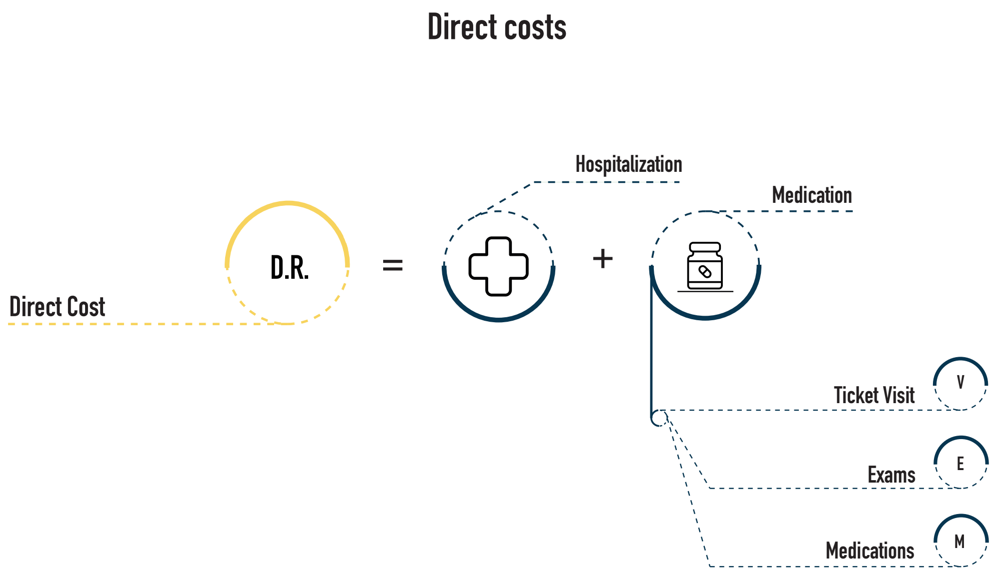


Fig. 2. Representation scheme about elements which composes the Direct Cost.

The hospitalization price is given by the average of the various hospitalizations that are carried out, for the respiratory and cardiovascular system.

Direct costs

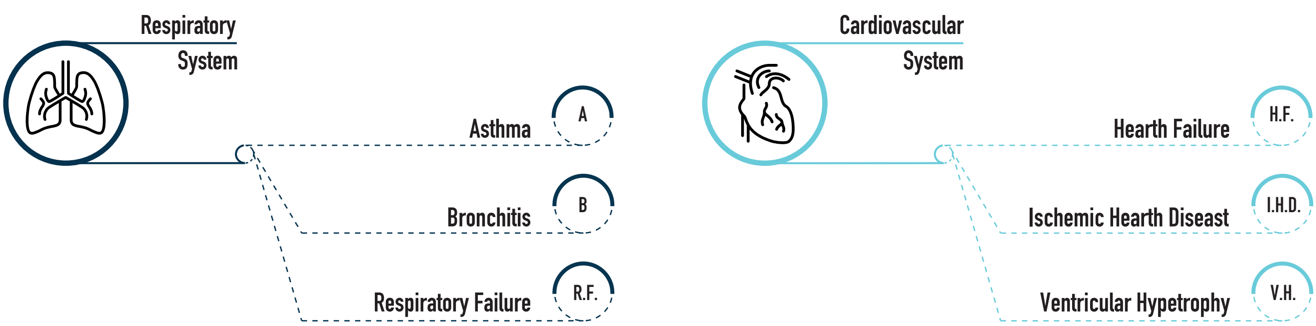


Fig. 3. Representation scheme about the principal disease for the respiratory system and the cardiovascular system.

Above there is a scheme that represents the main disease for the respiratory and cardiovascular system that we took in consideration. The types of the disease which we took in consideration, arrived by the literature review. We must emphasize that people are more prone to contract respiratory diseases instead of cardiovascular diseases.[6]

As follow, there are two tables where are reported the cost of hospitalization that we took in consideration, for the respiratory and cardiovascular system. The value is given by the average of the cost for the different diseases that we took in consideration.[5]

Hospitalization

Price Hospitalization of Respiratory System.

DESCRIPTION DRG	PRIZE (euro)
• Infezioni e infiammazioni respiratorie	4.009
• Infezioni e infiammazioni respiratorie	5.744
• Infezioni e infiammazioni respiratorie, età > 17 anni senza CC	4.422
• Infezioni e infiammazioni respiratorie	5.768
• Edema polmonare e insufficienza respiratoria	3.802
• Altre diagnosi relative all’apparato respiratorio con CC	2.666

• Bronchite e asma, età > 17 anni con	2.537
• Bronchite e asma, età > 17 anCCni senza CC	1.832
• Bronchite e asma, età < 18 anni	1.538
• Segni e sintomi respiratori con CC	2.782
• Segni e sintomi respiratori senza CC	1.484
• Altre diagnosi relative all'apparato respiratorio con CC	1.724
AVERAGE	**3.192**

Table 2. Cost of hospitalization of respiratory system. Sources, "Prezzario della regione Piemonte di ospedalizzazione 2018"

Price Hospitalization of Cardiovascular System.

DESCRIPTION DRG	PRIZE (euro)
• Interventi maggiori sul sistema cardiovascolare con CC	14.208
• Interventi maggiori sul sistema cardiovascolare senza CC	10.500
• Malattie cardiovascolari con infarto miocardico acuto e complicanze maggiori, dimessi vivi	4.700
• Malattie cardiovascolari con infarto miocardico acuto senza complicanze maggiori, dimessi vivi	3.377
• Malattie cardiovascolari con infarto miocardico acuto, morti	4.018
• Malattie cardiovascolari eccetto infarto miocardico acuto, con cateterismo cardiaco e diagnosi complicata	3.392
• Malattie cardiovascolari eccetto infarto miocardico acuto, con cateterismo cardiaco e diagnosi non complicata	2.142
• Arresto cardiaco senza causa apparente	4.00
• Malattie vascolari periferiche con CC	3.308
• Malattie vascolari periferiche senza CC	1.090
• Altri interventi cardiotoracici	16.419
AVERAGE	**6.964**

Table 3. Cost of hospitalization of cardiovascular system. Sources, "Prezzario della regione Piemonte di ospedalizzazione 2018"

The other costs which we took in account are the costs of the medication (pharmacology), as well in this case related to the cost for the respiratory and cardiovascular system. For achieving the value, we used the dataset, “Agenzia Italiana del Farmaco”[7] as sources. In this way was possible to find the main drugs used, and so to add to the direct cost.

Medication costs, as expressed in the previous scheme, are given by the sum of three main factors, the costs of the visit, the examinations, and the medications that are used to heal. Obviously, the final value that is reported is an average, since the drugs are different and change according to the severity of the disease.

Medication

Price of Medications of Respiratory System.

	Medications	Euro
B Bronchitis	• Amoxicillina	7,52
	• Azitromicina	6,72
	• Moxifloxacina	10,61
	• Limeciclina	12,13
A Asthma	• Salbutamolo	27,05
	• Ropinirolo	16,55
	• Formoterolo	11,54
R.I. Respiratory Insufficiencies	• Biperidene	5,33
	• Ipratropio	5,90
	• Glicopirrolato	8,46
	• Ossibutinina	821,58

Table 4.Price of medications for the respiratory system. Sources, “Agenzia Italian del Farmaco”

TOTAL Price of Medications.

		TOT. (Euro)
T.V. Ticket Visit	36,15 €	
E Exams	15,50 €	
M Medications	238,19 €	289,84

For respiratory diseases, the visit that is carried out is not a general visit, but it is a special visit, and the maximum ticket price that the patient can pay is 36.15 euros.[8] The exam that is prescribed is a chest X-ray, which costs 15.50 euros through the ASL.

Medication

Price of Medications of Cardiovascular System.

	Medications	Euro
H.F. Hearth Failure	Nebivololo	9,01
	Moxonidina	10,16
	Fosinopril	6,23
	Potassio Canrenoato	4,33
	Telmisartan	7,22
	Tandolapri	4,54
V.H. Ventricular Hypetrophy	Olmesartan medoximil	7,73
	Diltiazem	8,35
	Verapamil	5,18
I.H.D. Ischemic Heart diseast	ASA	4,23
	Ticlopidina	3,47
	Clopidogrel	14,11

Table 5. Price of medications for the cardiovascur system. Sources, "Agenzia Italian del Farmaco"

For cardiovascular disease, the cost of the assessment visit is 22.70 euros, (Preziairio esami speciali regione Piemonte 2020) [8]. Instead, the visits that are prescribed are different according to the disease.

Price of Visits.

		Euro
H.F. Hearth Failure; I.H.D. Ischemic Heart diseast	ECG	80,8
	Chest X-ray	15,5

Medication

V.H. Ventricular Hypetrophy

• ECG	80,8
• Chest X-ray	15,5
• Magnetic Resonance	71,80

Table 6. Price of visiti for the cardiovascular system. Sources, "Prezzario della regione Piemonte di ospedalizzazione 2018"

TOTAL Price of Medications.

T.V.	Ticket Visit	22,70 €
E	Exams	181,95€
M	Medications	55,85 €

TOT. (Euro)
260,50

INDIRECT COSTS

For the indirect cost, which is related to the lost day of productivity (WLD), the value was taken from the average value of employee annual salary, by Istat Data [4], this value was dived for the number of the productivity day in one year, in this way was possible to achieve the value of the one-day worker.

Normally in the bibliography, this value has already estimated, but we decide to don't take into consideration this value. The reason for this choice is because in this way it was possible to have the value that is related to our specific case study, instead to have a value that is approximate and more general.

The number of the working day in one year is given by total days in one year, work (253) less the 35, average holiday days by employees.

DATA :

Annual salary of employee = **28.500 (euro)**

Number of working day in one year = **218 (days in 2019)**

Value of one working day = **130,73 (euro)**

5. 1.2.2. Willingness to pay (W.T.P.)

The other methods that we took in account, and so to have all the costs that are part of the cost of illness is the Willingness to pay (W.T.P).

Thank to this approach it was possible to have the intangible cost, and so to don't have just the social cost, but also the individual cost, as we will see have a strong influence on the total cost.

The reason that we took this value as well, it was because we want to follow the idea of the economics of welfare, which is based on the welfare of the people, so the individual cost.

In the majority of the case, the WTP is based on the approach of "Stated preferences" (SP), in which "the market for a good is being constructed through the use of questionnaires" [9].

For this project, we have been chosen the bibliography reference value, because the WTP method requires time, from the creation of the questionnaire to the studies of data.

The value that we took in consideration is associated with the cost of one year of life lost (YLL) due to pollution, PM10.

We took for the value of YLL by the European Project, clean Air For Europe CAFÉ [10], this project is based on ExternE [11], an acronym of "external Cost of Energy". The ExternE methodology is an approach to calculating environmental external costs.

As follow we report the formula to evaluate the value of the YLL (years Lost Life) which is:

$$YLL_x = E_x * e_x$$

Equation 1

Where:

E_x **=** are the deaths attributable to exposure to PM by age class x and sex

e_x = are the life expectancies.

From the statistic point of view, especially in the value statistic life, (VSL) the VOLY (value of Life years) it allows an economic quantification of the risk of early death.

From the statistic point of view, especially in the value statistic life, (VSL) the VOLY (value of Life years) it allows an economic quantification of the risk of early death.

There is a main difference between the VSL and the VOLY, in fact, the VSL gives the value

of life as an economic value used to quantify the benefit of avoiding a fatality. An example could be the case of the airbags, where it was used this method to demonstrate that the absence of the airbags increased the number of deaths.
VSL, as the ExternE team argues, is not very suitable for assessing mortality from pollution, as in this case we are dealing with a risk that has a significant latency period before impact and where the probability of survival is normally altered only after a prolonged period of exposure.
The method of the VOLLY was introduced in the bibliography since 1999, by ExternE to calculate the reduction of life expectancy, caused by the pollutions, in fact, the VOLLY is referred at value of the years lost (YLL).
The main reference in calculating the value of a lost year of life is always the assumption VSL, however, that the latter represents the discounted value of the future years of life considered taking into account the probability of survival of the subjects.
VSL is understood as the present and the discounted value of future life years.

According to the ExternE method (1999)[11], the value of one year of life lost VLYL (Value of Life Years Lost) in the estimates referred to chronic mortality is expressed by the following formula which takes into account both the latency period between an increase in the pollution rate and the consequent increase in the mortality rate specified based on the age of the population and in the discount rate for future years.

$$\text{VLYL chronic} = \sum_{i=1}^{T} \frac{YOLL_i}{YOLL_{tot}} \cdot \frac{YLYLr}{(1+r)^{i-1}}$$

Equation 2

Where:

YOLLi / YOLLtot indicates the ratio between the years lost due to an increased risk of death in the year i and the years lost by the total population. In this way, it is possible to give a value of mortality over the years according to the latency period that is assumed.

Doing a bibliographic research, it emerged that there are no VOLLY values associated to the emission of pollutants by the heating system, but we found values that are associated with the pollution created by traffic.
For this reason, we used the benefit -transfer valuation technique [12].
This technique is used to estimate economic values by transferring the goods information from studies already completed in another location and/or context.

SOCIAL DISCOUNT RATE

Before to give the references value regards years of life, is important give an explanation to the discounted value of a lost year of life, depends on the discount rate to be applied as an expression of the different social inter-temporal preference. The hypothesis underlying the discount rate is the different assessments assigned to benefits and costs distributed over time. Normally the discount rate implies a greater appreciation of an immediate benefit compared to a benefit extended over time. There are different hypotheses underlying this assumption:

- The **social rate of time preference**; (**z**) also called the "impatience rate", which tries to give a measure of whether consumption is now preferred to consumption in the future due to limited life expectancy. In other words,is based on the idea of better today than tomorrow.
  The social rate of time preference takes in account the rate at which social well-being or the utility of consumption decreases over time. This depends on the individual preference rate. The social rate of time preference also depends on how fast consumption grows (**g**) and how quickly utility decreases as consumption increases (**n**).
- The **opportunity cost of capital** is instead obtained by looking at the rate of return on the best investment with a similar risk that was not carried out due to the particular project that was undertaken(based on references to other projects).

ExternE (1999) estimates the value of the VLYL assuming thre discount rates: 0%, 3%, 10%.

However, in the case of the evaluation of human life, the application of a discount rate equal to 0. It's considered more reasonable, since normally a subject hardly places intertemporally in the evaluation of his life, the risk of death is perceived as a **temporal problem**, consequently also determining a subjective **evaluation of the atemporal type**.
Anyway, as well this system have limits, firstable the value of the years of life lost remains independent and constant over time.
Secondly, another criticism of the VOLY method is raised in consideration of the fact that there is not much empirical evidence to support the assessment of the years of life lost, especially in Europe.

The value that we have taken in consideration comes from the CAFE [10] project, which was realized in 2005. This project is based on the ExternE method and project.

In the same year, the ExternE project realized the latest manual with updated values, where there was also the updated value of the VOLY which is 125. 250 [13], a higher value than the CAFE project which is 120,000 euro for year.[10]

Although the prices are similar, we didn’t choose the highest value and therefore the worst-case, but the decision was based on the origin of the project, in fact, the Externe project was carried out in America, instead, the CAFE project was done in Europe.

Since the latest values rise to 2005, thanks to ISTAT data it was possible to update the monetary value to the current year, 2020.

Starting from an initial value (2005) of 120.000 euro/ year to 145.320 euro / year (2020), thanks the coefficient value 1,211[-].[14]

5. 2. APPLICATION TO THE POPULATION OF TURIN

This section is dedicated to the application of the methodology, which we have explained until now, on our the case study.

Following the previous chapter (chapter four) that was connected to the residential buildings of the city of Turin, we now find ourselves applying the methodology to the population present in the city.

To better understand, where the data come from and how will be the steps on the development of the case study, we create a graph (figure. 4) which highlights the main steps that we will apply, attributed to the PM10 pollutant for just the heating system.

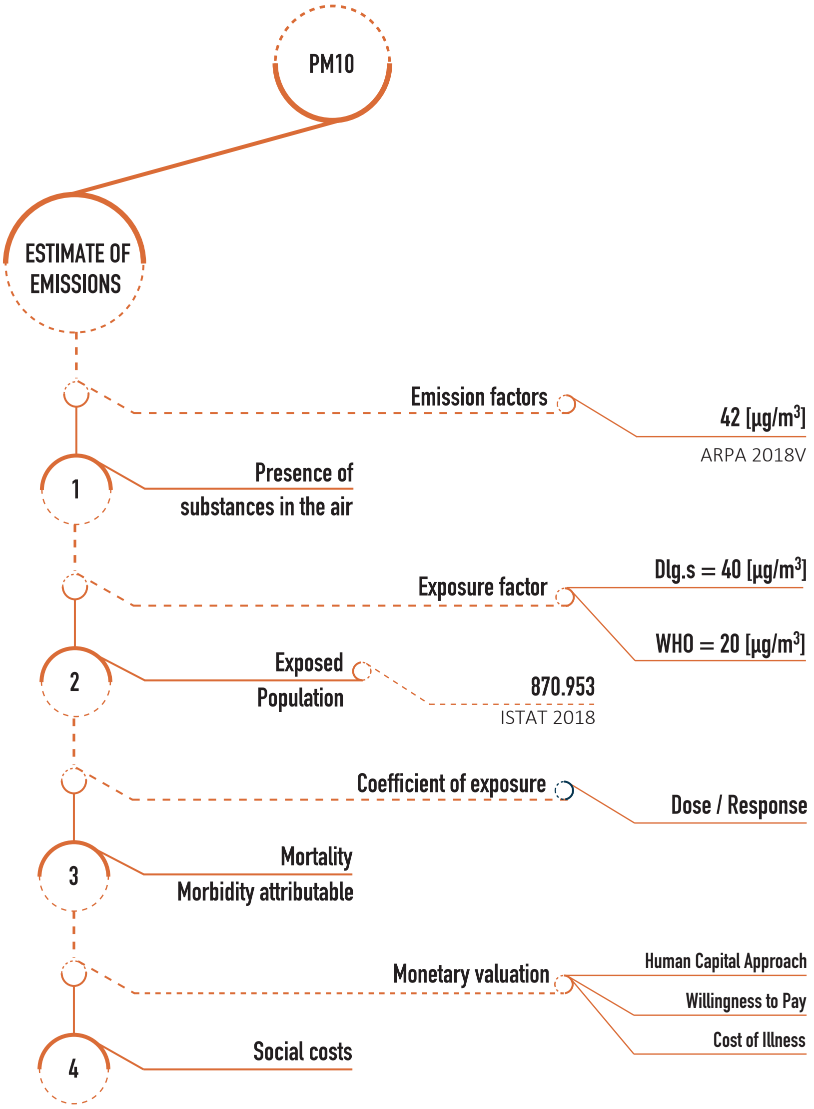
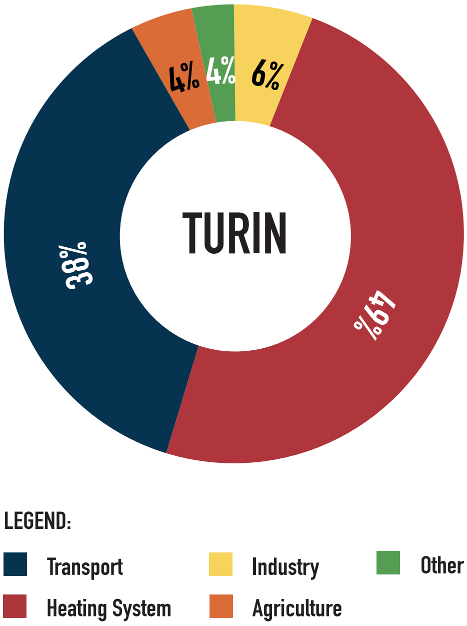


Fig. 4. Representation scheme about the mains steps of the Application for the case study of Turin.

For the application case, it was taken in consideration the entire population of Turin , the reason for this choice is base on the fact that everyone breathes the air and so the air pollution. It was take in consideration the emission of pollutants from the heating system, not only from the residential system which we calculate but in totality.

The reason for this choice is since from the point of view of the dispersion of pollutants in the atmosphere, which it is not possible to define a volume of air characteristic of a given spatial area, on the vertical axis. In fact, the maximum height within which the pollutants can be distributed varies over time (even by an order of magnitude) as a function of a series of meteorological parameters, while on the horizontal plane the pollutants are subject to transport by the winds, which on the one hand removes the pollutants themselves from the area considered and from the others can provide additional input from other areas.

Furthermore, on the basis of the scientific literature, the legislation expressly requires that for this type of evaluation (technically known as “source apportionment”), modeling systems must be used, which are precisely able to simulate the complex set of phenomena that give rise to the concentrations of pollutants that we measure in the air.[15]



CONCENTRATION OF PM10 (Primary and Secondary)

DATA :

Emission Factors =	**42 [μg/m³]**
Heating Percentage =	**49 %**
Emissions Factor Heating =	**20,58 [μg/m³]**

Graph 1. Rappresentation of the total emisison of PM10 by sector. Sources: Arpa 2018.

In other words, the reason why we didn't take the PM10 emissions calculated by us, because our PM10 take in consideration only the primary reactions when secondary chemical reactions are also present in the air deriving from the primary emission.
For this reason, we took the PM10 value from the Arpa Piemonte, (2017). [16] [17]

EXPOSED POPULATION

The population, that we have considerate is all the population of Turin, which according to the ISTAT census of 2018, it's 870,953.

DATA :

Population (All)	**870,953**
Population (15-64 year)	**542.042**
Population (30-64 year)	**422.071**
Life Expectancy	**83 year**

Age and age classes (year)	Population	Survivors (lx) (year)	Deaths(dx)	Probability of Death (qx) (per 1000)	Life Expectancy
until 4	31.819	100.000	283	2,83	83,00
5-9	35.285	99.717	44	0,44	78,23
10-14	36.785	99.673	44	0,45	73,26
15-19	35.881	99.629	92	0,92	68,30
20-24	38.647	99.537	137	1,38	63,36
25-29	45.443	99.400	180	1,81	58,44
30-34	50.858	99.220	176	1,78	53,54
35-39	52.450	99.043	274	2,77	48,63
40-44	59.693	98.769	421	4,27	43,76
45-49	69.927	98.348	707	7,19	38,94
50-54	70.098	97.640	1.201	12,30	34,20
55-59	63.571	96.440	1.908	19,79	29,59
60-64	55.474	94.532	2.859	30,24	25,13
65-69	49.281	91.673	4.341	47,35	20,83
70-74	50.740	87.332	6.808	77,95	16,74
75-79	44.607	80.524	10.510	130,52	12,93
80-84	40.800	70.014	16.072	229,55	9,46
85-89	25.982	53.942	22.554	418,11	6,49
90 +	13.612	31.388	20.219	644,16	4,32

Table 6. Turin's population Data. Sources, censum "ISTAT 2018"

5. 2.1. HEALTH, Mortality & Morbidity

For the calculation of the Mortality and the Morbidity we use the Formula which is explained in the chapter three (section 3.1.4.3. Number of the case study associated with a given factor, which for our case study is the PM10). As follow we report the equation, we have to undelight that the limit of exposed factor of PM10 that we took for our case study, is the **WHO** limit that is **20** [µg/m3].

$$E = A * B * (C/10) * P$$

Equation 3

Where:

P = the population exposed

C = the relevant change in concentration (difference between the observed concentration and the counterfactual level), obtained from monitoring networks in each city;

A = the proportion of effect on health attributable to air pollution

B = represents the estimated incidence of deaths, hospitalizations, health events on the exposed population net of the effect of the pollutant.

Mortality

HEALTH OUTOCOMES	MORTALITY [event/year]
CHRONIC EFFECTS:	
• All (excluding accidents)	• 2.937 (2.772-3.182)
• Lung cancer	• 283 (259 - 317)
ACUTE MORTALITY	
• All (excluding accidents)	• 53 (35 - 71)
• Cardiovascular causes	• 61 (34 - 88)
• Respiratory cause	• 81 (12- 123)

Table 7. Mortality data calculated on the Turin population of PM10 emissions by the heating system.

Morbidity

MORBIDITY OUTOCOMES	MORBIDITY [event/year]
• Hospital admissions for Cardiac	• 55 (18 - 110)
• Hospital admissions for Respiratory	• 107 (24 - 131)
• RADs (days)	• 53.991
• WLDs (days)	• 84.853

Table 8. Morbidity data calculated on the Turin population of PM10 emissions by the heating system.

5. 2.2. ECONOMY

In the following section we report the calculation that we did on the Turin's population, by using the two methods that we explain in the previous paragrapher (5.1. METODOLOGY, in the specific in the section, 5.1.2. Economy), which was dedicate to methodology.

5. 2.2.1. Human Capital Approach (H.C.A.)

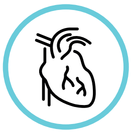
	Symptomatology	Attributable Cases	Costs per symptomatology [euro/year]	Total Value [10^3. euro/year]
	• Hospitalizations	107	278,29	559,09
	• Medications		289,84	9,51
	• Hospitalizations	55	9,007	495,06
	• Medications		260,50	15,30
	• WLD (Work Loss Day)	1.578.266,93	130,73	206.333
	TOTAL			**207.430,25**

Table 9. The tablerepresent the tangible costs, calculate by the HCA method.

5. 2.2.2. Willingness to Pay (W.T.P.)

Symptomatology	Attributable Cases	Costs per symptomatology [euro/year]	Total Value [10^3. euro/year]
• Year of Life Lost	2.024	145.320	295.558
TOTAL			**295.558**

Table 10. The table reppresent the intangible costs, calucate by the WTP method.

5. 2.2.3. Cost of Illness (C.O.I)

After having calculated the human capital approach and the willingness to pay, since we have all the costs which compound the cost of illness (C.O.I) which are the direct costs, indirect costs, and intangible costs, we can calculate it.

As follow there is the table regard all the cost of cost of illness (C.O.I).

Symptomatology	Attributable Cases	Costs per symptomatology [euro/year]	Total Value [10^3. euro/year]
• Year of Life Lost	2.024	145.320	295.558
• Hospitalizations	107	278,29	559,09
• Medication		289,84	9,51
• Hospitalizations	55	9,007	495,06
• Medication		260,50	15,30
• WLD (Work Loss Day)	1.578.266,93	130,73	206.333
TOTAL			**502.969,73**

Table 11. The table represents the COI, the sum of the direct and indirect costs.

SOCIAL COST

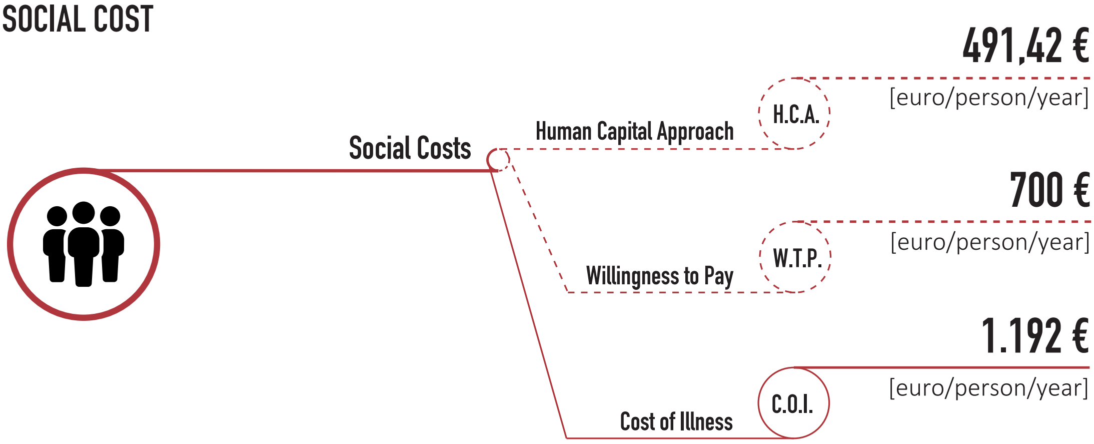


Fig. 5. The scheme represents the comparison of the social cost per person in the different economic methods

The scheme above shows the comparion betwwen the three prices, the Human Capital Approach, the Willingness to pay, and the Cost of illness. It showed how much would be the cost per person per year that a person would have to pay for the costs derived from the disease, created due to the PM10 by the heating system.

The age of the population that has been taken in consideration for the economic part, between 30-64 years, which it's equivalent to 422,071 people.

The reason of this choice arises from the fact that for the economic calculations of direct and indirect costs, this age group is considered as the active part at work level.

5. 3. VARIATIONS OF SOCIAL COST

Until now we calculated the emission deriving from the heating system in the residential building, we calculated the number of mortality and morbidity associated with the emission of pollutants and, in the end, we calculate the social cost that arising from the impact of pollutants.

The last step, which we will explain in this section, is based on the association of the variation of the PM10 emission to the cost coming to the impact of PM10 on the heath people. So, we created an index, which associates the social cost whit the current state of emissions of PM10 (**12,15 [t]**),as follow the formula:

$$INDEX = \frac{EURO}{TONS}$$

Equation 4

After having found the index for both the methods which we used for the calculation of the cost associated to the PM10.

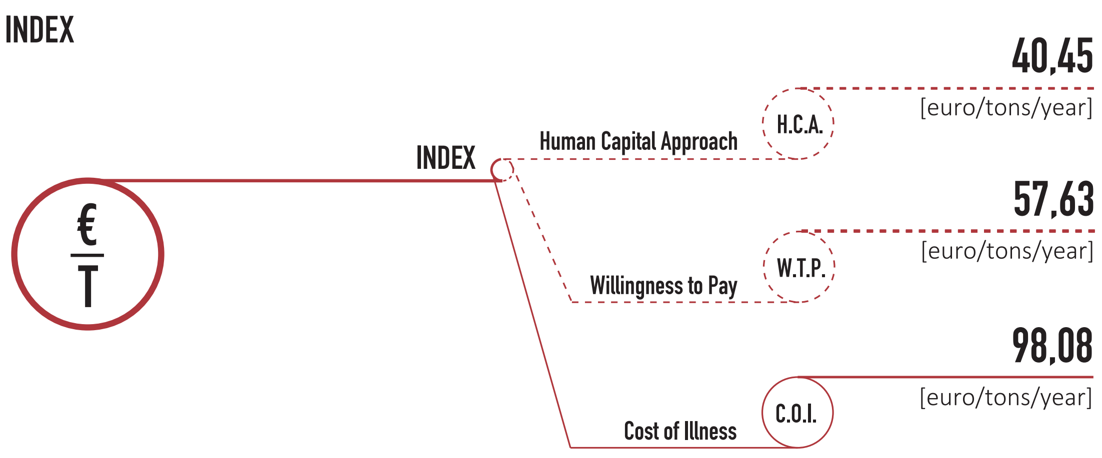
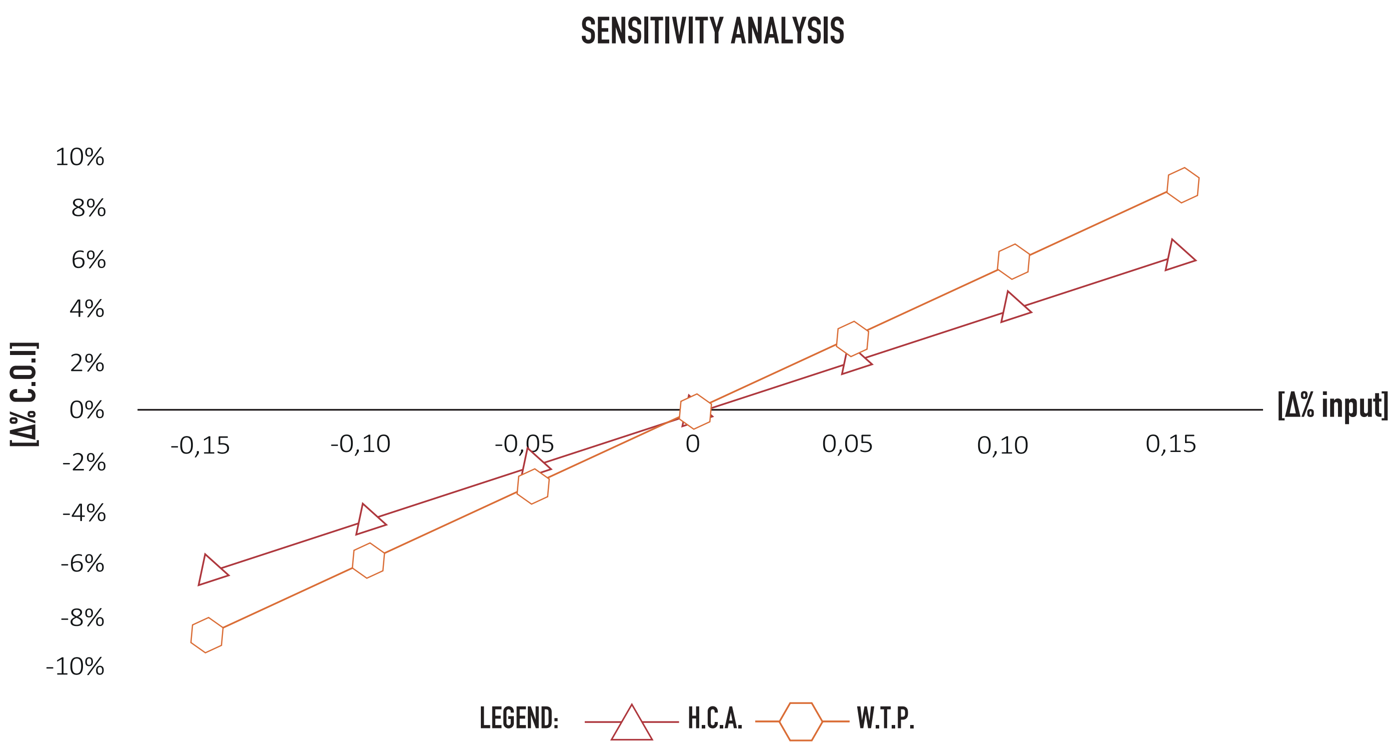


Fig. 6. The scheme represent the indexes that we calculated for the different economic methods.

After calculating the COI index, it is important to evaluate the quality of the calculated parametric data. For this reason, a sensitivity analysis was developed with the aim of verifying which of the two variables has the greatest impact on the value of the COI index and evaluating how the result varies if some of the assumptions set in the previous phases in the evaluation of the HCA and WTP. The methodology chosen is the "what if?" which shows the sensitivity of the results and which changes have a significant impact on the overall report. If the result is sensitive to changes in a particular indicator, more care must be taken to determine that indicator. The method therefore envisages varying the input parameters one at a time for a finite quantity (± 5%, ± 10%, ± 15%) considering all the other constant variables and calculating the relative variation of the output. In this case, we varied the HCA and WTP valued indices according to the predetermined percentages and verified how much these affected the COI.



Variation of the H.C.A. parametric Index

	H.C.A. [€/t]	W.T.P. [€/t]	C.O.I. [€/t]
-5%	38	58	96
-10%	36	58	94
-15%	34	58	92
5%	42	58	100
10%	44	58	102
15%	47	58	104

Variation of the W.T.P. parametric Index

	H.C.A. [€/t]	W.T.P. [€/t]	C.O.I. [€/t]
-5%	40	55	95
-10%	40	52	92
-15%	40	49	89
5%	40	61	101
10%	40	63	104
15%	40	66	107

Figure 7. Graphyc that represent the sensitivity analysis of the C.O.I.

After drawing trend lines it is necessary to calculate the cosine of the angle between the straight lines. The parameter incidence is as much higher as the cosine of the angle value. From the results of the analysis it is possible to deduce that the variable WTP is the variable that most affects the COI. This conclusion highlights how the WTP data taken as a reference may not be congruent with the local context of the analysis as they are detected at

the European level. This would imply the need to elicit investigations at a local or national level, in order to measure the availability of the actors really involved in the proposed retrofit process and validate the data identified in the literature taken as a reference. But since this is not the goal of this thesis, we assume the data identified in the literature to be reliable, as the variation of the COI does not exceed 9%. Besides, we propose as future prospects the investigation of the benefits in terms of WTP to validate the results obtained in the literature also for the Italian context.
The following step, it was associated index with the scenarios that we created to find a better solution to reduce the emission of pollutants (S.R.-0.1, S.R.-0.2, S.C.R. and A.C.R.) by multiplying the emissions of pollutant with the index, (explained in the table…). For example:

$$H.C.A = PM10_{T.R.,0.8} * I_{hca}$$ *Equation 5*

Where:
$PM10_{T.R.,0.8}$ = PM10 emission for the case Technology Retrofit (with Biomass) with renovate rate 0.8.
I_{hca} = Index of Human Capital Approach.

As follow, we will see the estimated benefit for the human capital approach and the willingness to pay for the different scenarios that we have been creating for reducing the emission of PM10 (explained in chapter 4). We divided in two tables as in the previous chapter, in the renewable rate taken from the annual report of intervention (0.8%,1.2% and 2.5%) and the renewable rate that we supposed (25%, 50%, 75%, 100%).

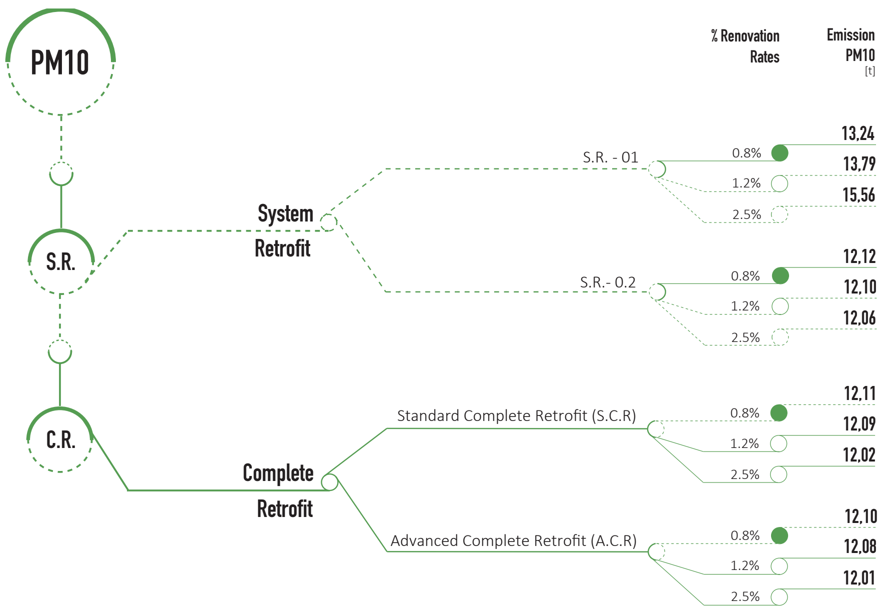


Fig.8. Representation scheme about the emission of PM10, for the different scenarios, with the renovation rate 0.8%, 1.2%, and 2.5%.

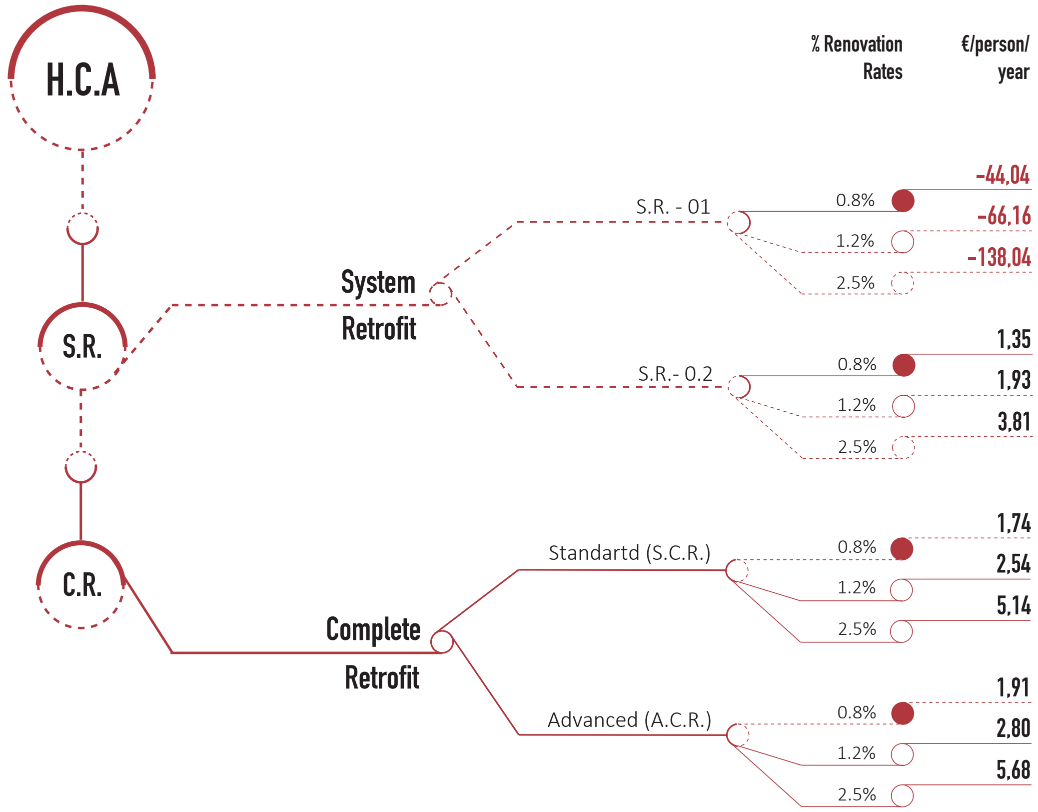


Fig.9. Rappresentation scheme about the estimated benefit by the H.C.A. method, for all the scenarios with the renovation rate 0,8%,1.2%, and 2.5%

ESTIMATE BENEFIT_H.C.A.

Fig.10 Estimated benefit graph by the H.C.A. method.

ESTIMATE BENEFIT (No S.R.- 0.1)_ H.C.A

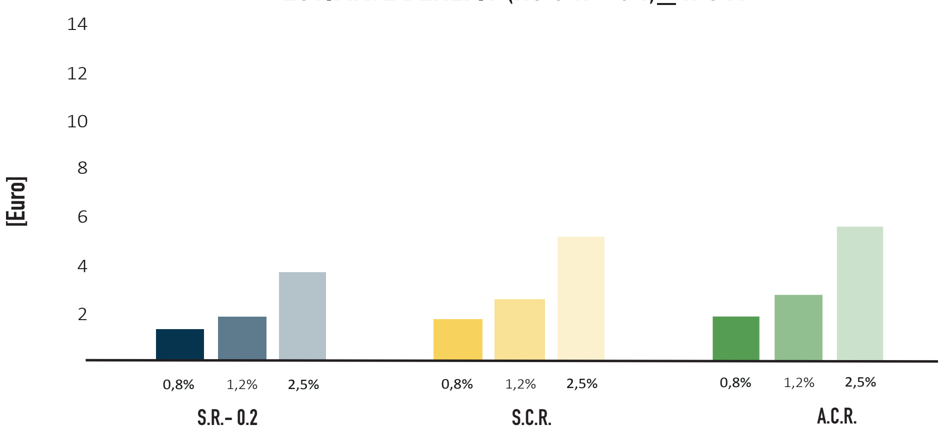


Fig.11 Estimated benefit graph by the H.C.A. method, without the S.R.-01 scenario.

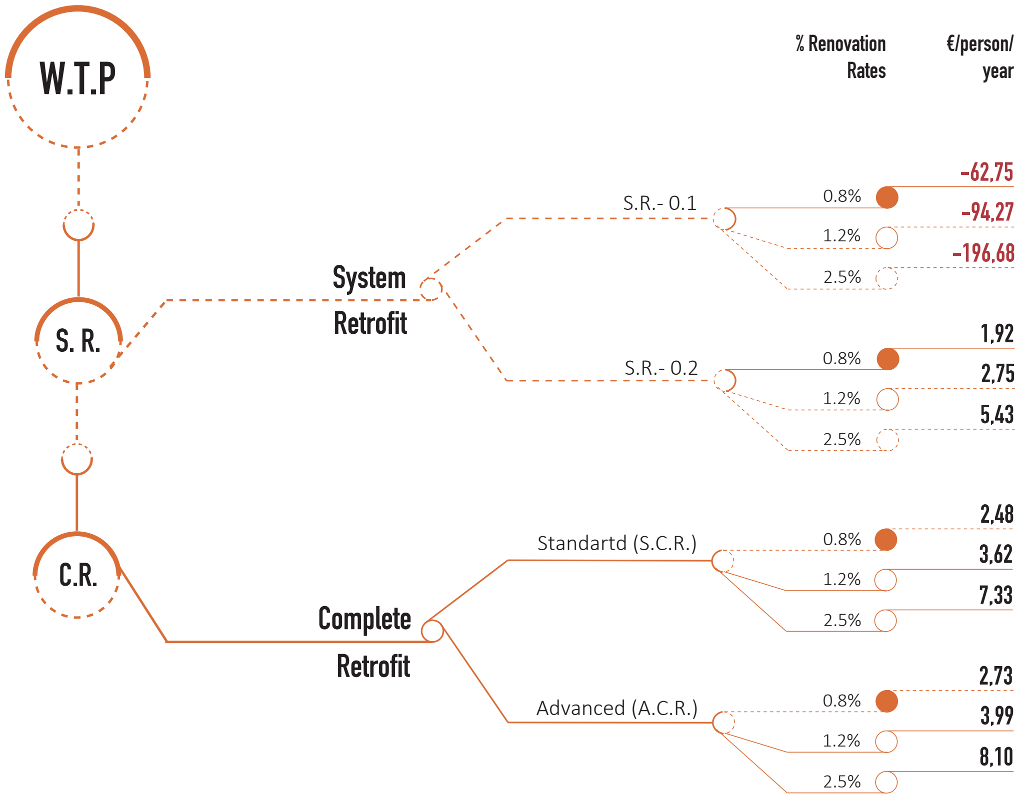


Fig.12. Representation scheme about the estimated benefit by the method W.T.P., for all the scenarios with the renovation rate 0,8%,1.2%, and 2.5%

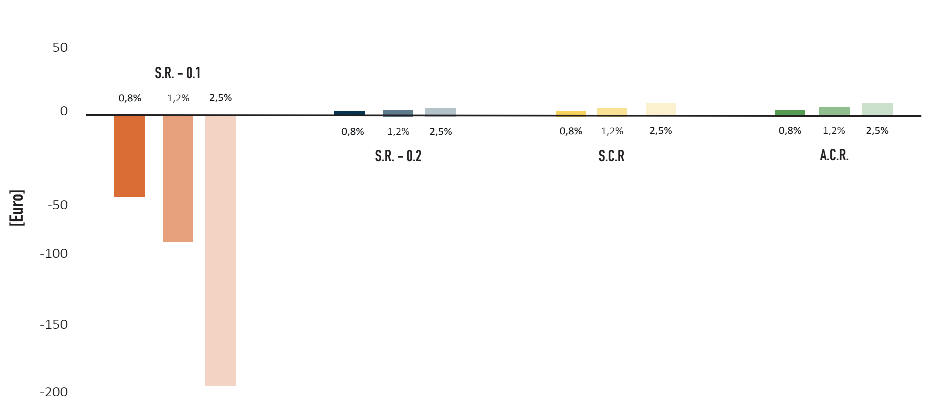


Fig.13 Estimated benefit graph by the W.T.P. method.

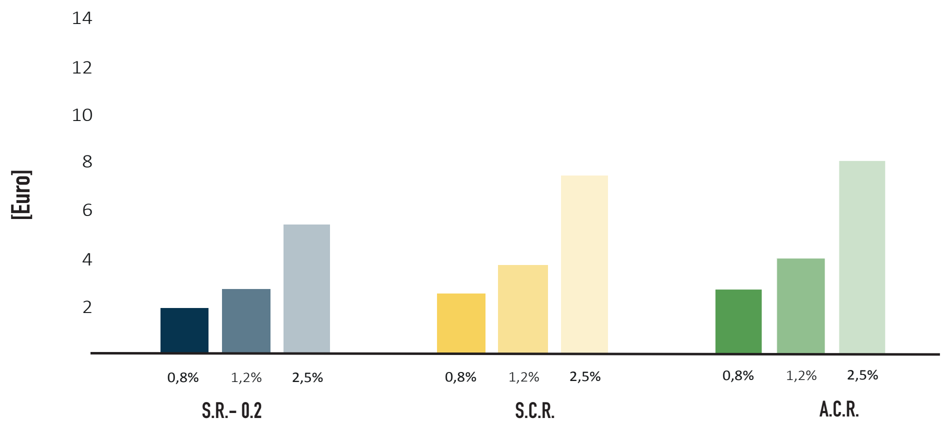


Fig.14 Estimated benefit graph by theW.T.P. method, without the S.R.-01 scenario.

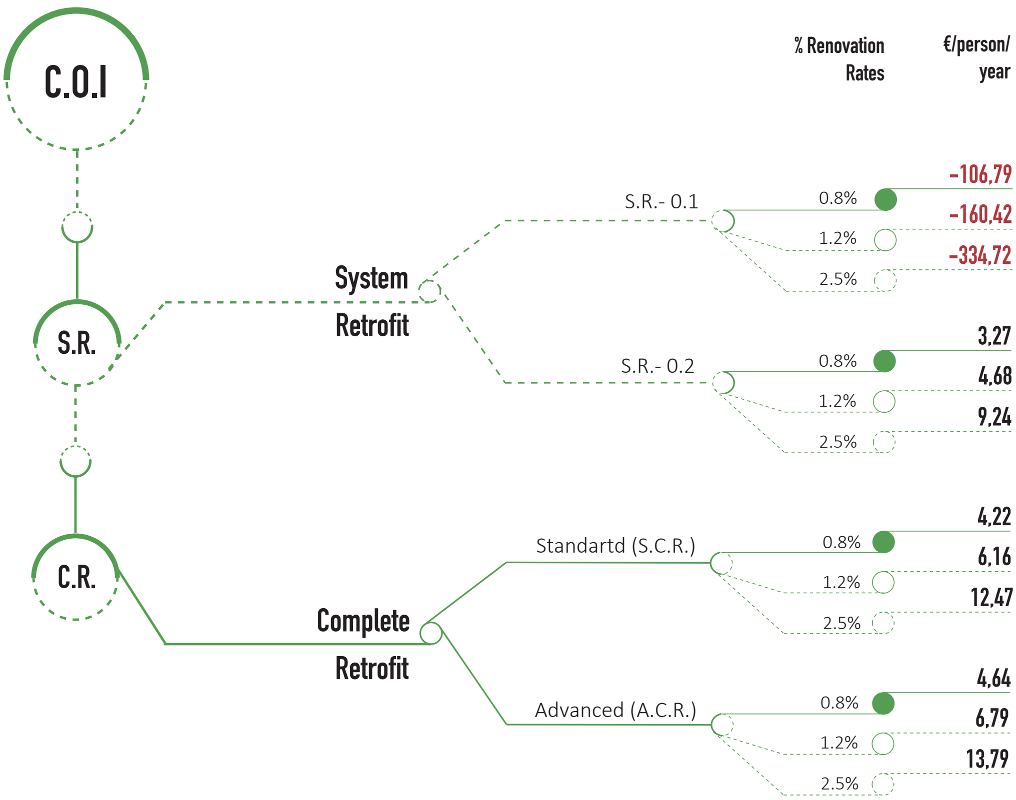


Fig.15. Representation scheme about the estimated benefit by the C.O.I. method, for all the scenarios with the renovation rate 0,8%,1.2%, and 2.5%

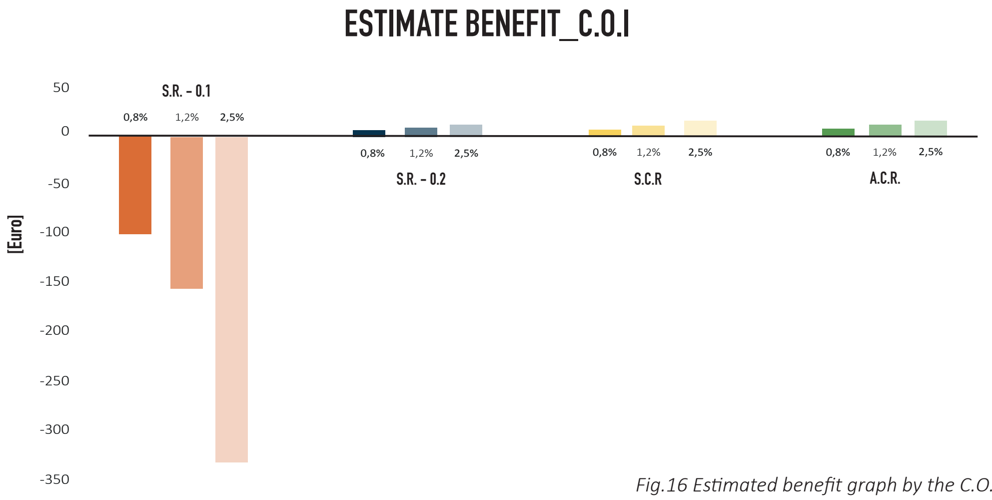


Fig.16 Estimated benefit graph by the C.O.I method.

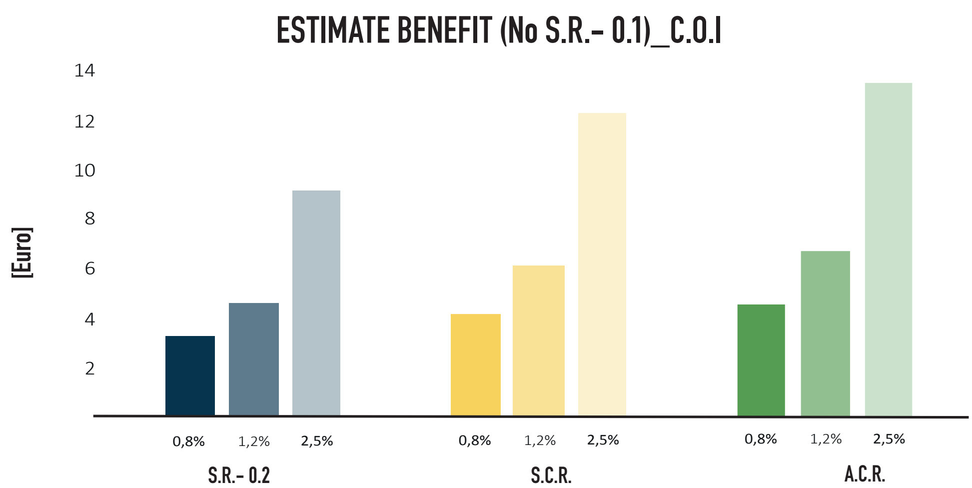


Fig.17 Estimated benefit graph by the C.O.I. method, without the S.R.-01 scenario.

It can be noted from the results, there is no benefit in the first scenario, (S.R.-0.1), on the contrary, there is a worsening, this is given by the fact there is an increase of emission di PM10 instead of the decrease. From these first results emerge that the maximum reduction for the HCA method is **5.68** €/person per year (renovation rate 2.5%) and for the WTP having a higher initial cost, it has a reduction of **8.10** €/person per year r, therefore a total reduction of only **13.79** euro/person/year (COI).

As follow we will see the same approach but with a renovation rate of 25%,50%, 75%, and 100%, for all four scenarios.

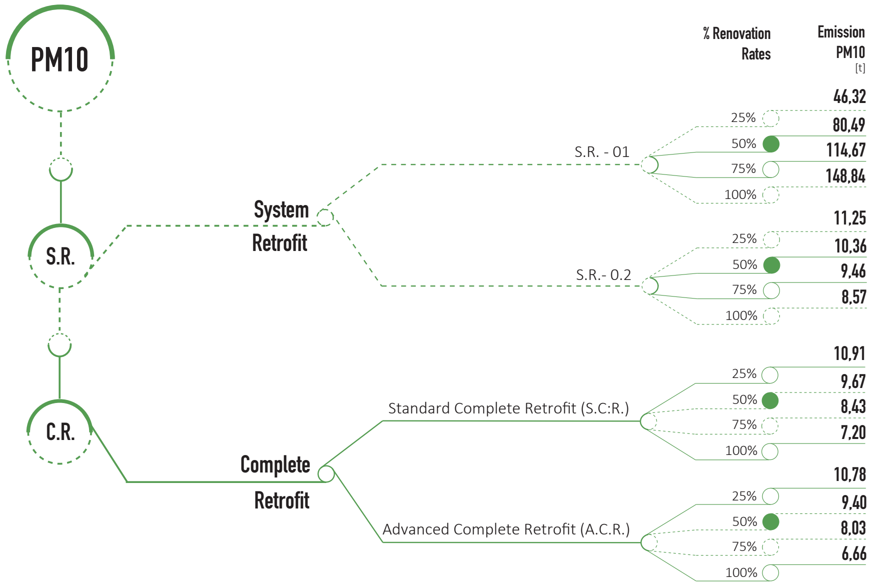


Figure 18. Representation scheme about the emission of PM10, for the different scenarios, with the renewable rate 25%,50%,75% and 100%

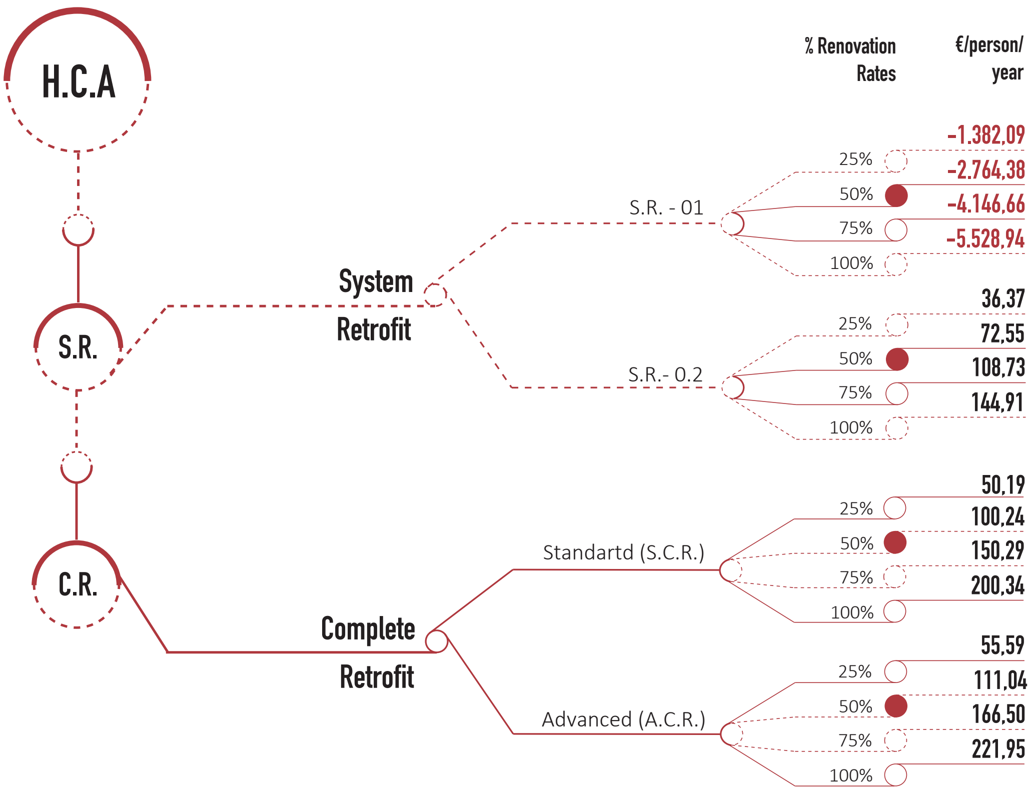


Figure 19. Rappresentation scheme about the estimated benefit by the H.C.A method, for all the scenarios, with the renovation rate 25%,50%,75% and 100%

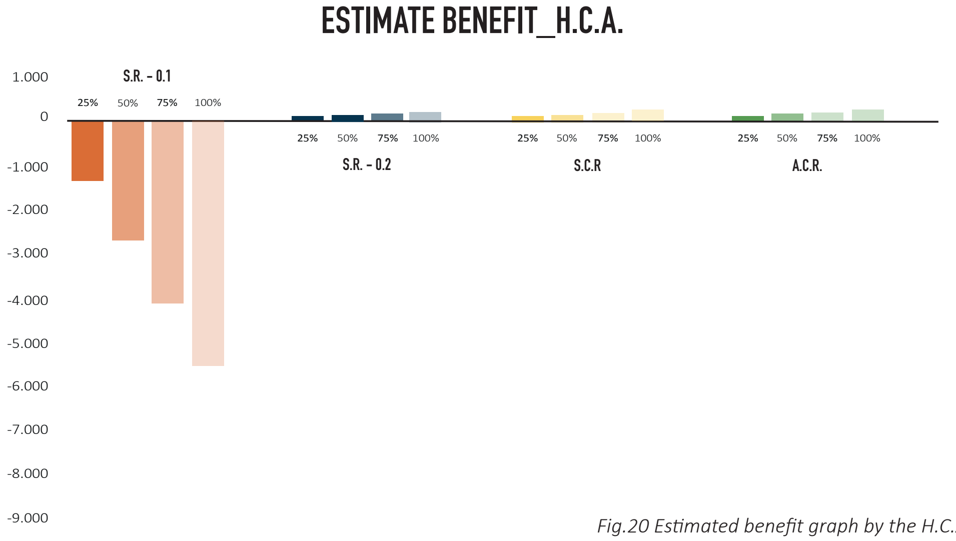


Fig.20 Estimated benefit graph by the H.C.A method.

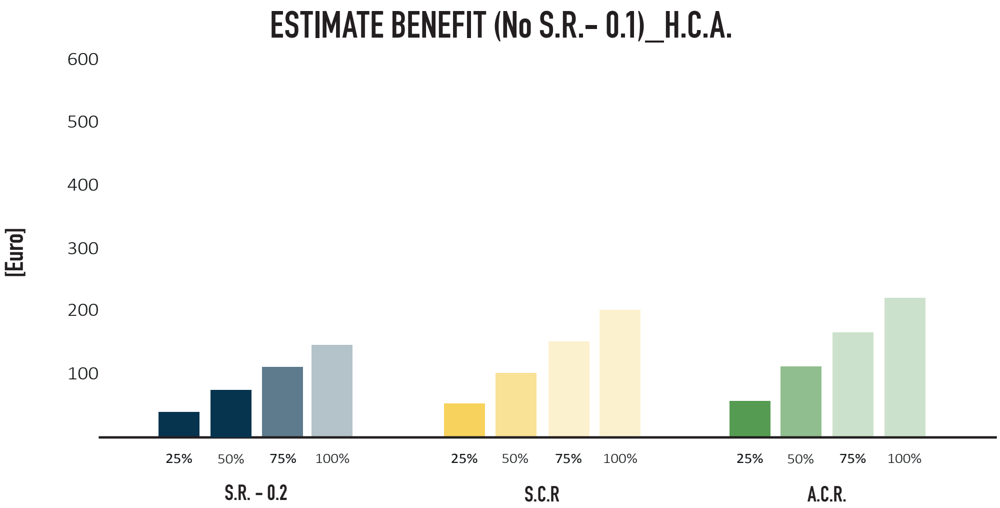


Fig.21 Estimated benefit graph by H.C.A method., without the S.R.-01 scenario.

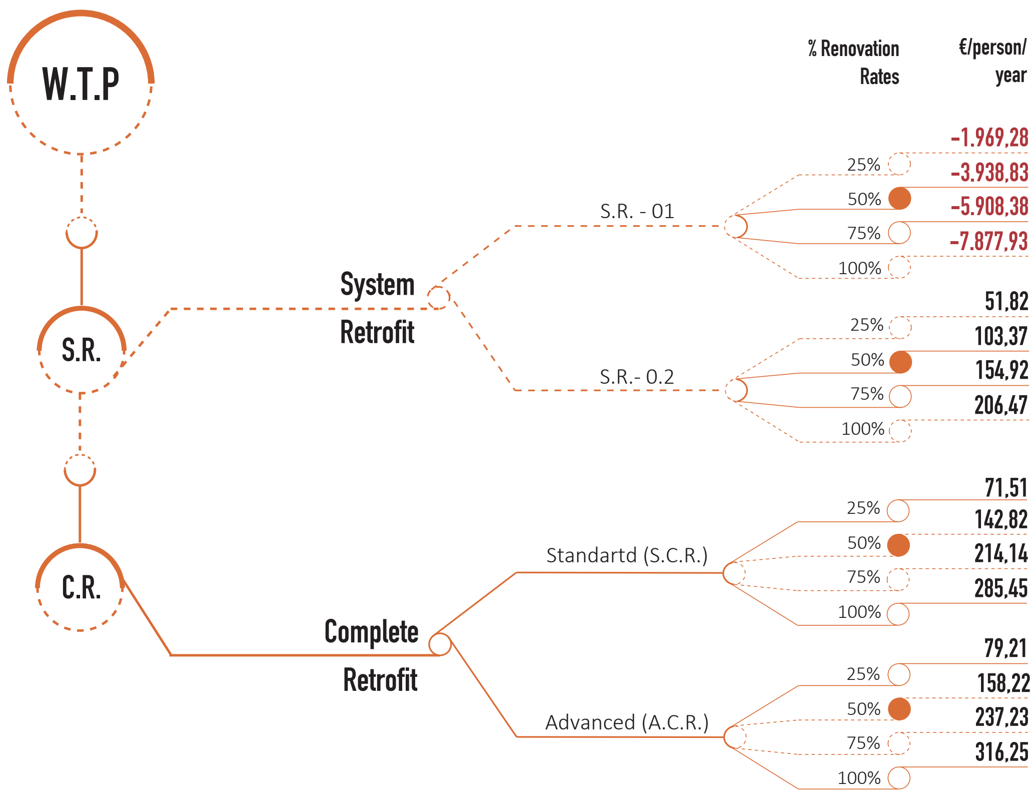


Fig.22 Rappresentation scheme about the estimated benefit by the W.T.P. method,or all the scenarios, with the renovation rate 25%,50%,75% and 100%

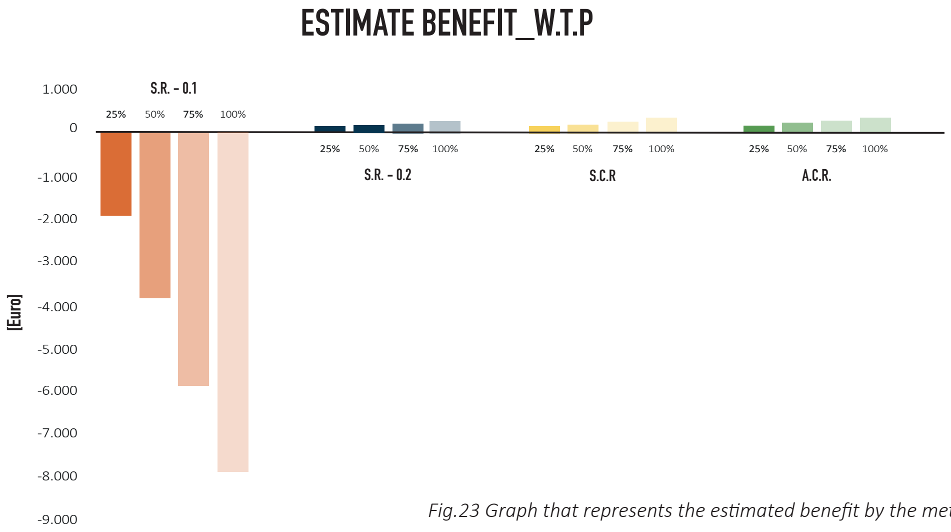


Fig.23 Graph that represents the estimated benefit by the method W.T.P.

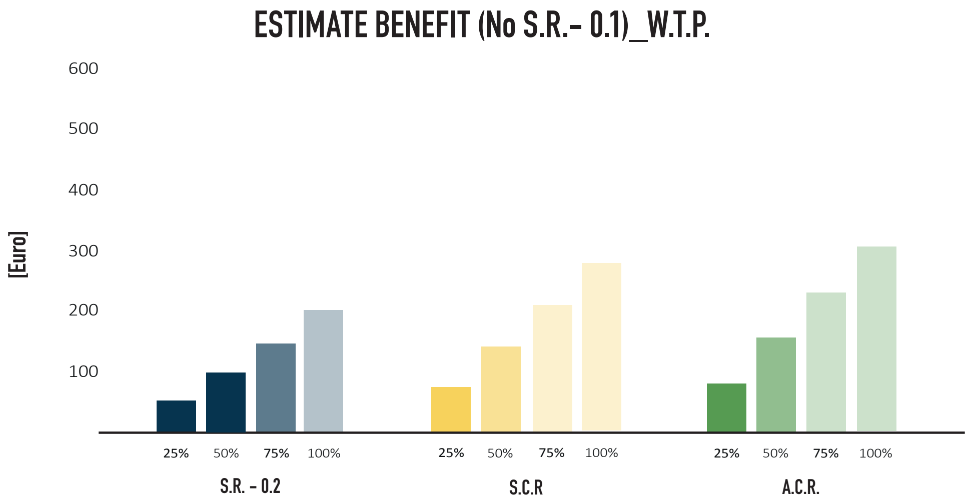


Fig.24 Graph that represents the estimated benefit by the W.T.P. method, without the S.R.-01 scenario.

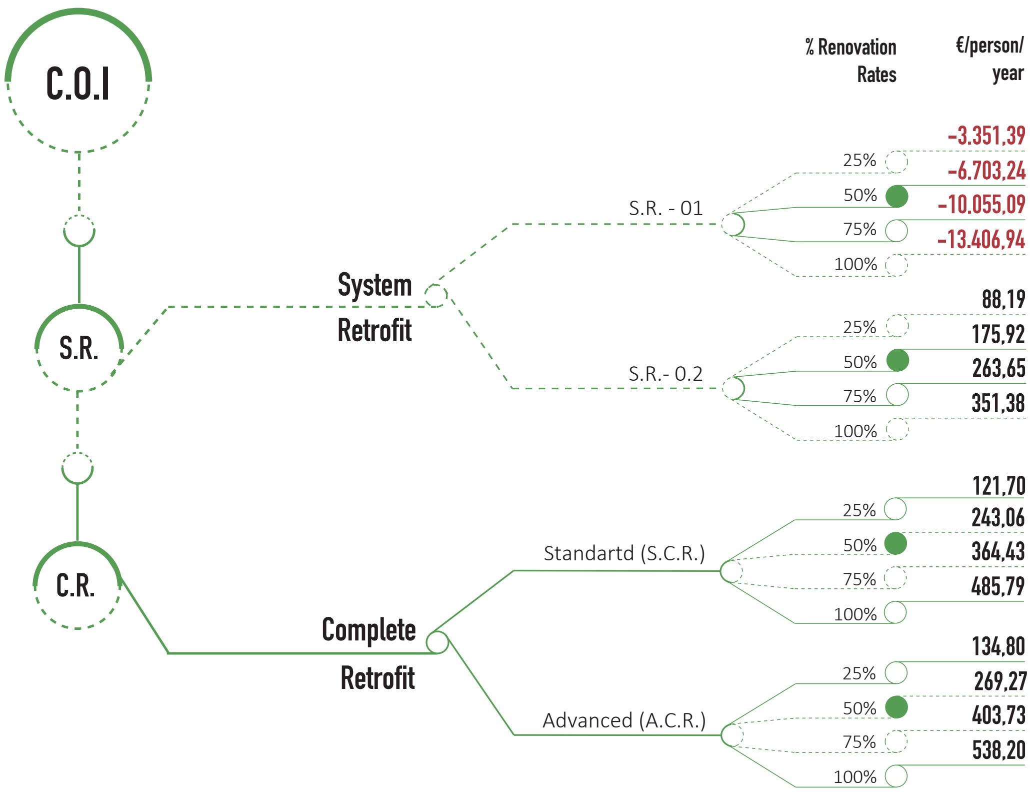


Fig.25 Rappresentation scheme about the estimated benefit by the C.O.I. method,or all the scenarios, with the renovation rate 25%,50%,75% and 100%

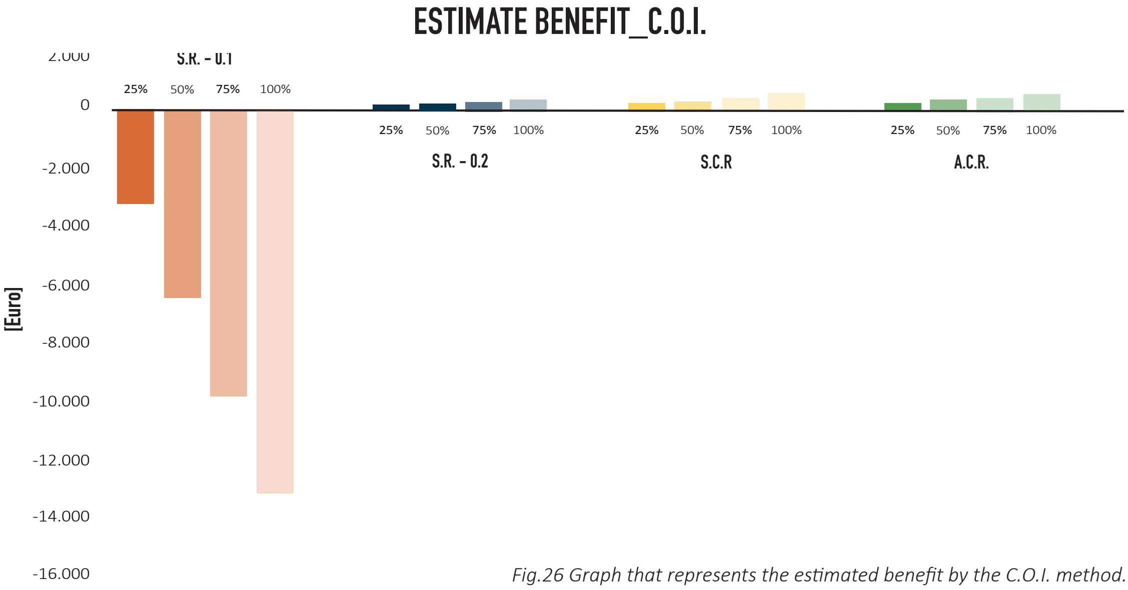


Fig.26 Graph that represents the estimated benefit by the C.O.I. method.

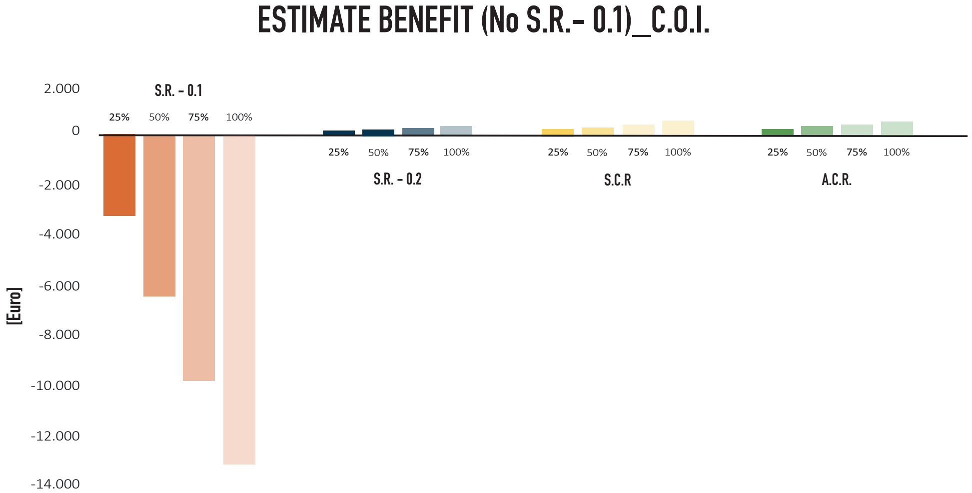


Fig.27 Graph that represents the estimated benefit by the C.O.I. method, without the S.R.-01 scenario.

As expected, by increasing the energy efficiency of buildings, there is an economic benefit. There is a significant improvement already at 50% on the scenario of S.R.-0.2, where it has a reduction of **175** €/person per year . Value that increases with the Standard scenario (S.CR.) with a reduction of **243** €/person per year reaching a reduction of **269.27** €/person per year for the scenario with the better performance that we have created.
In fact, in the last scenario A.C.R. with the renovation rate of 100%, there is a reduction in the COI of **538** €/person per year.

5. 3.1. Discussion / remark

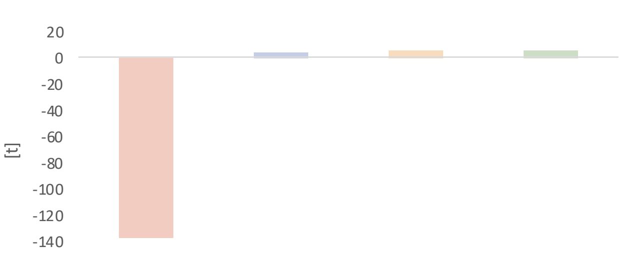
In conclusion, by applying the epidemiological study on the city of Turin, it emerged that PM10 emissions generated by heating cause **2,937** deaths per year, which **283** causes lung cancer and reduces life expectancy by **3** years.

From this study, it emerges that 162 is the number of hospitalizations caused by the emission of pollutant PM10, where, 55 are cardiovascular hospitalizations and 107 are the respiratory hospitalization.

From the analysis of these first results, it was possible to calculate the impact of the disease at an economic level.
Using the human capital approach, we calculated the direct costs, which are composed of the cost of hospitalization, and the work lost days due to illness, therefore the loss of productivity, with a total of 207,430.25 (103) €/year.
Analyzing the costs of the HCA, it's emerged that the world lost day (WLD), equal 206,333 (103) €/year, have greater weight respect the costs of hospitalization, 1,097.19 (10^3) €/year.

Regarding the individual costs, we used the W.T.P..Specifically, the intangible costs are based on the value that people attribute for one year of life lost due to the disease caused by pollutions.
Due to a lack of time, we took as a reference a value from project conducted at the European level. From this project it emerged that 146,000 euros / year is the value that people attribute to a year of life.
Thanks to these data we were able to calculate the individual costs for the population of Turin, which are 295,557.71 (10^3) €/year.
After this, it was possible to calculate the cost of illness (COI), where, for the city of Turin is equal to 502,990.40 (10^3) €/year, an equivalent to 1.192 €/person per year.
Analyzing the data emerge that the greatest weight of these costs is given by the individual costs, 700 €/person per year, otherwise, the direct costs have a value equal to 491 €/person per year.
After having calculated the COI in the current state, by using the reference index (euro/ton) we were able to analyze how much the COI can increase or decrease, in relationship with the pm10 emissions that we calculated in the energy scenarios.
As follow we report the data with the 100% renovation rates, to show the relationship between the emission of PM10 and the cost-benefit.

Net Avoided Emissions PM10 (100% renovation rate)



	S.R.-0.1 [t]	S.R.-0.2 [t]	S.C.R. [t]	A.C.R. [t]
PM 10	-136,69	3,58	4,95	5,48

Estimate Benefit (100% renovation rate)

	S.R.-0.1 [€/person per year]	S.R.-0.2 [€/person per year]	S.C.R. [€/person per year]	A.C.R. [€/person per year]
PM 10	-13.406,94	351,38	485,79	538,20

Fig.28 Graph which represents the relationship between the emission of pollutant with the cost-benefit .above

As showed in the graphs above with a negative effect in the emissions of PM, retrofit scenarios with the presence of biomass (S.R.-0.1), there is an increase of the social cost, -13.406,94 €/person per year.

On the contrary, starting from the second scenario S.R.-0.2 there is a benefit-cost equal to 351,38 €/person. The benefit value increase, arriving, at the last scenario (A.C.R.) an economic benefit equal to 538,20 €/person per year.

PART SIX

6.0. CONCLUSIONS

6.0. CONCLUSION

Nowadays, due to the constant increase of outdoor air pollution, the impact on the health of the people is becoming serious. Moreover, in the current vulnerable and crucial historical period, when society is experiencing and dealing with the Covid-19 pandemic, the issue of people's health is becoming even more important.

In 2019,the Global Burden of Disease Study estimated that outdoor air pollution is one of the main reasons for death in the world, with estimated 3.4 million deaths in 2017. These data highlight the danger to the health of people, taking into attention the international agencies such as the United Nations, that mentioned "good health and well-being" (SDG3) as a part of the 17 goals of the Sustainable Development declaration.

The concept of Outdoor Air Quality (OAQ) is a relevant topic, especially in the urban area, where population will continue to grow, expectingto reach 6.5 million people in 2050. Therefore, it is essential to take in consideration the health and wellbeing of the people.

The main goal of my thesis was to study the effects of air pollution on people's health and to investigate how the diseases affect the society and the economy. In particular, the developed analysis allowed to provide scientific outcomes which could be suitable for supporting the urban planning decision-making process.

Studying the main sources of air pollution, 30% of emissions are caused by the heating systems in Europe. Based on this information, the thesis had set two main objectives, focusing on the residential sector of the city of Torino. Firstly, using the reference building approach, a simplification of the residential building stock of Torino was done, in order to evaluate its current emissions, not only in terms of CO2 emissions, but also considering the local impact due to air pollutants (i.e. PM, NOx, SOx, CO, etc.). Based on the current state, different retrofit scenarios were identified, in order to evaluate those able to guarantee the highest emissions reductions. Two families of scenarios were developed, the first improving only the heating systems, and the second coupling also envelope interventions with heating system retrofit. Four scenarios were then compared in terms of total emissions and net avoided emissions (with respect to the current state). Moreover, the thesis aimed also to quantify the impact of health diseases caused by air pollution exposure on

economy and society, and thus to evaluate the benefits on social costs guaranteed by the developed scenarios. The methodology used to monetize the air pollution health effects was defined after a preliminary literature review on the topic. In particular, thanks to an epidemiological bibliographic study, the social cost assessment was developed only considering particulate matter (PM) emissions, which emerged to be the most dangerous pollutant, causing respiratory and cardiovascular diseases.
The thesis focused on the method of Cost of Illness (C.O.I.). In particular, the Human Capital Approach (H.C.A.) was used to calculate direct costs, while the Willingness to Pay (WTP) method was deployed to estimate the intangible costs.

Based on the retrofit scenario analyses, the results brought out that the use of biomass source produces a negative effect, showing an increase of CO, NMVOC, and PM emissions with respect to the current state. Therefore, when considering a system retrofit scenario without permitting a shift towards biomass systems, a PM10 emission reduction of almost 30% can be achieved. However, the complete retrofit scenarios (built coupling envelope and system interventions) allowed to increase the emissions reduction, obtaining a 40% and 45% PM10 reductions when considering the standard and advanced complete retrofit scenarios, respectively. Moreover, the four scenarios were built assuming different renovation rates, some similar to the typical Italian annual renovation rates (0.8%, 1.2% and 2.5%), and some assumed to simulate stronger retrofit uptakes (25%, 50%, 75% and 100%). Clearly, the highest emissions reductions are associated to the highest renovation rates. However, it is important to clarify that only 75% of the building stock floor area was assumed to be potentially renovated (excluding buildings built before 1945 and built after 2005).

Focusing on the social effects of air pollution, it appears that PM10 causes approximately 2900 deaths cases per year and reduces life expectancy by 3 years. Applying the COI method, it was possible to associate to PM10 emissions an annual social cost of more than 1100 € per person. Intangible costs contribute to two thirds of this social cost, while direct costs only account for around 500 €/person per year.

A parametric index expressed in €/tPM10 was used in order to estimate the social costs and the associated benefits guaranteed by the developed retrofit scenarios. Almost all scenarios, with the diverse renovation rates assumptions, allowed to guarantee some economic benefits, increasing with the renovation rate. The highest values are achieved for the standard and advanced complete retrofit scenarios, for the 100% annual renovation rates, equal to almost 450 €/person per year and 550 €/person per year respectively. The sole exception is represented by the system retrofit scenario with biomass (for all the assumed renovation rates), which induced negative effects on the overall social cost.

The thesis and the obtained results are interesting, since they clearly show the effect that residential heating has on outdoor air quality. Moreover, it is clear that the highest benefits are associated with the highest renovation rates, showing how urban policy should stress on this topic.
The work opens the way to future work on this field. In particular, on the economic side, it would be interesting to estimate the local (or national) WTP, by submitting surveys to the population of Torino. On the energy side, the thesis concentrated on traditional technologies (i.e. condensing gas boiler, biomass boiler, electric heat pump). However, it would be interesting to consider the same technologies with higher efficiency, or to explore other technologies (e.g. district heating), as well as renewable energy sources, in order to evaluate how their adoption could strongly increase the urban emissions reductions.

Finally, the thesis was developed considering a single year assessment. In the future, it would be interesting to expand the research to a long-term study perspective, trying to explore the evolution of the urban residential sector up to 2050, considering the future technological maturity, in order to estimate the potential environmental and social benefits associated to the residential energy transition.

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PART FIVE

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ANNEXES

ANNEX 1
ARTICLE

AIR POLLUTION AND HEALTH EFFECTS: REVIEW OF INDICATORS AND EVALUATION METHODS

Cristina Becchio[1], Giulia Crespi[1], Tiziana Binda[2], Stefano Paolo Corgnati[1]
[1] TEBE-IEEM Group, Energy Department, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[2] Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

Abstract

Nowadays, the concept of outdoor air quality is gaining interest, especially considering the impacts that air pollutants have on people health. In the view of providing more sustainable cities to respond to global challenges, policy decision-maker should integrate in urban planning processes also proper solutions to safeguard people health from air pollution, making the built environment healthier and safer. To do so, proper methodological approaches are needed in order to estimate the social costs related to the health effects caused by air pollution exposure, as well as to explore significant indicators able to express them in quantitative terms. In line with this, the paper presents a literature review on the main metrics used to quantify health impacts, as well as on the most diffused socio-economic evaluation methods used to translate them into externalities for the society.

Keywords: Outdoor Air Quality, Health Effects, Urban Planning, Economic evaluation methods.

1 Introduction

Nowadays, the concept of outdoor air quality is gaining interest, especially considering the impacts that air pollutants have on people health. Last data of Global Burned Disease revealed that 3.41 million deaths were caused by outdoor air quality (Ritchie et al., 2019). The cruciality of the theme is also recognized by the international attention, as detailed by the Sustainable Development Goals, which identify the assurance of people health and wellbeing as an objective for all countries (UNDP, 2020). Moreover, by 2050 almost 6.5 billion people will live in cities (UNDP, 2020), thus highlighting the need for appropriate urban planning. Due to the prominent weight of air pollution on health effects, its accounting should be explicitly included in urban and economic planning (Saptutyningsih et al., 2015), in order to identify proper solutions to safeguard people and to make the built environment healthier and safer. For this reason, there is the need to provide suitable tools to estimate the potential benefits arising from the reduction of outdoor air pollution and, thus, to enable the decision-makers to design appropriate policies, aiming to further improve urban air quality (Saptutyningsih et al., 2015). In line with the above, the paper presents a literature review in order to respond to two objectives: impacts quantification and economic evaluation. Firstly, attention is devoted to the identification of the main metrics used in order to quantify the health effects generated by air pollution exposure. Then, a review of the most diffused economic evaluation methods is presented, aiming to investigate the techniques typically used in order to translate these health effects into monetary terms, and thus to provide estimates of social costs deriving from outdoor air pollution.

2 Methodology

Traditional research engines (i.e. Research Gate, ScienceDirect, and Google Scholar) were used to collect the bibliography, using appropriate filtering keywords (e.g. outdoor air quality, health, mortality, morbidity, respiratory disease, cardiovascular disease, social cost, etc). To achieve its objectives, the review focused on collecting information on two main areas (Silveira et al., 2015): i) quantitative assessment, aiming to identify the existing metrics most traditionally used to quantify the health impacts caused by outdoor air pollutants exposure, through a review of epidemiological studies; and ii) economic evaluation, aiming to study the different techniques used to assign monetary values to non-marketed goods or services, among which health impacts.

In regard to the first point, it was possible to identify the main metrics used to estimate the disease risks, namely mortality and morbidity. The former is related to the number of premature deaths caused by an event under investigation, while the latter is defined as the state of being symptomatic or unhealth in relation to a disease or condition, and it is usually estimated in terms of prevalence or incidence terms (Hernandez et al., 2020). Table 1 reports the results of the literature review, focusing on the diseases caused by particulate matter (both PM10 and PM2.5) emissions, which effects are better documented and quantified (Silveira et al., 2015). As shown in Table 1, health impacts are generally differentiated into short-term (i.e. the effects are observed in few days) or long-term (i.e. the effects are observed after years of exposure or after the time of exposure) effects.

***Table 1**: Review of main metrics from epidemiological studies.*

Metric	*Reference*	*Exposure*	*Pollutant*	*Disease*
Mortality	Anderson et al., 2004	Short-term	PM10	All causes, respiratory, cardiovascular
	Biggeri et al., 2004	Short-term	PM10	All causes
	Ostro et al., 2007	Short-term	PM2.5	All causes, respiratory, cardiovascular
	Brunekreef et al., 2009	Long-term	PM2.5	All causes, respiratory, lung cancer, cardiovascular
	Dong et al., 2012	Long-term	PM2.5	All causes, respiratory, cardiovascular
	Pope et al., 2002	Long-term	PM2.5	All causes, cardiovascular, lung cancer
Morbidity	Biggeri et al., 2004	-	PM10	Chronic obstructive pulmonary disease
	Dominici et al., 2004	-	PM2.5	Chronic obstructive pulmonary disease, heart failure, ischemic heart disease

Secondly, effort was put in order to review the available methods for the economic evaluation of those impacts. Generally, health is monetized accounting for direct, indirect and intangible costs. The former consists of healthcare and non-healthcare costs due to treatment and caring, and based on market values (Silveira et al., 2015); the indirect costs generally refer to productivity losses, as a consequence of workers' absence; finally, the intangible costs attempt to include non-market costs, by monetizing more subjective factors, as quality of life or pain and suffering (Silveira et al., 2015). Different methods could be used to value these costs. The most diffused approach is the Cost of Illness (COI), which aims to "evaluate the economic burden that illness imposes on society as a whole" (Jo, 2014), estimating the costs using available information from existing markets (NSW, 2005). Differently, Willingness to Pay (WTP) allows the estimation of non-marketed goods and it aims to measure the amount of money that an individual is willing to pay to reduce his/her probability of illness or premature death (Jo, 2014). In other words, WTP allows to investigate how much individuals value their health and longevity (European Commission, 2018), by stating their preferences in a hypothetical market, or by revealing them thanks to the observation of real markets. Different techniques are available in literature to quantify either indirect or intangible costs. They can be classified into two main categories: i) "Revealed Preferences" (RP) methods, which "rely on market observations to capture the value of an environmental good that it is not itself traded in any market but is in a way connected with other marketed goods" (Kougea et al., 2011); and ii) "Stated preferences" (SP) methods, in which "the market for a good is being constructed through the use of questionnaires" (Kougea et al., 2011). Table 2 reports the reviewed techniques, classified according to the belonging category (RP or SP) and the type of cost they contribute to compute.

***Table 2**: Review of main economic evaluation methods.*

Method	*Category*	*Cost*	*Reference*
Human Capital Approach	RP	Indirect	Garattini et al., 2000
Friction Cost Method	RP	Indirect	Garattini et al., 2000; Koopmanshap et al., 1995
Hedonic Pricing	RP	Indirect/Intangible	Kim et al.,2003; Saptutyningsih et al., 2015
Contingent Evaluation Method	SP	Indirect/Intangible	Guo et al., 2006; Ndambiri et al., 2015
Choice Experiment	SP	Indirect/Intangible	Sarabdeen et al., 2020; Yoo et al., 2008

3 Discussion

The review on epidemiological studies allowed to identify the main quantification techniques used to correlate health effects with their main causes (mainly with a dose-response approach). Attention was also devoted to the identification of other methods for non-monetary assessment of health impacts. In particular, the Health-Adjusted Life Years (HALY) can be cited (Gold et al., 2002), which allows to express both mortality and morbidity with a single value. HALY could be assessed in terms of Quality-Adjusted Life Years (QALY), which shows the health benefits obtainable thanks to pollution reduction (Gold et al., 2002), or of Disability-Adjusted Life Years (DALY), which accounts the negative effects of pollutants on health, expressed in terms of Years of Lost Life (YLL) (i.e. years of potential life lost due to premature death) or of Years Lived with Disability (YLD) (i.e. years of productivity lost due to disability) (Arnesen et al., 1999). Coming to the economic evaluations, there exist several methods to monetize the health effects due to air pollution exposure. According to (Jo, 2014), in COI calculations, intangible costs are rarely quantified, due to measurement difficulties. As reported in Table 2, the most diffused methods for the calculation of the indirect quota are: Human Capital Approach (HCA), which estimates the loss of productivity for all the period of worker disease, and Friction Cost Method (FCM), which considers the potential substitution of the sick worker, thus reducing the number of lost working days. For this reason, it is estimated that in the long run, FCM will results in lower estimations of indirect costs than HCA (Jo, 2014). As for the intangible costs, different techniques can be identified in order to estimate the individuals' WTP. Among these techniques, the Contingent Evaluation Method (CVM) appears to be the most used (Jo, 2014). Even though it is recognizable that WTP, being based mainly on individuals' preferences, allows to account for both indirect and intangible costs, it is not always possible to separate the intangible costs from the production losses (Pervin et al., 2008). It is worth noting that WTP method can be time-consuming, since it often makes use of surveys to be submitted to significant groups of people, in order to estimate their willingness to pay for a service or good; moreover, WTP results are strongly dependent on respondents' personal interpretation of the questions (Pervin et al., 2008) or on additional variables, as income or age (Silveira et al., 2015).

4 Conclusions

The growing attention on people health is pushing towards the need to provide scientific outcomes to policy decision-makers to include outdoor air quality standards in the urban planning processes. The paper focuses on the theme of outdoor air pollution, identifying the main metrics used in order to quantify its effects on people health. Moreover, attention is devoted to the classification of the most diffused socio-economic evaluation methods to monetize direct, indirect and intangible health costs, in turn associated to diseases caused by outdoor air pollution. The work highlights the complexity of the theme, which, despite the growing interest, is still new. Future study will be developed to test methods and metrics for different case studies, focusing on the urban environment.

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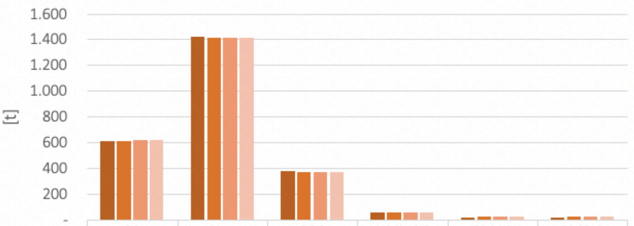
ANNEX 2

CHART

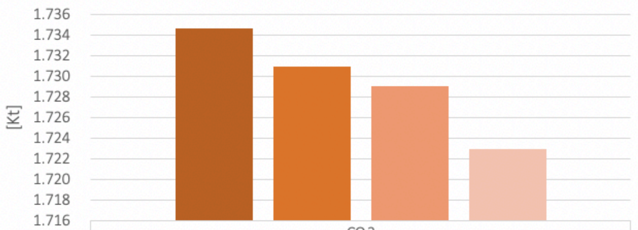
Emissions (S.R.-0.1) (0,8%,1.2% and 2,5%)

Emissions of air pollutants (S.R-0.1)



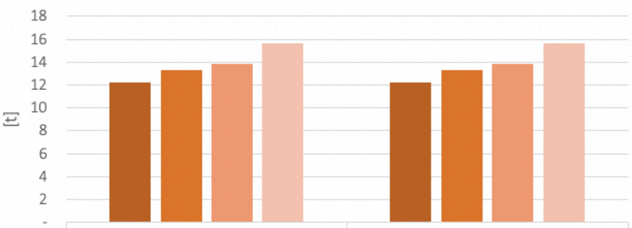
	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1.412,02	366,35	49,39	12,15	12,13
0.8%	605,87	1.409,92	365,54	49,40	13,24	13,22
1.2%	607,93	1.408,87	365,25	49,43	13,79	13,77
2.5%	614,62	1.405,47	364,30	49,55	15,56	15,55

Emission of CO2 (S.R-0.1)



	CO2
S.F.	1.734,69
0.8%	1.730,92
1.2%	1.729,04
2.5%	1.722,91

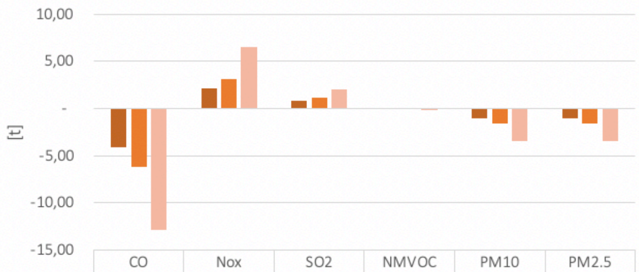
Emissions of PM (S.R-0.1)



	PM10	PM2.5
S.F.	12,15	12,13
0.8%	13,24	13,22
1.2%	13,79	13,77
2.5%	15,56	15,55

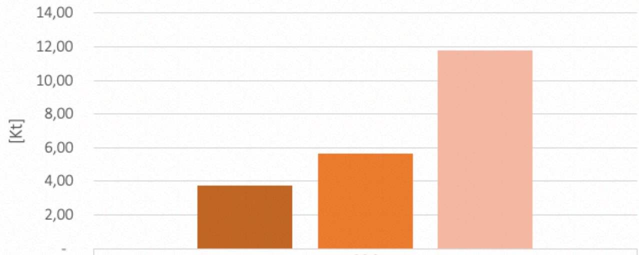
Net Avoided Emissions (S.R.-0.1) (0,8%,1.2% and 2,5%)

Net Avoid Emissions (S.R.-0.1)



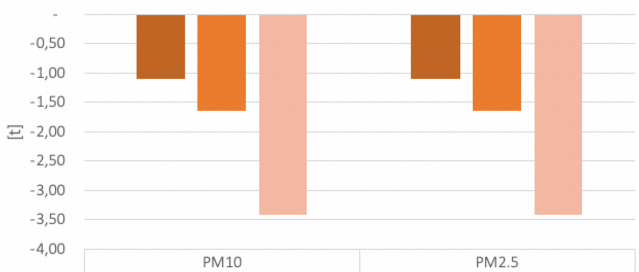
	CO	Nox	SO2	NMVOC	PM10	PM2.5
0.8%	-4,12	2,10	0,81	-0,01	-1,09	-1,09
1.2%	-6,18	3,14	1,10	-0,05	-1,64	-1,64
2.5%	-12,87	6,55	2,05	-0,16	-3,42	-3,42

Net Avoid Emission of CO2 (S.R.-0.1)



	CO2
0.8%	3,77
1.2%	5,66
2.5%	11,78

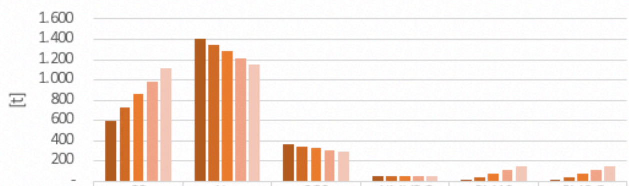
Net Avoid Emissions of PM (S.R.-0.1)



	PM10	PM2.5
0.8%	-1,09	-1,09
1.2%	-1,64	-1,64
2.5%	-3,42	-3,42

Emissions (S.R.-0.1) (25%,50%,75% and 100%)

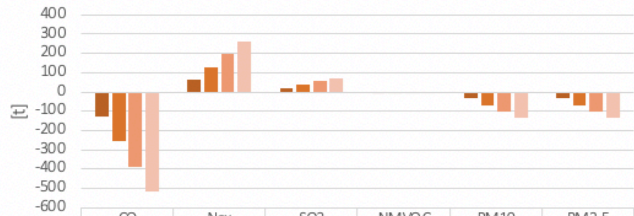
Emissions of air pollutants (S.R.-0.1)



	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1.412,02	366,35	49,39	12,15	12,13
25%	730,43	1.346,53	347,84	51,60	46,32	46,30
50%	859,11	1.281,04	329,56	53,88	80,49	80,47
75%	987,79	1.215,55	311,27	56,15	114,67	114,64
100%	1.116,46	1.150,06	292,99	58,43	148,84	148,80

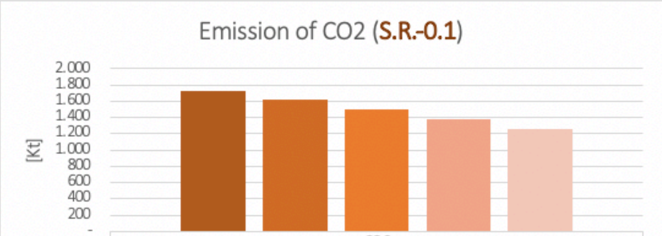
Net Avoided Emissions (S.R.-0.1) (25%,50%,75% and 100%)

Net Avoid Emissions (S.R.-0.1)

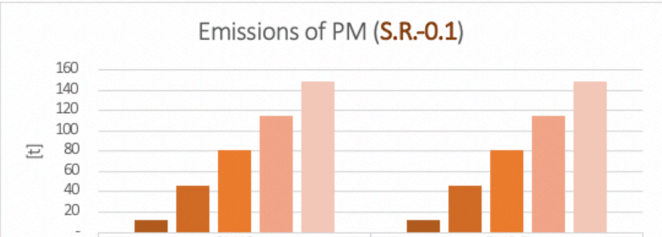


	CO	Nox	SO2	NMVOC	PM10	PM2.5
25%	-128,68	65,49	18,51	-2,21	-34,17	-34,17
50%	-257,36	130,98	36,80	-4,49	-68,35	-68,34
75%	-386,03	196,46	55,08	-6,77	-102,52	-102,51
100%	-514,71	261,95	73,37	-9,04	-136,69	-136,67

Emissions (S.R.-0.1) (25%,50%,75% and 100%)

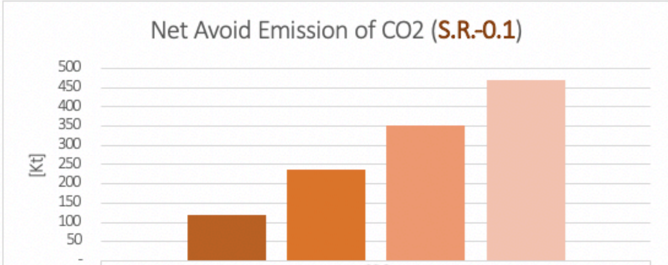


	CO2
S.F.	1.734,69
25%	1.616,86
50%	1.499,03
75%	1.381,20
100%	1.263,37

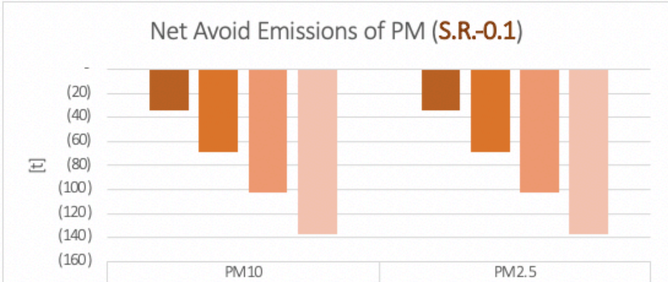


	PM10	PM2.5
S.F.	12,15	12,13
25%	46,32	46,30
50%	80,49	80,47
75%	114,67	114,64
100%	148,84	148,80

Net Avoided Emissions (S.R.-0.1) (25%,50%,75% and 100%)



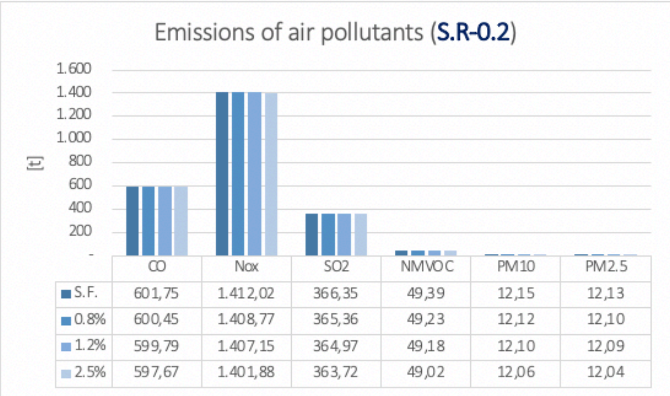
	CO2
25%	117,83
50%	235,66
75%	353,49
100%	471,32



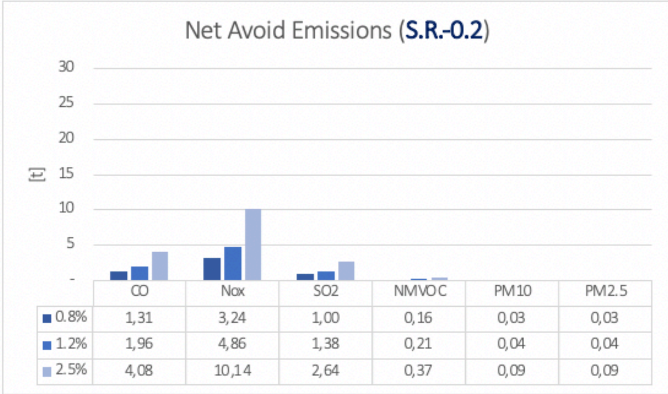
	PM10	PM2.5
25%	-34,17	-34,17
50%	-68,35	-68,34
75%	-102,52	-102,51
100%	-136,69	-136,67

Emissions (S.R.-0.2) (0,8%, 1,2% and 2,5%)

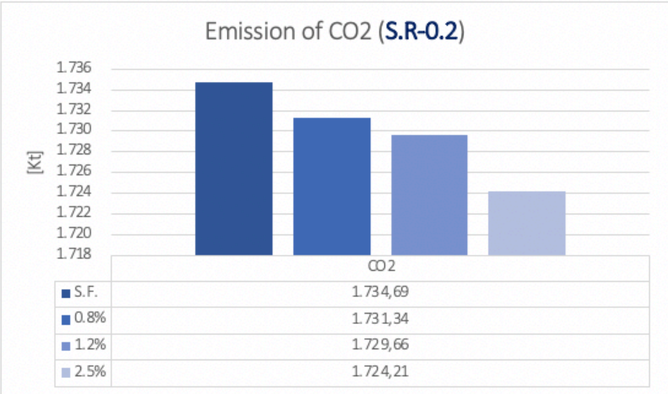
Net Avoided Emissions (S.R.-0.2) (0,8%, 1,2% and 2,5%)



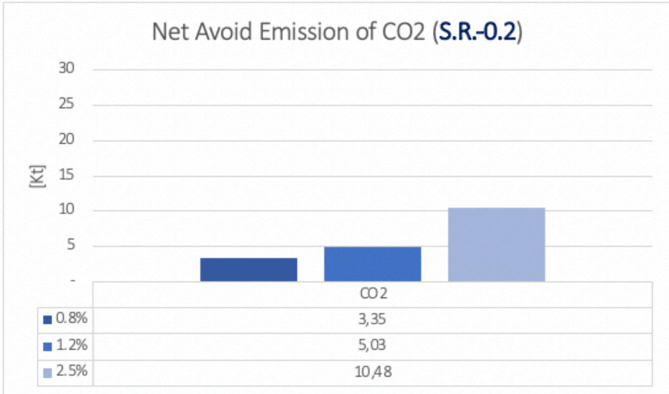
	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1.412,02	366,35	49,39	12,15	12,13
0.8%	600,45	1.408,77	365,36	49,23	12,12	12,10
1.2%	599,79	1.407,15	364,97	49,18	12,10	12,09
2.5%	597,67	1.401,88	363,72	49,02	12,06	12,04



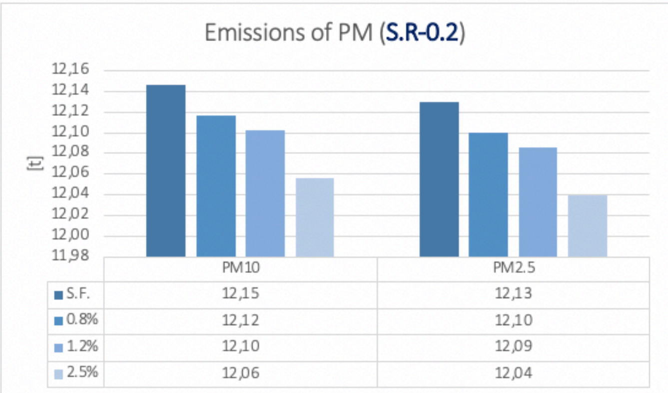
	CO	Nox	SO2	NMVOC	PM10	PM2.5
0.8%	1,31	3,24	1,00	0,16	0,03	0,03
1.2%	1,96	4,86	1,38	0,21	0,04	0,04
2.5%	4,08	10,14	2,64	0,37	0,09	0,09



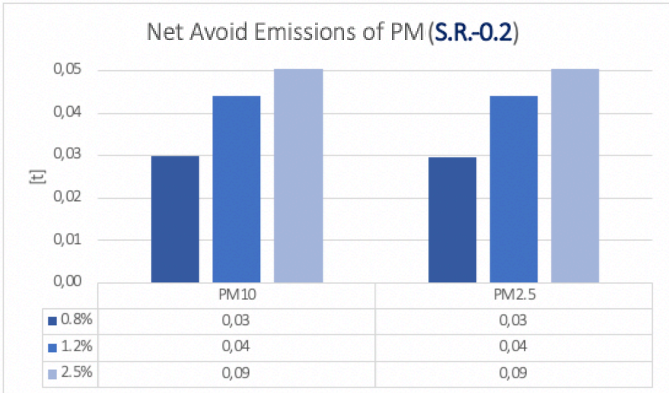
	CO2
S.F.	1.734,69
0.8%	1.731,34
1.2%	1.729,66
2.5%	1.724,21



	CO2
0.8%	3,35
1.2%	5,03
2.5%	10,48



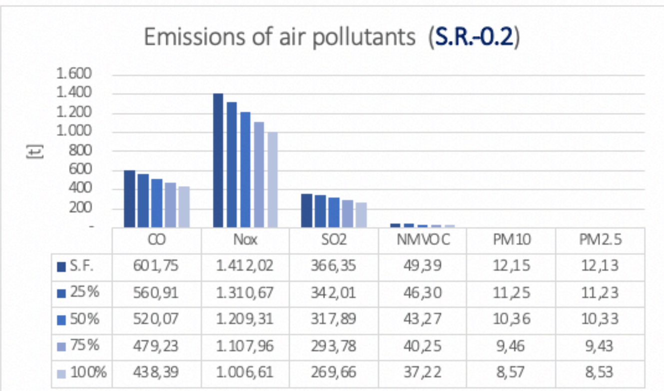
	PM10	PM2.5
S.F.	12,15	12,13
0.8%	12,12	12,10
1.2%	12,10	12,09
2.5%	12,06	12,04



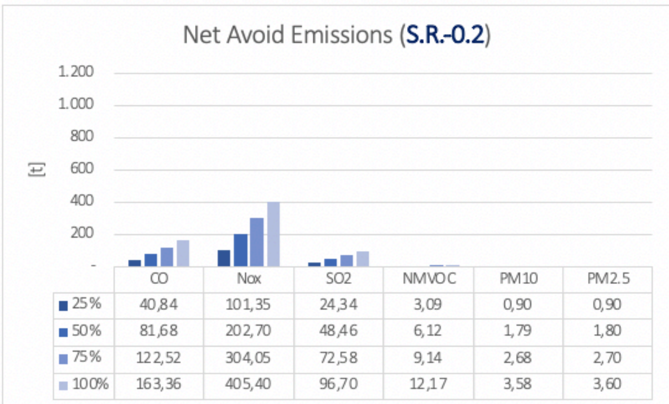
	PM10	PM2.5
0.8%	0,03	0,03
1.2%	0,04	0,04
2.5%	0,09	0,09

Emissions (S.R.-0.2) (25%, 50%,75 and 100%)

Net Avoided Emissions (S.R.-0.2) (25%, 50%, 75% and 100%)

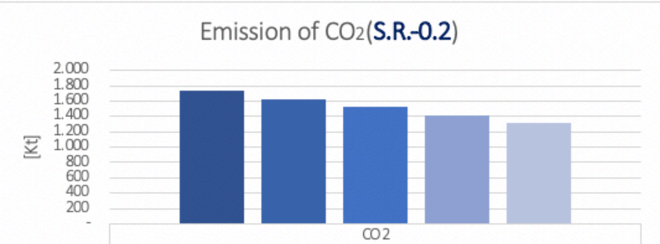


	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1.412,02	366,35	49,39	12,15	12,13
25%	560,91	1.310,67	342,01	46,30	11,25	11,23
50%	520,07	1.209,31	317,89	43,27	10,36	10,33
75%	479,23	1.107,96	293,78	40,25	9,46	9,43
100%	438,39	1.006,61	269,66	37,22	8,57	8,53

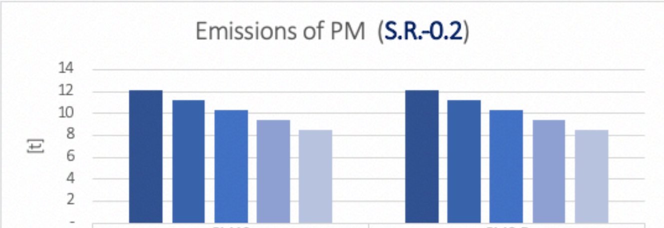


	CO	Nox	SO2	NMVOC	PM10	PM2.5
25%	40,84	101,35	24,34	3,09	0,90	0,90
50%	81,68	202,70	48,46	6,12	1,79	1,80
75%	122,52	304,05	72,58	9,14	2,68	2,70
100%	163,36	405,40	96,70	12,17	3,58	3,60

Emissions (S.R.-0.2) (25%, 50%,75 and 100%)

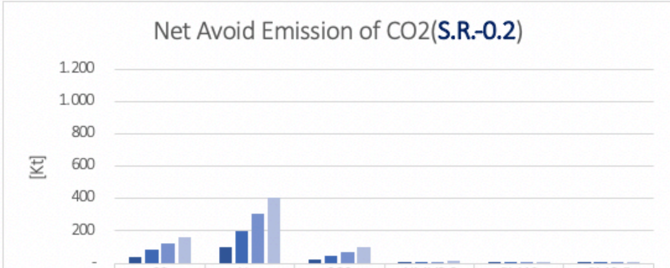


	CO2
S.F.	1.734,69
25%	1.629,86
50%	1.525,03
75%	1.420,20
100%	1.315,37

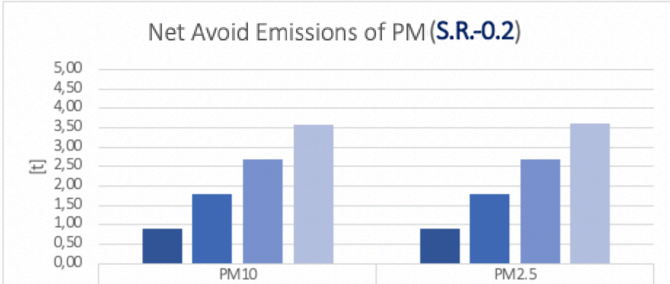


	PM10	PM2.5
S.F.	12,15	12,13
25%	11,25	11,23
50%	10,36	10,33
75%	9,46	9,43
100%	8,57	8,53

Net Avoided Emissions (S.R.-0.2) (25%, 50%,75 and 100%)

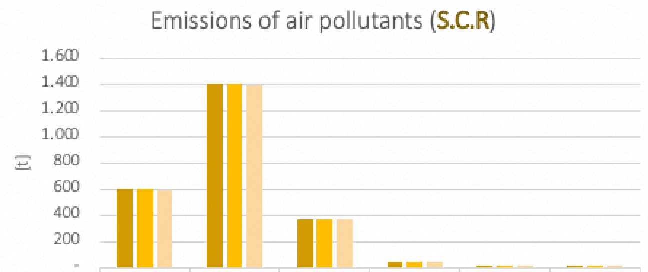


	CO	Nox	SO2	NMVOC	PM10	PM2.5
25%	40,84	101,35	24,34	3,09	0,90	0,90
50%	81,68	202,70	48,46	6,12	1,79	1,80
75%	122,52	304,05	72,58	9,14	2,68	2,70
100%	163,36	405,40	96,70	12,17	3,58	3,60

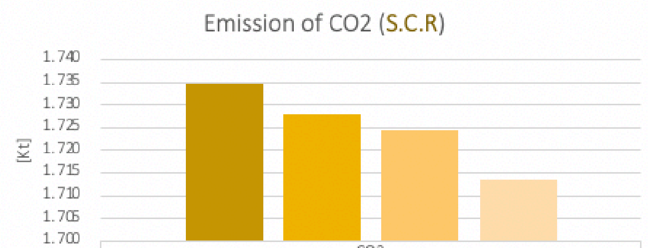


	PM10	PM2.5
25%	0,90	0,90
50%	1,79	1,80
75%	2,68	2,70
100%	3,58	3,60

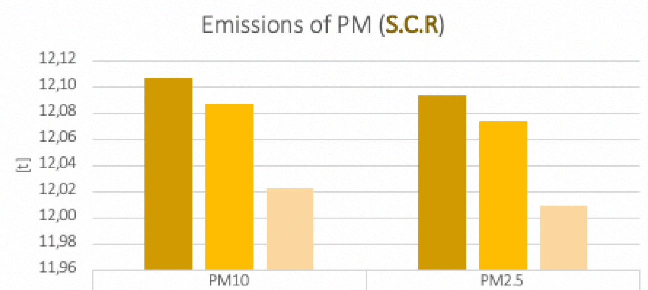
Emissions (S.C.R.) (0,8%,1.2% and 2,5%)



	CO	Nox	SO2	NMVOC	PM10	PM2.5
0.8%	599,13	1.406,34	365,50	49,18	12,11	12,09
1.2%	597,82	1.403,50	365,07	49,07	12,09	12,07
2.5%	593,56	1.394,27	363,68	48,73	12,02	12,01

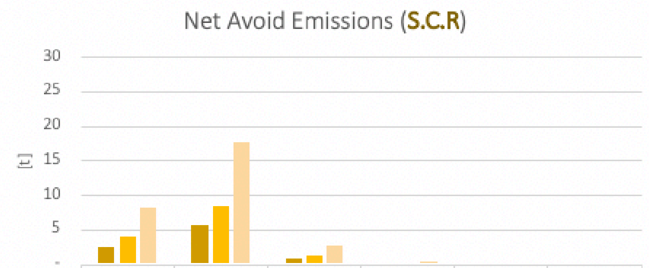


	CO2
S.F.	1.734,69
0.8%	1.727,87
1.2%	1.724,47
2.5%	1.713,39

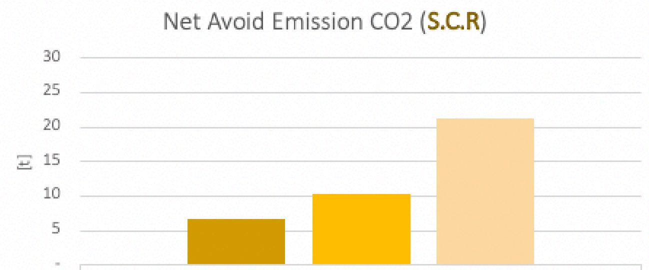


	PM10	PM2.5
0.8%	12,11	12,09
1.2%	12,09	12,07
2.5%	12,02	12,01

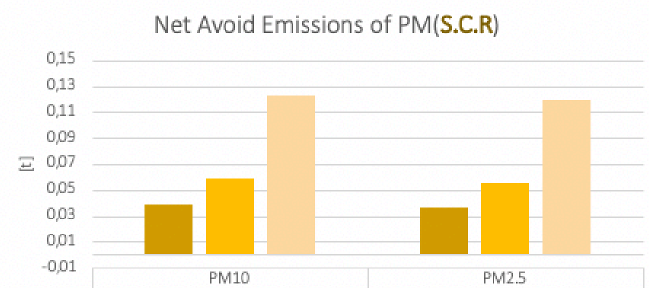
Net Avoided Emissions (S.C.R.) (0,8%,1.2% and 2,5%)



	CO	Nox	SO2	NMVOC	PM10	PM2.5
0.8%	2,62	5,68	0,85	0,21	0,04	0,04
1.2%	3,93	8,52	1,28	0,11	0,06	0,06
2.5%	8,19	17,74	2,67	0,34	0,12	0,12

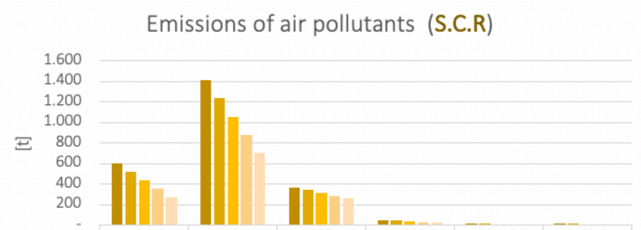


	CO2
0.8%	6,82
1.2%	10,23
2.5%	21,30



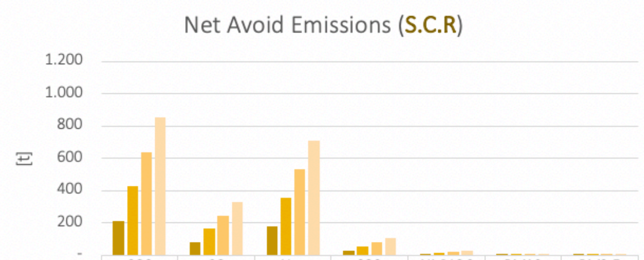
	PM10	PM2.5
0.8%	0,04	0,04
1.2%	0,06	0,06
2.5%	0,12	0,12

Emissions (S.C.R.) (25%,50%,75% and 100%)



	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1.412,02	366,35	49,39	12,15	12,13
25%	519,86	1.234,60	339,65	42,79	10,91	10,89
50%	437,97	1.057,17	312,94	36,18	9,67	9,65
75%	356,08	879,75	286,23	29,58	8,43	8,42
100%	274,18	702,33	259,53	22,98	7,20	7,18

Net Avoided Emissions (S.C.R.) (25%,50%,75% and 100%)

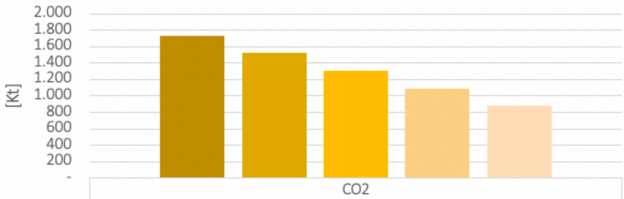


	CO2	CO	Nox	SO2	NMVOC	PM10	PM2.5
25%	213,04	81,89	177,42	26,71	6,60	1,24	1,24
50%	426,08	163,79	354,84	53,41	13,20	2,47	2,47
75%	639,12	245,68	532,26	80,12	19,81	3,71	3,71
100%	852,16	327,57	709,68	106,83	26,41	4,95	4,95

Emissions (S.C.R.) (25%,50%,75% and 100%)

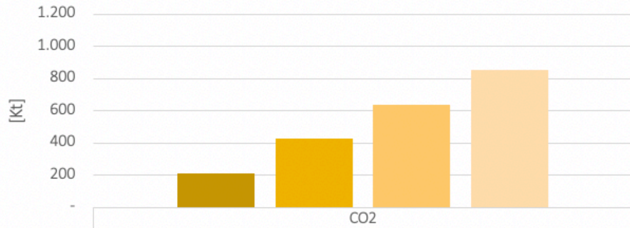
Net Avoided Emissions (S.C.R.) (25%,50%,75% and 100%)

Emission of CO_2(S.C.R)



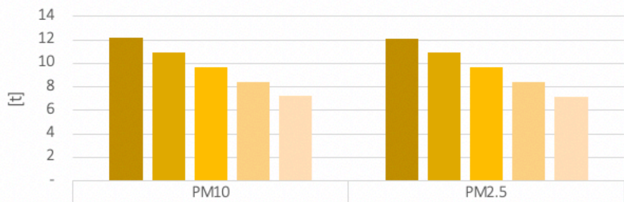
	CO2
S.F.	1.734,69
25%	1.521,65
50%	1.308,61
75%	1.095,57
100%	882,53

Net Avoid Emission of CO_2 (S.C.R)



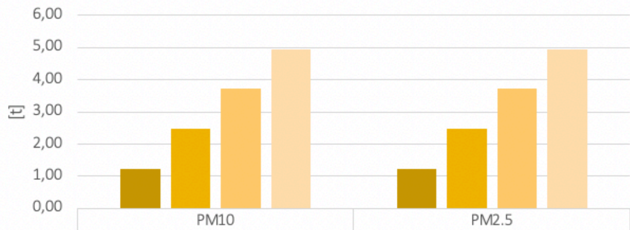
	CO2
25%	213,04
50%	426,08
75%	639,12
100%	852,16

Emissions of PM (S.C.R)



	PM10	PM2.5
S.F.	12,15	12,13
25%	10,91	10,89
50%	9,67	9,65
75%	8,43	8,42
100%	7,20	7,18

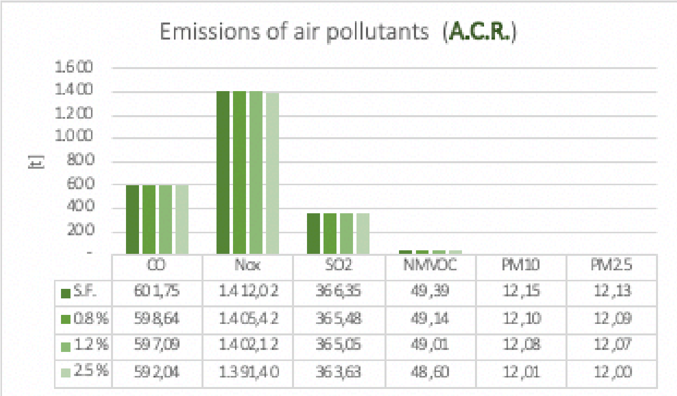
Net Avoid Emissions of PM (S.C.R)



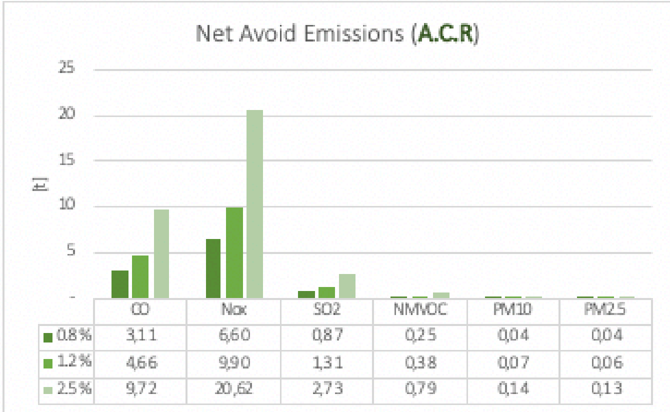
	PM10	PM2.5
25%	1,24	1,24
50%	2,47	2,47
75%	3,71	3,71
100%	4,95	4,95

Emissions (A.C.R.) (0,8%,1,2% and 2,5%)

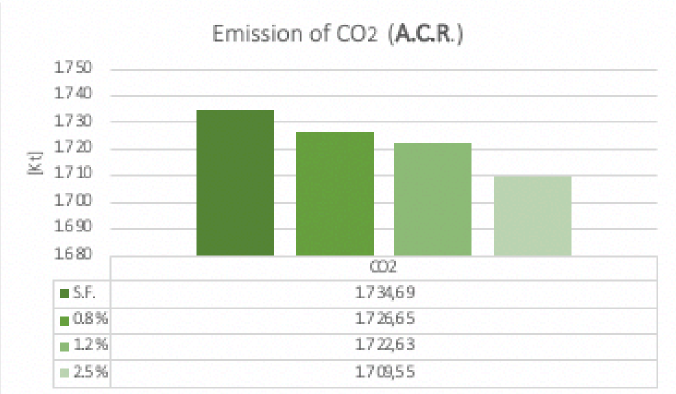
Net Avoided Emissions (A.C.R.) (0,8%,1,2% and 2,5%)



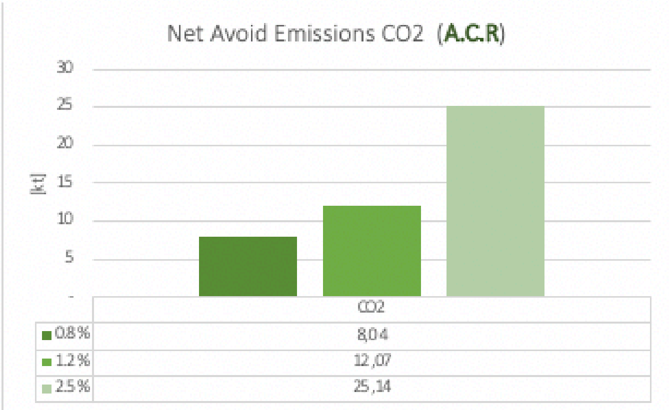
	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1412,02	366,35	49,39	12,15	12,13
0.8%	598,64	1405,42	365,48	49,14	12,10	12,09
1.2%	597,09	1402,12	365,05	49,01	12,08	12,07
2.5%	592,04	1391,40	363,63	48,60	12,01	12,00



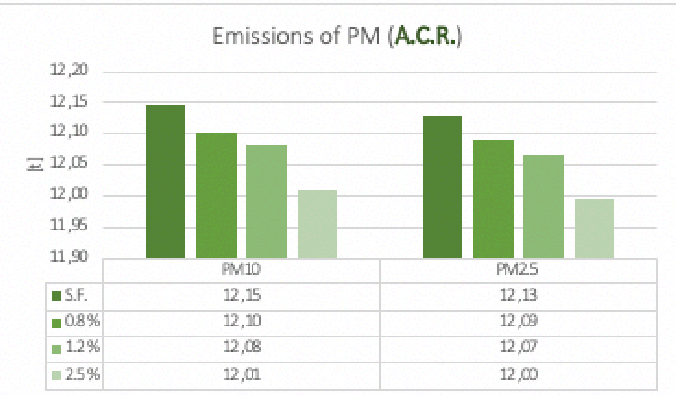
	CO	Nox	SO2	NMVOC	PM10	PM2.5
0.8%	3,11	6,60	0,87	0,25	0,04	0,04
1.2%	4,66	9,90	1,31	0,38	0,07	0,06
2.5%	9,72	20,62	2,73	0,79	0,14	0,13



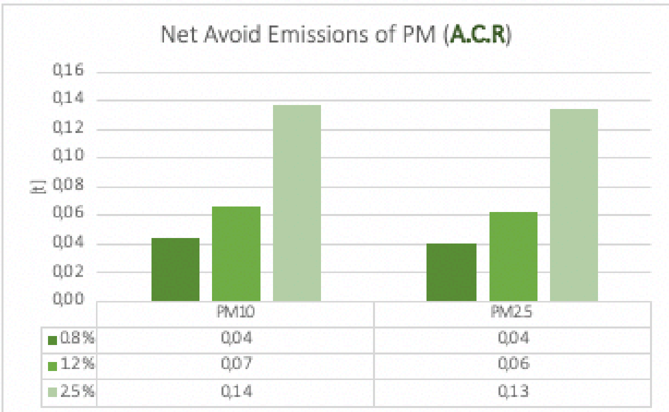
	CO2
S.F.	1734,69
0.8%	1726,65
1.2%	1722,63
2.5%	1709,55



	CO2
0.8%	8,04
1.2%	12,07
2.5%	25,14



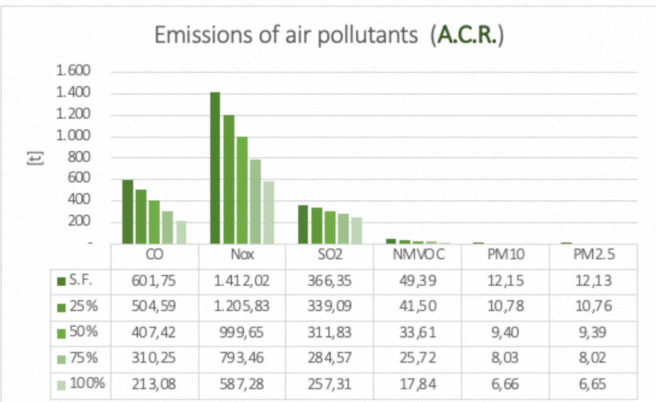
	PM10	PM2.5
S.F.	12,15	12,13
0.8%	12,10	12,09
1.2%	12,08	12,07
2.5%	12,01	12,00



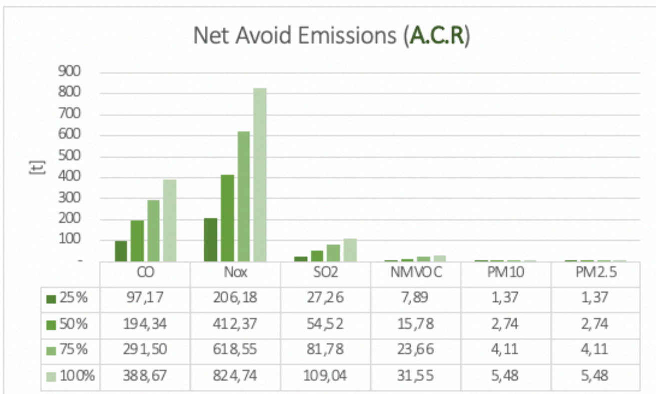
	PM10	PM2.5
0.8%	0,04	0,04
1.2%	0,07	0,06
2.5%	0,14	0,13

Emissions (A.C.R.) (25%,50%, 75% and 100%)

Net Avoided Emissions (A.C.R.) (25%,50%, 75% and 100%)

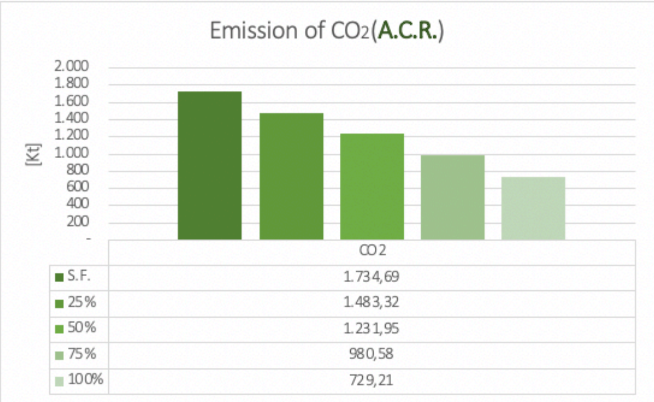


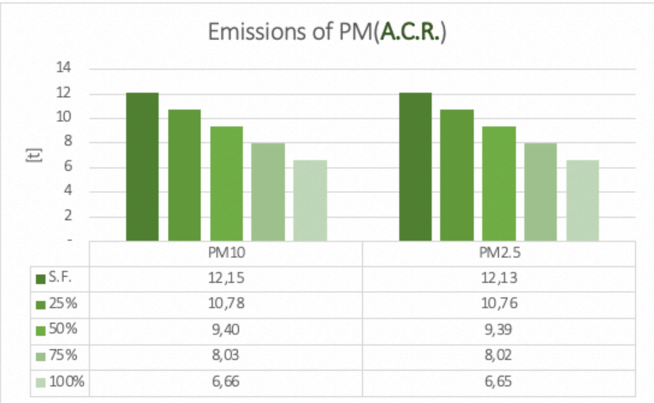
	CO	Nox	SO2	NMVOC	PM10	PM2.5
S.F.	601,75	1.412,02	366,35	49,39	12,15	12,13
25%	504,59	1.205,83	339,09	41,50	10,78	10,76
50%	407,42	999,65	311,83	33,61	9,40	9,39
75%	310,25	793,46	284,57	25,72	8,03	8,02
100%	213,08	587,28	257,31	17,84	6,66	6,65



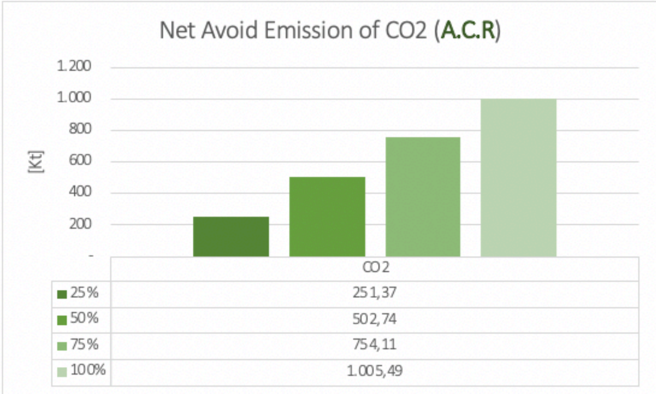
	CO	Nox	SO2	NMVOC	PM10	PM2.5
25%	97,17	206,18	27,26	7,89	1,37	1,37
50%	194,34	412,37	54,52	15,78	2,74	2,74
75%	291,50	618,55	81,78	23,66	4,11	4,11
100%	388,67	824,74	109,04	31,55	5,48	5,48

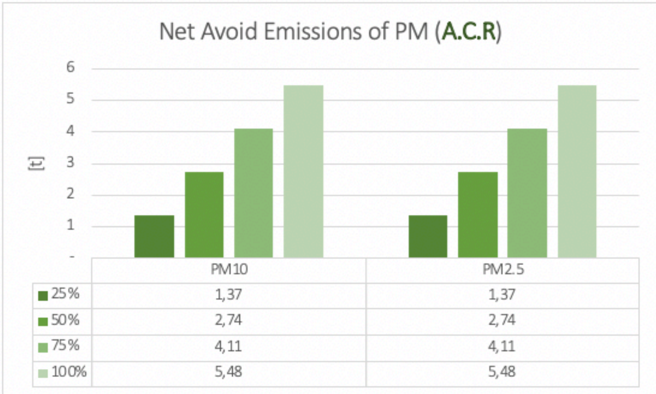
Emissions (A.C.R.)
(25%,50%, 75% and 100%)





Net Avoided Emissions (A.C.R.)
(25%,50%, 75% and 100%)





it's TIME to

ACT.