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A cost-effectiveness analysis of Milan's SEAP. The application of the Marginal Abatement Cost Curve approach for prioritizing climate mitigation measures

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Summary

In the field of climate mitigation, a more and more important crucial component of an effective decision making is the selection and the prioritization of which actions to implement among a range of possible alternatives. In this regards, the Cost-Effectiveness Analysis has become a quite common approach in supporting the prioritization process in a performative way. A specific type of cost-effectiveness analysis, emerged during the last years, is the Marginal Abatement Cost Curve (MACC). Despite its first application in the energy sector, this analytical tool is finding a growing interest also at the urban level, allowing to compare not only the economic costs of a measure but also its abatement potential in term of CO_2 reduction.

This research tries to investigate the application of the MACC approach at the city level in Italy, a country in which the previous examples of similar application are much fewer than in other countries. The municipality selected for this study is the city of Milan, due to its international dimension and a strong committment in the battle for climate changes emerged in the last years. In addition, during 2018 Milan's municipality has been also involved in the approval and adoption of the new Sustainable Energy Action Plan (SEAP), that includes a variety of measures with different targets and different emission reductions expected.

According to the availability of data, this research aims at developing a Marginal Abatement Cost Curves of some of the measures included in the SEAP, in order to assess their cost-effectiveness and contribute to the evaluation of which actions should be prioritized and implemented. A first part is dedicated to a detailed literature review in order to figure out the space for developing the MACC tool and the most critical point from a methodological point of view. Second, the process of data collection is presented, with also its limitations. Thirdly, different MACC are built in order to investigate the effectiveness of the measures part of the scope of the research.

In short, the most effective measures in terms of financial savings is the plan for the efficiency of the public light system, while for what concerns the abatement potential of CO_2 emissions the measures more performative are the municipal notices for increasing the energetic efficiency in private buildings. The limited availability of data and some intrinsic rigidities in the model call also for a broader evaluation, able to review and update in a flexible way the data collected. Furthermore, in the conclusion there is also the space for reflecting on future improvements of this research. Crucial points are the consideration of all the stakeholders involved in the measures proposed by the SEAP and the treatment of other issues conventionally excluded from the MACC approach, like co-benefits and other externalities.

Keywords

Cost-Effectiveness Analysis, Marginal Abatement Cost Curve, Sustainable Energy Action Plan, Climate Mitigation, Energy Sector

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Abbreviations

GHG	Greenhouse gas emissions
SEAP	Action Plan for Sustainable energy
MACC	Marginal Abatement Cost Curve
NPV	Net Present Value

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Chapter 1: Introduction

1.1 Background. The cities as key-sites of climate mitigation and the problem of selecting and prioritizing climate mitigation measures

During the last years, in the context of climate change policy, cities have been receiving growing importance both for what concerns their role in the international governance of climate change and in taking effective actions of mitigation and adaptation. One of the data more emphasized in the last year is the forecast of the number of people who will live in cities in 2050, expected to become around the 70% of the world population (World Health Organization, 2016). Also in the academic literature, it seems to be nowadays a quite general accepted and recognized trend. For example, McCartney, Blanco, et al., (2011) stress the need for an empowered governance of cities in order to face the challenges of climate changes, recognizing them as relevant sites of governance in national and international context. Reckien, Flacke, et al., (2015) point how cities are largely responsible of global greenhouse gas emission and that if on the one hand they are particularly vulnerable to climate hazard, on the other hand they are pivotal for climate mitigation and adaptation. In this regard, Gouldson, Colenbrander, et al., (2015) underline how the rapidly growing significance of cities, especially in the developing world, has profound implications for the mitigation of climate change. In a more simple and concise way, it is more indicative to report the words of Joan Clos, under-secretary and Executive-Director of UN-Habitat, in the foreword of the Comparative review of Nationally Determined contribution for Urban Content in the Paris Agreement (2016): "The battle for sustainable development will be won or lost in cities. Our cities have become the main driver of economic development and prosperity. Yet past and present urban practices are unsustainable … We must address this quickly, and effectively."

Therefore, given as accepted the role of cities in climate change, the question turns immediately on how to achieve significant results in terms of mitigation and adaptation (Reckien, Flacke, et al., 2015). Looking at both academic studies and real urban case studies, cities that strongly aim at facing climate change in a serious way should follow some specific steps in the process of adoption and realization of effective climate mitigation and adaptation plans. Following the Guiding Principle for Climate City Action Planning (UN-Habitat 2015), the advised method could be split in three different main steps: firstly, the identification and understanding phase, with the setting of the political commitment and the understanding of the scientific knowledge and information; secondly, the envisioning and planning phase, with the prioritization of the actions, the participation and the coordination to them; and lastly, the implementation phase with management and monitoring activities. More in detail, for what concerns climate mitigation, the suggested steps are developing an inventory of greenhouse gas emission (GHG), setting objectives and target to achieve, assessing and selecting the most appropriate measures, implementing and monitoring them. The same process is valid also for adaptation plans, with the difference of realizing an initial vulnerability profile instead of an inventory of the emissions. Of course there is no a single way for accomplish each step of the process, and many aspects remain problematic. What is clear nowadays and generally accepted is the crucial importance that the phase of selection and prioritization of actions has, and the strong consequences that it can have in the politics of climate change.

1.2 Background. Climate mitigation in Italy and Milan: ambitious targets but which actions?

As a member of the European Union, Italy has to subscribe and follow a series of over-national regulations in matter of climate change. In 1998 Italy signed the Kyoto Protocol. In the period of first commitment (until 2012) it was able to reduce its emission by 6.5% below the 1990 level, 1.5% under the target of 8% fixed by EU. For the second commitment period (until 2020) Italy is expected to reduce its emissions by 20% compared to 1990. Furthermore, according to the Effort Sharing Decision of European Union, Italy needs to reduce its GHG emissions by 13 percent compared to 2005 levels until 2020. Following the ratification and the entry into force of the Paris Agreement and the ratified Intended Nationally Determined Contribution (INDCs), the forecast for 2030 is to reduce emissions by 40% compared to 1990 levels (Climate Policy Observer 2018). After all, according to the CMCC (Euro-Mediterranean Centre for Climate Change), the projections for the period 2071-2100 in Italy see an increase in the average temperature of about 3.2°C compared to one century before, with a flow of precipitations that will increase in colder season and reduce in warmer seasons. Nevertheless, despite the international obligations and the alarming national and global scenarios, the battle for climate change in Italy seems to be relatively different from the several and general slogan in favour of climate sustainability. Looking at the Executive Summary of the Climate Report presented by The Foundation for Sustainable Development (2016), the GHG emissions grew in 2015 of about 2,5%, after years of slightly reduction, and the contribution of renewable energies to the energy consumption in the period 2013-2015 just increase from 16,6% to 17,2%. Unfortunately, if Italy seems able to achieve the European target for 2020, it is really unlikely that it will be able to achieve the 2030 targets if the current scenario is not going to change.

Not more positive is the situation for what concerns the public opinion and the general awareness about the issue of climate change. In an interesting paper, Beltrame, Bucchi, Loner (2016) focus on climate change communication in Italy, considering it as essentially pragmatic and "commonsensical", arguing that Italian citizens mainly rely on information provided by mass media, while environmental organizations sustain that public communication by scientists is still marginal.

The only significant national document produced was the National Adaptation Plan in 2015, which provides a national vision to address climate change adaptation, actions and guidelines to build adaptive capacity (Climate Policy Observer, 2018). Despite the presence of a significant number of suggested measures and guidelines for dealing with the problem of uncertainty, the Document clearly states that it is necessary to design a set of prioritization criteria for assessing this large portfolio of actions, even if it does not say anything else about this issue. In other words, there is not enough attention on how to choose the best or preferred options, and there is no evidence of any other kind of reliable cost-effectiveness analysis.

Moving into the Municipality of Milan, it is nowadays generally accepted that it is the most innovative Italian city under many point of view (ICITYLAB 2017). Also for what concerns the environmental issues, and specifically the problem of pollution and climate mitigation, Milan is a city that presents several problems, mainly related to its geographical position (it is located in the centre of a vast flat area, dense and deeply urbanized), and to its dimension and its economic role. During the last years, the municipality has already started doing an effort in reducing the pollution inside the city and in following the national and international targets for reducing emissions. Some important actions have already been taken in the field of energy efficiency and transports. An important moment was also the adhesion to the Covenant of the Major in 2008. This initiative fostered the realization of two different plans: a Plan for Sustainable Energy and Climate in 2009, and a more recent SEAP (Action Plan for Sustainable Energy) in 2015. The first plan was probably more complete, considering that it included a preliminary evaluation of the costs related to the abatement measures, although it did not arrive to a clear ranking and prioritization of the measures. The SEAP is directly defined by the Covenant of Mayors for Climate and energy as "the key document in which the Covenant signatory outlines how it intends to reach its CO_2 reduction target by 2020. It defines the activities and measures set up to achieve the targets, together with time frames and assigned responsibilities" (Covenant of Mayors 2010). This second Plan seems to present some problems, despite a very good emissions inventory, a detailed abatement potential and the consideration of a plurality of actions in different sectors (from buildings, public illumination to transports). If it is true that it has the ambitious plan to achieve the reduction of greenhouse gas emission target for 2020 in comparison to the level of 2005, on the other hand there has been a significative delay in the final approval of the plan (the deadline of the target is just in two years) and also the economic feasibility of the measures presents some weaknesses. In other terms, the SEAP proposes an assessment of a range of sustainable measures based on their emissions abatement potential, and on the rather general guideline to include only those measures that have some tangible possibilities to be implemented and to be financed. In short, the SEAP does not present a deep analysis of other important variables which can really affect the implementation process, like simply the real cost of the measures (only a few economic data are reported, and probably those missing were not excluded by choice, but simply because not calculated yet). Furthermore, the only criteria that contributes to the prioritization process is the division of the measures in a "consolidated scenario" and a "further scenario". However, given the richness of the plan in term of variety of actions introduces, there is no evidence about which measures are the most effective in terms of goal achieved and implementation.

The need to fill this gap seems to be very important, considering also the relevancy attributed to the Action Plans for Sustainable Energy, at least in Europe. In fact, according to a recent international research published on the Journal of Cleaner Production, among 885 European cities, the 66% has adopted a mitigation plan, the 26% an adaptation plan, and the 17% both. In addition, 40% of these cities is part of the Covenant of Mayors, and the 94% of them have already arranged a SEAP (Insalutenews 2018). To be fair, it also important to underline the fact that all the European SEAP are not binding plans, and often the economic dimension covers a secondary space in favour of the emission inventory, planning phase and the monitoring process.

Summing up, it seems there is a not irrelevant gap in the policy of climate mitigation in the city of Milan, with ambitious plans and goals but few understanding of which actions could be more effective and easy to implement. The very recent Municipal Plan for Sustainable Mobility (2017) and a further step in the approval of the SEAP demonstrate a coherent effort of the Municipality, but also weak indications for the implementation process.

1.3 Problem Statement. The possible space for developing a Marginal Abatement Cost Curve at the urban scale in Italy

The interest of this work is on the phase of assessment and selection of mitigation measures, exploring the possible application at the city level of the so-called Marginal Abatement Cost Curve (MACC) in a country like Italy, which traditionally presents a weak use of this cost-effective economic tool if compared to other countries. In other words, what Gouldson, Sudmant et al., (2015) call "the economic case" for investment in climate change mitigation. The MAC curve is a particular graphical ordered representation of potential actions and measures that could be developed in order to achieve a specific goal. In recent years its growing popularity has encourage several decision makers and experts to apply this model in the field of climate policy, with particular regard to climate mitigation. Some decision makers have recently even tried to develop MAC curve at the urban level, reinforcing the popularity of the tool but also the debate about the reliability and utility of a cost-effective perspective in selecting and prioritizing mitigation actions. Despite its worldwide application, it is still surprising that this approach has found very few attention and application in Italy. Therefore, it seems interesting and relevant to mind this gap and exploring the application of a Marginal Abatement Cost Curve in the case of an Italian city and in the context of climate mitigation policy.

This operation presents a certain degree of ambitious, given the few previous similar applications in Italy, considering an intensive and necessary work of data collection (not all the data are always available), and most of all the need of a critical methodological review, in order to address the most evident limits highlighted until now both in academic literature and in the recent experiences.

1.4 Research Objectives. The application of a MAC curve for assessing urban measures of climate mitigation

The ultimate objective of this research is to develop a Marginal Abatement Cost Curve related to the SEAP of Milan, in order to assess which are the most potentially cost-effective measures and actions for reducing GHG emission in the city. The ideal point of view is addressing the problem of climate mitigation from the perspective of the Municipality, since the Italian municipalities are often increasingly dealing with bigger and bigger budget constraints. Naturally, in doing that, it is in unavoidable to look the existing academic literature and review practical experiences and case studies in a critical way, reviewing methodological proposals, critics and the intrinsic limitations of this tool. A further ambition is to try to figure out an updated methodology, solidly built on the previous ones and adapted to the Italian context, that allow to build a MAC curve that works at the city level and that could be applied and tested in a real case. In doing that, two elements become the most relevant for this research: on one side the critical review of the existing approaches in order to propose some refined methodological alternatives; on the other side their application in a relatively new context, both geographically (Italy and the case of Milan), and as level of governance (the municipal level).

1.5 Provisional Research Questions: which measures of SEAP are more cost-effective?

The main research question of this work is what are the most cost-effective measures that can be implemented by the Municipality of Milan in order to reduce the emission of pollutants in the city.

Beside the main question, it is also possible to formulate some sub-questions, for better structuring the research. A preliminary sub-question refers to what the municipality of Milan is currently doing in the field of climate policy mitigation, as already presented in this chapter. A further sub question asks which are the variables and the parameters that seem to affect more strongly the cost-effectiveness of some initiatives in different sectors. In addition, a last methodological sub-question investigates which are the current limitation of the MACC approach and the existence of a space for an upgrade in its methodology and application.

Given this structure of the questions, it is necessary to follow some specific steps for developing the research. First, a preliminary step is a recognition of what the municipality of Milan is doing in the field of climate mitigation and sustainable development; as already introduced, the 2018 represents an important moment for the city, since the new SEAP has been finally approved. Second, a methodological research in order to investigate what is the state of the use of the MACC tool, which are the possible limitations that have emerged in recent years and which are the most reliable and solid methodologies developed until now. The following step concerns the investigation of the SEAP and its official document recently approved (in particular the Document of Plan and the Report about the State of Advancement). According to the availability and reliability of the data collected it will be possible to figure out which measures could effectively be object of the cost-effectiveness analysis and which have to be excluded from the scope of this research. The last step will be the most relevant and refers to the ranking and prioritization process of the measures object of analysis, with the relative design of the new Marginal Abatement Cost Curves. Lastly, according to the data collected and the results achieved, it is possible to design some new updated methodological considerations, highlighting also limits and recommendations for further researches.

1.6 Significance of the Study. A new application and a contribution to the academic debate

Without doubts the phase of assessment and prioritization of climate mitigation measures represent a crucial moment along the decision-making process, able to affect strongly the following decisions, the implementation of the measures, and ultimately the quality of the results achieved in addressing the challenges of climate mitigation in cities. For this reason, understanding the mechanisms and the tools that can support municipalities and public decision makers in the phase of selection of actions and measures can be very important from a practical point of view. In addition, following Gouldson, Colenbrander, et al., (2015), these economic tools "could be critical in building political commitment, strengthening institutional capacities, securing large-scale finance and targeting investment and implementation in cities". Therefore, it does not seem a case that these economic tools have found a quite large application in recent years, and that there are some innovative example of application of MAC curve at the city level in the world. Indeed, this research aims at investigate the application of the MAC curve at the city level, given that until now it has found broad application especially at the country or regional level (Vogt Schilb and Hallegatte, 2013).

Furthermore, looking at the context of application, the relevance of this research lays also on the fact that in Italy there is no evidence of a large use of neither MAC curves nor other cost-effective tools at the cities level for what concerns climate mitigation. Therefore, the application of an updated methodology in a tangible real case study could be considered also a kind of pioneer exploration, despite its limitations. Especially for the city of Milan, there is no evidence of a comprehensive Marginal Abatement Cost Curve for climate mitigation measures, able to mobilize the discussions on which actions the municipality should prioritize. Furthermore this study enters in the process of implementation of the municipal SEAP, becoming an interesting and useful tool for the process of selection and prioritization of specific measures.

Moreover, beside the real application in the practice of city management, this kind of research seems to have also a specific relevance also at the academic level, questioning and taking into account the different critics and suggestions that come from literature, and that make the issue of Marginal Abatement Curve still a hot topic. In fact, from an academic point of view, there is no a wide consensus about the application of the MAC curve and its methodology: someone claims for a lack of academic studies in this specific field (Gouldson, Colenbrander, et al., 2015), while other scholars question not only the methodology of MACC but also its mean and outcomes for the policy of climate change (Ponz-Tienda, Prada-Hernandez et al., 2016).

1.7 Scope and Limitations. A city and a SEAP as case study for climate mitigation

For what concerns the scope of the research, this work focuses on the use of cost-effectiveness analysis and the application in a case study of the Marginal Abatement Cost Curve. For a more valid and reliable research, different existing methodologies derived from academic literature are presented and developed, highlighting their working mechanisms and their main limitations. Subsequently, the space and relevance for a new methodological proposal is questioned, with the intention to overcome some of the most important limitations that have emerged in the application of the previous methodologies.

The choice of focusing the interest of the research in mitigation rather than adaptation (or even both) basically lays on the minor difficulties in finding adequate data concerning the potential risks and impacts of disastrous events, and on a more structured academic debate that allow an higher degree of data accuracy and a deeper analysis also at the methodological level. If the part related to review of academic literature allows a wide overview of the main insights and criticalities, the application in the case study (the city of Milan) creates much more difficulties. Those are essentially related to the problem of achieving relevant and feasible data for building the MAC curve, trying to cover as much as possible those sectors that are currently under investigation in order to achieve concrete results in terms of greenhouse gas emissions reduction inside the city. As many scholars have already underline, it is hard to accept this economic approach as a definitive statement about the actions that need to be implemented by a municipality, but can be anyway a meaningful tool for exploring some specific situations, make comparisons and foster the knowledge and the involvement of different stakeholders. Ultimately, an ambitious goal is also trying to import this not-absolute model in a country in which it has always received for now few application and probably not enough attention.

Lastly, moving to the physical context of the study, this research considers the city of Milan as case of analysis. Basically, this is due to the fact that is a large city, with several environmental problems, but also one of the most dynamic and active city for what concerns the politic of climate changes. Furthermore, a bigger city is expected to have a more structured administrative organization that (at least in theory) should allow to collect data and information in an easier and more exhaustive way. In this regards, there are also previous studies related to the case of Milan which focus on climate change and cost-effectiveness analysis and which already have reported relevant data and results. An example is the survey made by Sabrina Melandri in 2010 for the Municipality and related to the strategic lines for reducing the emission of CO_2 in the city of Milan (Melandri 2010). The actions that are considered in the analysis and that are part of the assessment thought the MACC approach are directly advanced by the Action Plan for Sustainable energy. Therefore, this document informs the set of measures that are currently at the study of the Municipality and that are assessed in this research work. This choice presents two consequences: firstly, the measures considered are not arbitrary but solidly placed in the decisional context of the Municipality of Milan, and they do not even have to be considered as the comprehensive, finite list of all the possible actions; secondly, the measure refer to different sectors, being the issue of energy and the intentions of SEAP relatively transversal.

Chapter 2: Literature Review and Theory

This chapter aims at providing a general overview of climate mitigation policy, Cost-effectiveness analysis and MAC curve in the field of climate change. It presents both a review of academic literature and an analysis of the methodologies applied in some case studies, especially those in which the MAC curve was developed at the urban level (the same of the scope of this research). A first part explores from a theoretical point of view the debate concerning the nature of this approach, the strong and weak points and their relative outcome; the following part considers the existing applications and case studies, describes the methodologies applied, the assumptions considered and the results produced.

2.1 Climate Mitigation Policy and the European Context State of the Art of the Theories/Concepts of the Study

Nowadays it is generally accepted that urbanization and climate changes are source of environmental and developmental challenges, calling for both the need to adapt and the urgency to mitigate the causes of climate change (UN-Habitat 2011). It is also clear that cities represent the main field of actions for this battle, especially in the developed countries where the production of emissions is higher and therefore the need of mitigation more necessary. Moreover, also relatively clear are the main urban drivers of emissions (like the economic base, the individual lifestyles, the urban shape and density, the carbon intensity and the weather conditions), and the impact of climate change effects at the city level (from the urban heat island effect, to the increase of the risk of floods, the stress on the public health, the resource scarcity and the ecosystem degradation).

Despite mitigation can also contribute to the achievement of local development goals and despite cities could potentially reinforce, intensify or precede national policies (United Nations Development Programme 2010), many issues concerning the governance and the financing of mitigation actions still need to be faced. In fact, according to McCartney, Blaco et. al., (2011), "cities governments are constrained on a number of fronts when it comes to formulating and implementing climate action" (p. 250), calling for a stronger empowerment of cities, based on effective leadership, efficient financing, inclusive citizens participation and jurisdictional coordination. Likewise, Sippel and Jansen (2009) recognize the main barriers to formulate more targeted policies for local climate governance (costs of climate policies, lack of cooperation, lack of leadership and political support, limited monitoring and evaluation of policies and tragedy of the commons) and state that the three main motivations for local mitigation policies are cost savings, improvement of air quality and reduction of vulnerability (p. 251).

It appears evident that in climate mitigation policy the issue of financing the measures is as important as the issue of governance, and is one of the most relevant barrier to overtake. Many studies of feasibility fail because of idealized assumptions, like the availability of large technologies, an immediate universal participation, an economic optimal reduction and few constraints to implementation (IPCC 2014). Much caution has to paid in conducing these kind of investment decision analysis for assessing the costs that a specific mitigation measure requires. Especially for local municipalities this represent a very crucial moment in the decision making, in particular when they are forced to act with very limited budget. In addition, it is important to underline that, for environmental decisions, the assessment is particularly difficult, because very often it is necessary to include other kind of evaluations that do not concern only the financial analysis, but also other more complex effects, rather difficult to calculate (like the environmental impact, the institution capacity and the appropriate technology). In these regards, the three most common analysis applied are the Cost-Benefit analysis, the Cost-Effectiveness analysis and the Multicriteria Analysis.

Another issue related to climate mitigation policy is the realization and implementation of specific mitigation plans. Especially after the Paris Agreement (that fixed the target to keep global temperature rise in this century below 2°C above pre-industrial level and to limit the temperature increase even further, to 1.5°C), the focus on cities as crucial protagonist in climate change mitigation has increase, especially in Europe. According to a study by Reckien, Salvia et al., (2017), European national and local government have prioritised mitigation over adaptation, probably with the intention to reduce emissions and increase economic saving and energetic security. The results of that research show that around 66% of the European cities considered has developed autonomous or inter-national induced plans; these plans have also been classified among comprehensive, stand-alone, mainstreaming, partial stand alone, operational, related or areal plans. Another finding is that international climate networks (like the Covenant of Mayors), and national regulations are able to strongly affect the development of local climate plans. For the short-term future, the challenge for climate change mitigation will be especially in these local climate plans, in those city that are more largely responsible of the amount of GHG emission produced in the last years.

2.2 Cost-effectiveness analysis and Marginal Abatement Cost Curve: new applications for traditional economic tools

As starting point, it is important to highlight that the Cost-Effectiveness analysis and more specifically the Marginal Abatement Cost Curve are not recent tools in the economic field. The Cost-Effectiveness analysis was develop with the intention of overtaking some of the most evident limits of the Cost-Benefit analysis. This last one can be considered as a policy assessment method with the aim of quantifying in monetary terms the value of all consequences of a decision to all members of society (Boardman, Greenberg, et al., 2011). However this economic approach has showed some limitations and dissatisfactions, basically related to the accuse of evaluating all the impacts in monetary terms (also those not normally traded in market, like the cost of human lives) and to the suspect of undermining democracy by imposing both a single goal and the criteria of efficiency in the assessment of public policies (Boardman, Greenberg, et al., 2011). What Cost-effectiveness analysis tries to do is to compare alternatives in terms of the ration of their costs and a single quantified, but not monetized, effectiveness measure (Boardman, Greenberg, et al., 2011). Indeed, sometimes analysists can quantify impacts but not monetize them at all, making impossible to estimate net benefits: in the case of climate mitigation, the problem is the quantification of the GHG emissions, which are hard to estimate only in monetary terms. The presence of two different metrics (in the case of climate mitigation, the cost and the level of GHG emissions reduction) allows to include one of the most important policy impacts in the evaluation, taking into account also some potential social benefit. For this main reason Cost-Effectiveness analysis seems to perform better of a rather "short-sighted" Cost-Benefit Analysis in the context of climate policy, overtaking at same time three main constraints, as reported by Boardman, Greenberg, et al., (2011): firstly, the unwillingness or inability to monetize the most important policy impacts by the analysts or the clients; secondly, the difficulties to capture all the social benefits of each alternatives; thirdly, the necessity to deal with intermediate goods whose linkages to preference are not clear.

The Marginal Abatement Cost curve can be considered as a detailed application of a Cost-Effectiveness Analysis. The graph that represents the curve has indeed two parameters (or criteria), allowing the identification of benefits not only in monetary terms. Referring to climate mitigation, "a MAC curve is defined as a graph that indicates the cost, usually in $ or another currency per t CO_2, associated with the last unit (the marginal cost) of emission abatement for varying amounts of emission reductions (in general, in million tons of CO_2). Therefore, such a chart contrasts the marginal abatement cost on the y-axis and the emission abatement level on the x-axis" (Kesicki and Strachan 2011, p. 1195). Nevertheless, following the same authors, the earliest applications of MAC curves date back to the 80s and at the beginning they did not concern climate policy (Kesicki and Strachan 2011). In fact, designing a brief history of their application, the MAC curves were initially used as analytical tool in the field of energy efficiency, in the sector of transport, industry and buildings. Instead, the earliest examples of carbon-focused curves date back to the following decade, while only over the past 20 years a vast number of MAC curves have been realized with regard of climate mitigation.

Concerning the application of the MAC curve in the field of climate policy, an important moment has been the presentation of a series of curves by the McKinsey Company between 2007 and 2009. The report (that obtained a big success) included a global greenhouse gas abatement data base with the evaluation of more than 200 opportunities across 10 sectors and 21 world regions (McKinsey Company 2009). In addition, it has given an important contribution in increasing the popularity of the tool, even convincing several policy makers to consider the MAC curve as a standard tool for describing the possibility of action in climate mitigation policy. Despite this growing popularity of the MAC and nevertheless international bodies, countries and regions have tested and developed its application, several scholars have underline some critics and limitation in the academic field.

A basic element that helps in explaining the popularity of MAC curve is its bottom-up approach. According to Stevens and Senbel (2017), there are two different ways for setting targets: the first one is a top-down approach, essentially done by first selecting a relative ambitious target and then determining which types of policies would be necessary for achieving the target; the second one is a bottom-up process that works by first identifying feasible policy options, evaluating their potential emissions reduction, and then adopting a target in order to match the estimated reductions resulting from successful implementation of those policies. The MAC curve is part of this second case and its popularity depends also on the fact that if it is true that this bottom-up approach could discourage innovative or ambitious policy changes (Pitt and Randolph 2009), it is also true that is more likely to produce achievable targets that can help a municipality to secure "early wins" (Kotter 1995).

Remaining on the main features of the MAC curves, some authors have also proposed a distinction in different typologies for classifying the several graphs that have been produced worldwide. Kesicki and Strachan (2011) distinguish between expert-based curve and model-based curve, while Du, Hanley, et al. (2015) add a third group, the supply-side (or production-based) MACC. The first one, the expert-based curve, is the most popular (the McKinsey curves fall into this category) and it is also the one that this works aims at considering and developing, so it will receive more attention than the other two. The expert-based curve is also called the technological curve and it is an individual, bottom-up assessment of abatement measures. In other words, it assesses the emission reduction potential and the corresponding costs of each single technical option, based on assumptions developed by experts. As a result, the technical options are ranked, usually from the most to the least cost-effective in order to represent the cost of achieving incremental levels of emission reduction. Coming to the other groups, the Model derived MAC is based on an equilibrium model, with different strict emission limits and derived costs of the corresponding emission levels. Instead, the Supply-side MACC is based on the production theory and on the interpretation of constraint induced marginal costs as opportunity costs (the idea is that the production unit has to sacrifice some profit by reallocating its productive resources to abatement activities to cut emissions at the margin).

2.3 Strengths and limitation of the MAC curve

Generally speaking, both the Cost-Effectiveness Analysis and the MAC curve present some strong and weak points. In short, for what concerns the positive aspects and the strengths these economic models are able to deal with budget constraints, and moreover they are able to be target oriented and to represent benefits not only in monetary terms. At the contrary, concerning the main limitations, these are the consideration of just two parameters, the technical problems of having several and accurate data, and most of all the difficulties in capturing the interrelationships between the different options presented in the chart. However, the clarity of the curve represented and its easy communicability have made the MAC a growing popular tool. Du, Hanley, et al. (2015) underline the role of MAC curve as illustrative guide, simplified representation of more complex relations between the emission abatement effort and the marginal cost of cutting units of Co2 emissions. In other words, the key of its success lies on its apparent simplicity and communicability, making it a very good tool for increasing actors' awareness and an illustrative guide in climate mitigation. Especially it seems to be a performative approach able to bring together in the negotiation process both policy makers, stakeholders and experts and to help in designing a road map for emission reduction in condition of limited budgets.

Nevertheless, other authors have stressed how the debate among the methodology, the outcome of MAC curve and the use of the tool itself is still problematic and far from a definitive conclusion. In fact, "although MAC curves are proven to be extremely efficient in communicating results regarding the economic implications of climate mitigation by reporting the cost and potential of a list of mitigation measures, some discrepancies arose relating to the construction and interpretation of MAC curves in recent years" (Tienda, Prada –Hernandez, et al., 2016). In this section, some of the most relevant critics and limitations highlighted in academic literature are reported, in order to understand which are the main criticalities that need to the overtaken in order to develop a new MAC curve and which are the main intrinsic limitations that will remain anyway ingrained in the notion of the curve.

One of the scholars who more actively has tried to present in a comprehensive way the main limitation of the MAC curve is Fabian Kesicki. In a paper of 2011 he presented a series of "Analitical considerations in constructing and interpreting MAC curves" (Kesicki, Strachan, 2011). More in detail, he focuses on four main issues: implementation barriers, choice of the discount rate, intertemporal issues and uncertainty. For what concerns the implementation barriers, Kesicki underlines how generally MAC curves focus on direct costs associated with emission reduction, neglecting other social costs, the effective implementation costs and market imperfections or barriers that affect the outcomes of the curve, making the whole negative abatement potential probably not correct and therefore misleading. Regarding the choice of the discount rate, the dilemma is choosing a lower social discount rate in order to determine if a specific measure could be beneficial to the whole society, or if preferring a more realistic private discount rate; about the choice of the most appropriate discount rate there is a wide literature, and one example is provided by Goulder and Roberton (2012) with the distinction between a social-welfare equivalent discount rate or a finance-equivalent discount rate. The third issue considered is related to the timeline of the curve, which usually is one year: however, problems arise because the curve does not provide any kind of information about the permit and the insights into the timing and rate of investments in each measure, neglecting some necessary information that are the basis for long-lasting decisions. Lastly, the fourth issues is more generally the level of uncertainty that is always present in this kind of scenario development; such uncertainty concerns the future technologies available, the price of energy, the demand development and other factors. These four issues are considered by Kesicki as partially influencing and dependent by each other, somehow increasing the uncertainty about the results of the curve. In an another work Ekins and Kesicki (2012) go beyond, arguing a necessary caution in the use of Marginal Abatement Cost Curve for policymakers and questioning the compatibility of negative measure (below the zero in the graphical representation of the curve) with an efficient market, assuming that these measures should quickly taken up, so quickly exhausting their potential (Taylor 2012).

Other scholars focus more on single standing problems. For example Vogt Schilb and Hallegatte (2013) reflect on the issue of "optimal timing", from the point of view of how to help the public decision maker to design optimal emission-reduction strategies. Their main thesis is that the optimal strategy for reaching a short-term target in realty depends also on long-term target, considering that the measures required for accomplishing the expected emission reductions need time for their implementation.

Taylor (2012) focuses his work on the large presence in several MAC curves of negative measures and on how to treat them. His main argument is that the ranking of a set of negative-cost measures is not reliable. Using the formula $Mstd = c/g$ (where c is the specific cost of a measure and g is the specific emission saving) for calculating the standard metric of each measure, a misleading result happens when the specific cost c of a given measure M is negative (meaning that there is a net return on the investment or a profit). In fact, in order to achieve a more desirable ranking for the measure M, it results more convenient to reduce the relative emission savings g (in other words it is better to have a lower value for g). But selecting a measure that promotes a lower level of emission reduction is not only not desirable, it is also the contrary of what the MAC curve should try to achieve. Conversely, the formula does not seem to provide any problems when the specific cost c is positive. The same critics is advance by Ward (2014), arguing as MAC curves that presents a net negative cost is inappropriate and lead to incorrect outcomes. On this point, Ackerman and Bueno (2011) already claimed for the controversial nature of negative net costs. This critic about the outcomes of the curve clearly questions the validity of the selection process of the options and calls for an update in the methodology.

From another point of view Ponz-Tienda, Prada-Hernandez et al., (2016) underline the interest of the decision makers as a crucial element, and as something that is missing both in the traditional MAC curves and in the alternative methodological proposals. Furthermore, they even open at the possibility to choose a different methodology of building the curve, by proposing a Balanced Ordering Method that allows thought a weighted combination to compare different approaches and to select them according to a specific relative interest (like a stronger environmental sensitivity or a more pragmatic economical perspective).

Definitively, it is clear how there are some problems that need to be taken into account and that do not allow to consider the Marginal Abatement cost Curve as an absolute and valid individual tool for selection among a portfolio of actions. Some of these problems are related intrinsically to the nature of Cost-Effectiveness analysis, like the missing consideration of scale effects and a ranking system that fosters policies at relatively lower costs per unit instead of policies with larger impacts (Boardman, Greenberg, et al., 2011). Furthermore, costs and effectiveness are usually measured incrementally and additional information about the preferences of the context of the decision problem do not allow a strong basis for choosing among alternatives. Therefore, several authors do not deny the interpretation of cost-effectiveness ratios as measure of efficiency but call for care and caution. A last consideration regards the emerging challenge or dilemma that seems to emerge for what concerns the improvement and the application of the MAC curve: on one side the need to balance an improved methodology (more performative and reliable, but with the risk of becoming too much complicated and difficult to be adopted by public administrations), on the other side the necessity to look at the future implementation of the measures, possibly taking into account also environmental and social criteria beyond the pure economic argument.

2.4 Different methodologies proposed

As already introduced, the most common method for building a MAC curve is to divide the specific costs of a measure and its specific emissions saving. This is generally considered as the Traditional Marginal Abatement Cost Curve, and the author that probably presented it in the most comprehensive way in literature is Fabian Kesicki (2012, 2013). The costs are calculated subtracting the investment cost of the measure and its economic benefit generated; if the result of the cost is negative it means there is a financial return, while if the final result of the cost is positive it means there is a financial loss (WALGA 2014). Nevertheless some authors have recognized the popularity and the utility of the MACC but have also tried in recent years to overtake some emerging issues by proposing new methodologies. This section introduces shortly three different proposal by Taylor (2012), Ward (2014) and Ponz-Tienda, Prada-Hernandez et al., (2016). Some elements of their proposals have already been presented in the previous paragraph.

A first alternative method considered is the Taylor's Method: the reason of its consideration is the attempt to propose a solution for the shortcoming derived by an incorrect behaviour of the standard chart under some conditions. Given as accepted that all the measures present a positive amount of emission savings (otherwise they would not be useful actions in terms of climate mitigation), and therefore a positive denominator in the formula, the critical point concerns the incorrect ranking of those measures that present a financial return, and therefore a negative numerator because the economic benefits is greater that the investment cost (Taylor 2012). Taylor has focused his work on this specific flaw, and has been the first author who proposes an alternative method for facing this issue. In fact, a measures is preferable if it shows a lower result in the division between the costs and the emissions savings. The problem raised by Taylor is that a smaller final result is achieved by a greater financial return, that is a desiderable objective, or by a reduction in the specific emission savings, that is the opposite of the goals for climate mitigation. What happens is therefore that in the case of measures with a financial return, the MAC curve ranks in a preferred position those measure that in reality present a lower abatement potential. The intrinsic critic is the risk of prioritize actions that are not really effective in the battle for climate mitigation. For this reason Taylor argues the inapplicability of the standard metric of traditional MAC curves, and proposes a solution that implies a different way of ranking measures with negative costs, by applying a Pareto front. For the measures with positive costs the standard MACC approach does not present issues and therefore the existing methodology is maintained. For the measures with negative costs the "Nondominated ranking" method (Taylor 2012, p. 11) is applied, and basically it relies on a multi-objective optimization making use of the Pareto front. By maximizing two criteria (greater greenhouse gas reductions and lower costs) and then setting the condition of dominance, it becomes possible to treat the measures with negative costs. In short, the standard method for the measures with a financial loss and a Pareto front for ranking the measures with a financial return.

On Taylor's wavelength, Ward proposes an alternative dealing with the same problems of the wrong interpretation when net discounted costs are negative, claiming for the correct application of traditional MAC curve only in the presence of positive specific costs and positive emissions reductions. As potential optimal solution, Ward suggests to maximize the total benefit by adopting those measure for which the financial benefit, added to the width of the curve and multiplied by an assumed value of emission saved, is maximized. Nevertheless, He recognizes the complexity of this solution and the high risk of a wrong interpretation, therefore he suggests a simpler idea: to plot a function that is directly related to the benefit, taking a range of values for avoided emissions and simply plotting the net benefits of each measure (Ward 2014).

The third proposal is considered by Ponz-Tienda, Prada-Hernandez et, al. (2016), and it reviews Taylor and Ward's methods, recognizing once again some open issues and advancing own proposals. In particular, it directly tackles Taylor's proposal, considering not comparable two measures that have been calculated with different methods, like it happens in Taylor's Nondominated ranking method, generating discontinuous results. Furthermore, the authors stress another lack in the previous methodological proposal: the necessity to take into account the interests of decision makers, without regard of whether they are giving more importance to economic or environmental positions. For these reasons, they design two possible methodologies. The first one is the so called "Gain maximizing method" (Ponz-Tienda, Prada-Hernandez et al., 2016, 310) and aims at ranking negative measures in a continuous way, fostering those measures which present greater emission reduction potential and an higher benefit-cost relation. By introducing a specific indicator and a free variable, which a value between 1 and 0,001 in the formula, it is possible to build a model that is always negative, overtaking the diversity of treatment and of interpretation between measures with a positive or negative specific cost. In the formula, the financial benefit (B) of the measure is divided by the cost of the investment (C) and the free variable (e); then the result is multiplied for the abatement potential (E). The result is an indicator that the lower it is the better it is, and a graphical representation that is similar to the traditional Mac curve, with the exception that the height of the bars does not represent anymore the marginal cost, but the result of the method. The second model is the "Extended MAC method" (Ponz-Tienda, Prada-Hernandez et al., 2016, 311), that allows the direct and continuous ranking of both positive and negative measures as in the previous model, but in this case the index fosters those measures with lower costs instead of a greater reduction potential. By applying another specific variable, this approach allows to select the measures with greater cost-effectiveness in the positive range and measures with greater abatement potential and greater costs reduction on the negative side. It appears evident how the Gain maximizing method works better for a more eco-friendly approach, while the Extended MAC method gives more importance to the financial constraints. In addition, the authors suggested a complex way for comparing different methodology, in order to select which is the more performative in a specific situation, but without arriving at a definite statement about which method is in absolute the best. At the contrary, they recognize the need to further research for including inter-sectoral, inter-temporal and macroeconomic interactions or wider social implication.

2.5 The importance of assumptions and some recent "urban" applications

Although the graph of a Marginal Abatement Cost curve is realized ranking different measures according to two variables, there are a lot of data and evaluations before the final representation. Ekins and Kesicki, in the "Caveats on the use of MAC curves" (Ekins and Kesicki 2012, p. 4), underline the importance of the assumptions in the application of these economic tools. In fact, supporting the graphical representation of the curve with methodological premises and the (unavoidable) assumptions can contribute to give comprehensibility, transparency and accountability to the work. Considering the McKinsey curves, one of the strongest critics that that report received was exactly the opacity of the input assumptions used for providing an objective and uniform set of data (Ekins and Kesicki 2012).

In this paragraph, a review of some concrete applications of MAC curve is presented. Obviously major attention is given to those cases that assessed the cost-effectiveness at the "urban" level in a quite broad comprehensive way, rather than focusing on the sectorial applications or in some national or regional curves. The following cases are relative to cities like London, New York and Shanghai. The information reported are exclusively taken by the official reports or presentations.

A first very relevant example is the case of London, with the 2012 report "*Sustainable London Infrastructure. A view to 2025*". It includes a description of a series of different technological options, with varying effectiveness and cost implications, which can contribute to the environmental sustainability of the city. The explicit insight is the unavoidable crucial consideration of economic growth also in environmental issues, and the belief that many potential measures related to energy, water consumption and waste management could be sustainable not only from an environmental point of view but also from an economic one. Therefore, the primary aim of the report is to help decision makers to take solid and informed decision on available technologies, following a detailed and analytical approach. In order to pursuit this objective, the report quantifies the current and likely future carbon emissions and (through specific analysis and comparisons) defines the challenges and figures out the costs and the improvement opportunities of different technological options. A very detailed methodology description at the beginning explains the results emerged in the Marginal Abatement Cost curves realized. The methodological structure follows three points: the definition of quantifiable sustainability metrics, the setting of a baseline forecast and finally the determination of technology cost curves for each areas. In regards of the quantifiable metrics, the reports relies on the per capita environmental footprint, the demand for specific goods and services, and the overall efficiency with which the demand in met in the city. Moving to the baseline forecast, the reports define a likely scenario for 2025, with a constant technology adoption approach, which assumes that the current level of adoption and installation of relevant technologies will remain the same as in the present, so no future efficiency improvements are considered. Moreover, no additional measures are considered in the course of the next years. In the third point, the report designs an abatement cost curve for each infrastructure areas outlined (buildings, transport, energy supply, water and waste), showing the amount of annual improvement that would come from that technology's adoption beyond the baseline by 2025. A last point that need to be considered is the treatment of potential interdependencies in order to avoid doublecounting and the preliminary necessary assumptions. Without going into detail, they mainly regards the world market prices of some materials (like oil) that is considered as fix, the fact that the it considers only those technologies that can have an effective impact within 2025 and their implementation rate, and the association of behavioural changes only to purchase choices. Beside the methodology applied and the assumptions made, the interest for this study is the consideration of a decision maker perspective (like the scope of this research), calculating the costs and savings, assuming different discount rates and considering taxes and other duties.

Similarly, in 2013 the New York Mayor's Office of Long-term Planning and Sustainability presented the document "*New York City's Pathways to deep Carbon reductions*". The main goal of this study was to evaluate which are the most cost-effective measures for achieving long-term carbon reductions, by identifying the lowest cost pathways and the highest priority actions that need to be implemented by the Municipality. The study proceeded with the following steps: firstly, the evaluation of the technical potential for reducing GHG emissions in four sectors (buildings, energy, transportation and waste), secondly, the calculation of the abatement potential and the cost-effectiveness of a series of actions across those sectors, lastly the evaluation of the options and of the timelines. As in the case of London, the focus is on existing and emerging technologies, without including future further innovations. Moreover, there are also a series of assumptions, that regards essentially the ambitiousness but achievability of the measures proposed, the idea of replacing the equipment only at the end of their life-cycle in order to minimize costs and the no consideration of carbon price or other actions that would lead to a price signal in the marketplace. Other interesting points that come out from the document are the consideration of implementation barriers and of other indications, like the job opportunities and the possible co-benefits among sectors. Furthermore, there is also trace of the presence of a societal costs, assumed to be financed at a 4% discount rate; despite its strict limitation, this concept fosters a quicker comparison among different cost-effective measures.

Moving to Shanghai, in 2013 the World Bank presented the report "*Applying Abatement Cost Curve Methodology for Low-Carbon Strategy in Changning District, Shanghai*". Here the main difference is the scope of the research, which is not the entire urban municipality but just one district. As a result, three different scenario are presented and were developed thanks to bottom-up investigations, MAC curves and implementation considerations. The report calls also for a high replicability, at least in other Chinese cities. The abatement opportunity is calculated by establishing the current penetration rate of each abatement measure (with relative costs, efficiency and constraints), then projecting the growth curve of each technology's penetration rate, and lastly by estimating each abatement measure's potential in order to reduce the emissions in comparison with a pre-existing business as usual scenario. The main assumptions regards the strong government support, the applicability of the technologies involved and supply constraints. Even in this case, the study refers the costs to a societal basis and a societal discount rate because the perspective adopted is the one from Changning District government. Furthermore, a sensitive analysis is conducted and, all the measures are ranked in four different groups (retrofitting existing commercial buildings, green power, retrofitting existing residential buildings, low-emissions new buildings, behaviour changes and green mobility).

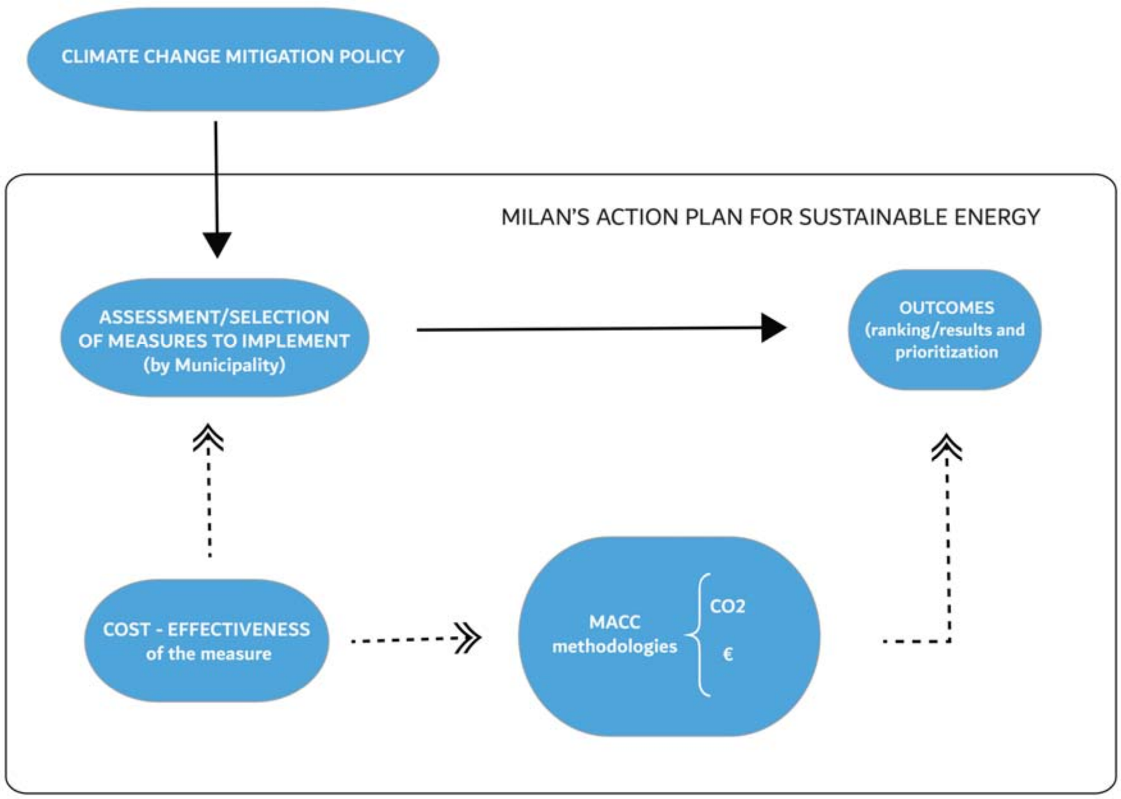
For what concerns the developing countries, Colenbrander, Gouldson, et al., (2015) provide an interesting case in the Indonesian city of Palembang. This study is based on a bottom-up assessment of costs, returns and emissions abatement from a portfolio of low-carbon measures. The key scope is to look at the direct, private economic costs and benefits, considering them as often the preliminary component for considering those kind investments. As consequence, co-benefits and important distribution effects are not included, and the same works for changes in land use. The considered sectors are housing, commercial buildings, transport, industry and waste, analysing the emissions from fuel and purchase electricity. The process saw the development of a business as usual scenario, with assumptions related to the population and economic growth; then a portfolio of action is presented after reviewing the existing literature and consultations with stakeholders; the last step is the evaluation of each measures' feasibility and impact on carbon emissions.

In addition to these cases reported above, there are several other researches that develop a MAC curve, even if the focus is more at the regional-national level or on some specific economic sectors. Among the others, some examples are: the "Greenhouse Gas Emissions Cost Effectiveness Study" made by Los Angeles County Metropolitan Authority (2010), the report to the Department of the Environment for Meeting Australia's 2030 emissions reduction target (2016), a study by Matute and Chester (2015) concerning the high-speed-rail and urban transportation projects in California; a cost-effectiveness valuation of GHG emission reduction from the use of hybrid electric vehicles (Kammen, Arons, et. al., 2008); and another study about the marginal cost of carbon abatement from planting street trees in New York City (Kovacs, Haight, et al., 2013).

2.6 Conceptual framework

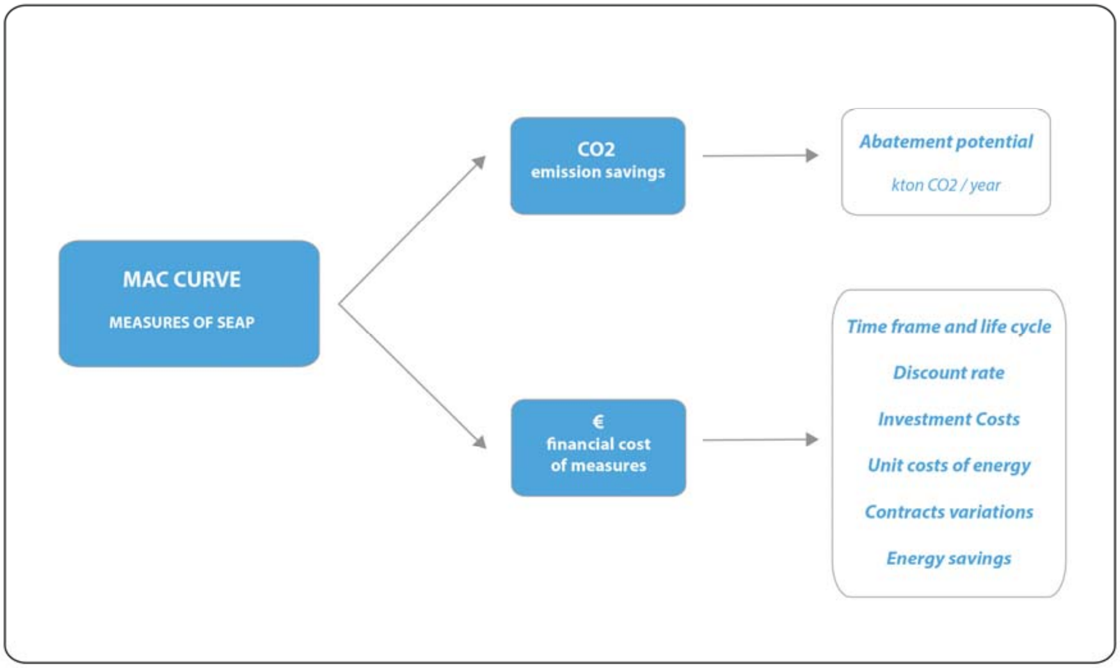
For what concerns the contextualization and the structure of the work, the Figure 1 shows how the space in which this research moves is the field of climate change mitigation, assuming the perspective of the policy maker who has to decide the most appropriate actions among a plurality of options. One of the most critical and relevant challenges is the assessment of which are the best measures to implement, and in the context of Milan the analysis covers the actions advanced by the new SEAP. In order to select and prioritize the most appropriate actions to implement, some kind of assessment is required. In this research the cost-effectiveness analysis has been considered, and more precisely the tool of the Marginal Abatement Cost Curve is applied.

Figure 1: Structure of the research



The application of this approach requires the consideration of two main variables in order to produce the results expected, the cost of the measures and their respective potential CO_2 emissions savings. Therefore the construction of the conceptual framework (Figure 2) shows the two variables with a relative set of indicators, able to affect the final ranking of the measures. For what concern the CO_2 emission savings, the only indicator considered is the abatement potential of each measure, as forecasted by the official document of SEAP. More complex is the second set of indicators, since each measure presents different cost items. However this group essentially includes the discount rate, the life-cycle of the physical assets of the measures proposed, the estimation of the investment costs and other variations able to change the final aggregate results.

Figure 2: Conceptual Framework



Chapter 3: Research Design and Methods

3.1 Revised research question

After the literature review, the question of this work concerns essentially which are the most cost-effective actions that the Municipality of Milan could adopt in order to face the problem of climate mitigation, and how to calculate them. More precisely, after the review of the current policies at the study of the municipality, the actions considered are the outcomes of the development of the Action Plan for Sustainable Energy (SEAP). Therefore, for each of these measures it is necessary to investigate which are the relative costs and the abatement potential.

Moreover, interesting outcome can come from those variables that affect deeper the final ranking of the measures (according to some sensitive variations).

Other issues that could be at least partially addressed are which is the best methodology for developing a MAC curve, which are the spaces for a methodological improvement and which are other factors that could be included in the assessment and prioritization process (like for example the consideration of the ease of implementation of the measures, or more social implications).

3.2 Research approach and techniques: a methodological update and a case study application

In order to measure and prioritize the mitigation actions from SEAP, the approach proposed is the Marginal Abatement Cost Curve, with the comparison of different potential actions, assessed on the basis of a different measurement in terms of costs and CO_2 emissions. Given the presence of more than one method for applying the MAC curves, this research figures out also a methodological comparison among some of the most relevant existing proposals in literature, and eventually designs a new methodological alternative, to be added to the previous ones.

Given the peculiarities of the context of the research (the administrative boundaries of Milan, its environmental problems and the state of arts of the policies for climate mitigation), it seems possible to consider the research strategy as a kind of case study (Van Thiel 2014), with some specificities. The ultimate goal of the work is indeed to achieve the understanding of which are the most cost-effective measure, without looking at the casual relations between independent variables and other dependent variables. In this regards, the intention is to assess the weight of different measures and actions, that are currently at the study of the municipality and reported in the existing policy documents. For these reasons, it could be considered a measurement study, immersed in the administrative and economic context of the city of Milan.

Another point that characterizes this research is the fact that it is a methodological work, with a critical reflection on how the Marginal Abatement Cost Curves have been realized, and the different bars of the chart calculated. Under this point of view it follows a chronological order, focusing on the incremental process of adjustment of the methodology proposed by different authors. The idea is to look at the congruence of the different proposals, considering both the strengths and the weaknesses, with the possibility to formulate a further new methodological proposal on that ground. This initiative does not mean to be alternative to the previous ones, but on the contrary to become the most recent, refined step along the process of methodological review of the traditional MAC curves, deriving its validity from the previous studies found in literature and without the ambition to solve all the critical points highlighted until now.

3.3 Operationalization: Variables, Indicators

Following the conceptual framework, the two main variables that build the marginal abatement cost curves can be operationalized in some indicators. According to Van Thiel (2014) the variables are the manifestation of the concepts in the real settings, while the indicators are empirical measures of the variables. This research defines as indicators all those parameters that concur in defining the final value of the two main variables, and therefore of the MAC curve.

Table 1: Operationalization of variables

VARIABLES	INDICATORS	
CO_2 emission savings	Abatement potential	Kton of CO_2 per year expected to be avoided
Financial cost of the measures	Time frame considered and life cycle of the measures	The horizon fixed for the analysis is the year 2030
	Discount rate	Social discount rate (Percoco 2007, Florio and Sirtoni 2013)
	Investment costs	Cost for financing specific interventions or buying specific items (ex. led lights)
	Unit cost of energy	Cost of methan, gasoil, district heating and electricity
	Contract variations	Variations or adjustments in the contracts for the provisions of some services (often they include also maintenance costs)
	Energy savings	Savings coming from efficiency interventions or replacement in the source of energy

3.4 Sample size and selection, data collection and analysis method

As already stated in the scope of the research, the measures and the actions that are part of the analysis and of the final assessment have already been proposed by the Municipality of Milan, and they have been presented in the Action Plan for Sustainable Energy. All the data and information inside the document could be considered useful for the assessment. Certainly, despite the SEAP present a very good emission inventory, it is crucial to collect the necessary data relative to the costs of the measure. In this regard, it is important the communication and the cooperation with the Municipal responsible of SEAP and other experts. For what concern the Plan, the Municipality of Milan is operatively organized by a General Direction, subdivided in further sectorial directions; one of these sub-entities is the Direction Mobility Environment and Energy. This direction is divided in six Areas, and the one responsible of SEAP is the Area Environment and Energy. This Area provides all the necessary information related to the measures adopted in the Plan and, thanks to a snowball process (Van Thiel 2014), allows the interaction with other experts, as for example AMAT (the agency for mobility, environment and territory, that contributed to the SEAP), the RSE (Research Energetic System) responsible of the technical and scientific support of SEAP, or the Resilience Office of the municipality of Milan.

Moving to the details of the SEAP, its approval and adoption is covering a long period of time. The input comes directly from the adhesion to the Covenant of Mayors in 2008, however the process of realization is still ongoing, with the not irrelevant point that the targets of the Plan were initially fixed for 2020. In February 2018 the Municipality has presented a Relation about the state of advancement of the Plan and its operative actions. Beside the goal of reducing the Kton of emissions from 7,418 in 2005 to 5,934 in 2020 (-20%), the Plan sets two different scenarios: a consolidated scenario with a series of actions already planned that should account for the 10,5% of the emissions reduction, and a further scenario where new measures have to be planned in order to achieve the further 9.5% of emission reductions. The Document of Plan (February 2018) reserves specific sheets for each of the actions proposed, with a detailed emission profile and forecast. Without entering in the quality of the actions proposed, the main challenge of SEAP remains the absence of a solid economic quantification of costs and of prioritization. Another elements that requires a review is the target year, because it is really unlikely that in two years all the actions could be implemented when the Plan is being adopted just now. In fact, the following target, not yet considered by the SEAP, is to reduce the emissions of 40% in 2030 (+20% in ten years if the goals of SEAP will be accomplished).

The Document of Plan includes 36 measures, from both the two scenario (the "Consolidated" and the "Further" one). All the actions are part of different sectors, from the energy efficiency to the waste management. The following chart shows the whole lists of actions and those that have been selected for the further Cost-effectiveness; the ones highlighted in bold are the ones selected for the further Cost effectiveness analysis.

Table 2: Measures proposed by SEAP and selection for the research

SECTORS	SEAP MEASURES
Public buildings (P)	P_1 Energetic requalification of not residential public buildings (P_1.1 Interventions in the contract for providing energy) (P_1.2 District heating connection for 29 buildings)
	P_2 Energetic requalification of residential buildings **(P_2.1 + P_2.2) requalification Via Feltrinelli 16 and Via S. Bernardo 48-50**
	P_3 Plan of efficiency of public buildings
	P_4 Purchase of green energy for municipal offices and services
	P_5 Interventions for efficiency and "good practices" for reducing consumptions in municipal structures
Private Buildings (E)	E_1 Energetic requalification private buildings **E_1.1 Reduction infrastructure costs for interventions of energetic requalification** (E_1.2 Building Code) (E_1.3 2 One-stop shop for energy) (E_1.4 Clear terms for energetic efficiency)
	E_2 Promotion of energetic efficiency **(E_2.1 Notice BE1)** **(E_2.2 Notice Be2)**
	E_3 Promotion of energetic efficiency in the tertiary service (E_3.1 Agreements for energy efficiency in the tertiary sector)

	(E_3.2 Agreements with Stakeholders associations) (E_3.3 Regulative measures and incentives)
	E_4 Development of district heating
Renewable sources (ER)	ER_1 Incentives and promotions of production of renewable energy
	ER_2 Recovering of heating from the integrated cycle of water (ER_2.1 Recovering of heat from sewage treatment plants) (ER_2.2) Recovering of heating from water supply
Public Illumination (I)	**I_1 Energetic efficiency of public illumination and traffic lights** **(I_1.1 Plan of energetic efficiency for public illumination)** **(I_1.2 Transition of traffic lights to LED)**
	I_2 Purchase of green energy for public illumination and traffic lights
Mobility (M)	M_1 Consolidated measures in the sector of mobility (M1_1) Enforcement and promotion of public transportation (M1_2) Intervention in favour of cycles and pedestrians (M1_3) Actions for the management of the demand of people and goods (M1_4) Development of services for shared and electric mobility
	M_2 Urban Plan for the Sustainable Mobility (PUMS) (M_2.1 Enforcement and improvement of public transportation at larger scale) (M_2.2 Enforcement and improvement of public transportation at urban scale) (M_2.3 Intervention in favour of pedestrian mobility) (M_2.4 Actions for managing the demand of people and goods) (M_2.5 Development of shared mobility and innovative services) (M_2.6 Development of electric mobility) (M_2.7 City logistics)
Waste management (R)	R_1 Policies for managing and reducing waste (R_1.1 Reduction of solid waste production and promotion of differentiated collection) (R_1.2) energetic recovering from solid waste (R_1.3) energetic recovering from waste-to-energy plant

As it is possible to notice, some sectors have been entirely excluded. In the case of the renewable energy, despite some missing information about the costs, it would have been very complicated to assess the emission reduction potential and to relate it to the administrative boundaries. The same is true for the waste management sector, because it would have implied a calculation of greenhouse gas emissions that do not directly and exclusively belong to the municipality of Milan, with the risk of including some measures that would have affected the validity and the reliability of the analysis. Also for mobility, despite the availability of quite detailed economic data, the main problem was the fact that the emissions reduction forecast was only aggregated for the whole sector, making impossible to sub-divide the total amount of CO_2 saved for each of the measures presented. For what concerns the other sectors, the data collections has been more feasible, and the measures have been selected according to the completeness of the data. The main challenge of this operation has been to find a balance between an adequate number of measures to include in the research and the maintenance of an acceptable level of validity and reliability of the data.

3.5 Data Collection Method

Given the nature of this research, an intensive work of data collection has been necessary. Indeed, during the month of July it was possible to directly meet the responsible of the SEAP and their collaboration has resulted crucial. A preliminary step has concerned the review of the official documents of the Action Plan, in particular the Document of Plan ("Documento di Piano") and the 2018 Report about the state of advancement ("Stato di Avanzamento"); thanks to this review it has been possible to have the precise list of all the measures included in and promoted by the SEAP, with linked some related important information, especially concerning the detailed estimations of the expected greenhouse gas emissions reductions. Under this point of view, a very completed and often detailed emissions inventory has represented a very important basis for the future development of the MAC curves. The second step has been to closely discuss with the municipal experts which were the existing gaps in the data relative to the costs of the measures. This operation was systematic and applied to each action of the Plan. Thanks to this consultation, it was possible since the beginning to understand which were the measures that could have been object of analysis and of data collection, while for those measures that presented significant gaps in the data collection, or the impossibility to find or quantify them, the decision was to exclude them from the analysis.

3.6 Data Analysis Methods

Accepting the validity of the estimations about the potential of GHG emission reductions, the main part of the data analysis and elaboration concerns the financial analysis of the costs and benefits of each measure.

A first issues is related to the decision about which timeframe should be considered. Under this point of view the setting of both the starting year and the last one are problematic. The SEAP itself has the peculiarity to include measures that are at a different stage in the implementation process: some measures are already defined by years and some intervention have already been completed, while other measures are still at a very early stage of development, and will be activate only in the next years. For overtaking this difficulty the 2014 is chosen as a good average time among all the measures for starting the financial analysis. Moving to other side, the definition of the last time is problematic as well, since all the measures belong to different sectors and differ among them, they are also likely to have different life cycles. Considering that all the actions expected aim at increasing the quality of the efficiency, premature breakups in the life cycles are not expected, or anyway considered. For a reason of uniformity, the final year of the analysis is the 2030. This choice relies on the fact that for the year 2030 the SEAP forecasts the second target of emissions reductions (-40% in comparison to the 2005 scenario), therefore this temporal horizon could be also functional to the municipality in order to assess and monitor the SAEP in the following year. A first option was also to design an analysis for the first target of 2020, but the delays in the adoption of the Plan have made the 2020 horizon a too short time frame for an effective financial analysis.

Another point concerns the general voices that are considered in the financial analysis, and some general assumption made. Generally speaking, the measure often include an investment for improving the efficiency and the quality of some assets or service. The expected savings are expected for the improved efficiency, and therefore from the reduced costs in the years. Of course each measures can present also other voices, depending from the specific situations. It is important to point out also the fact that in several cases it is not correct to indicate the net cash flow of investments and costs as the overall cost of the measure. In fact, as suggested by the Guidelines for developing a Marginal Abatement Cost Curve (WALGA 2014, p.10) the real overall cost of those measure is the net cost between the action planned and the other action that would have been implement in the baseline scenario, like simply a replacement or maintenance intervention without increasing or changing the technological level.

For what concerns the main common assumption made, all the measures are considered to start when they are planned and to last until 2030. This works also for those measures that presents clear financial indications for a more limited period of time; for example if a specific measures forecasts investment until 2020, no further expected investments are calculated in the following years, while the potential energy savings are extended until 2030. More difficult is to do a correct estimation of the maintenance costs, because some data are missing, except those already included and indicated in some contracts or conventions. Nevertheless, in the case in which the collection of these data is problematic (especially to calculate the difference between the previous maintenance costs and the new maintenance costs), it applies the idea that a new and more efficient action has also the effect to reduce the future maintenance cost (WALGA 2014). Another assumptions, typical of many MACC, is about the unit costs of energy, considered for the year 2018 and assumed to be constant, like the level of technological improvement, that is assumed to not further increase until 2030. The following paragraph provides more detailed information for each of the considered measures.

A last point of attention regards the discount rate. Since the perspective is from a municipal point of view, it seems more appropriate to adopt a social discount rate. For what concern Italy, a document provided by European Commission indicates 5% as a balanced indicator. However in the following years, some studies have pointed out how this number is not adequately supported and have made analysis that lead to a smaller social discount rate. In particular Percoco (2007), Florio and Sirtoni (2013) have adopted the Social Rate of Time Preference method and defined values respectively 3.8% of 1.13%. Moving to the current analysis, the social discount adopted is an average value, 3% with the possibility of running a sensitivity analysis with other values (like 1.5% and 5%). However, other studied have already shown like in the case of the MAC curves, slight variations in the discount rate do not produces very large alterations (Faber, Behrends et a., 2011). For the current analysis the first choose about the discount rate forecasts the average value of 3% (among the ones found in literature), and includes the possibility to run a sensitivity analysis in order to capture and interpreting potential variations in the final results.

Beside the explanation of the data collections and of the methodological issues considered, it is also possible to sum up some preliminary indications and problems that need to be addressed when developing a MAC curve for climate mitigation in the city of Milan. A first problem is which typology of curve seems more performative to develop. According to the academic literature (Kesicki 2011, Ponz-Tienda, Prada Hernandez, et al., 2016), expert-base curves are useful in climate policy and can provide guidance on the maximum abatement potential and on no-regret measures, therefore it seems appropriate to look for this kind of model. Nevertheless, the level of uncertainty, the potential overlapping of the measures proposed, and all the problems of implementation make difficult to translate directly the outcomes of a MAC curve in policy making without any further consideration. This is something that has to be taken into account and clearly declared. Other challenges emerged from literature review are some mathematical issues related to the construction of the model (basically the treatment of those measure that on the curve are negative, showing cost savings), the consideration of the time period and the assumptions that are unavoidable and partly dependent also on the data availability in the case of Milan. This could imply also the necessity to include a sensitivity analysis in order to increase the flexibility of the curve and include a wider range of data not enough rigorously defined. Indeed, given the fact that during the planning of a mitigation actions, the costs are only estimated and there could be significative differences in the end. Therefore, a special focus is required for those variables that result more uncertain, and it could be necessary to consider for them a range of values.

In general terms, the approach proposed for the city of Milan is carefully built according to the local conditions, assessing the solutions already considered viable from the perspective of the Municipality. The main implication of this point of view will be the necessity to consider as much as possible also a social and environmental dimension, going beyond a pure economic feasibility. The other big problem will be related to the implementation of the measures suggested, finding a way to balance and weight municipality's preferences and considering which measures realistically can be undertaken by the municipality.

Chapter 4: Research Findings

This chapter begins with a short presentation of the eight measures considered in the cost-effectiveness analysis. A remark has to be made: some data are considered “reserved” from the municipality, so for reason of privacy and confidentiality it is not possible to publish a detailed report of all the data that are part of the financial analysis.

4.1 Data collection and assessment of the 8 measures

As already shown in the previous charter, the measures are essentially related to the promotion of energetic efficiency, both in the public and private sector, aiming both at a higher efficiency and at lower consumptions. The sample size and the sectors to which the measure belong are already presented in the chapter 3.

P2 ENERGETIC REQUALIFCATION OF PUBLIC RESIDENTIAL BUILDINGS. This measure concerns the massive requalification of two public residential buildings, in Via Feltrinelli and Via S. Bernardo. These initiatives are part of a broader effort by the municipality to provide a higher offer of social housing, increasing also the physical quality of the buildings, with an estimated budget of 157 million (Comune di Milano 2017). Therefore the interventions concern both the realization of new residential complexes and the renovation of those buildings that were presenting high level of degradation. The situation was particularly difficult in the case of Via Feltrinelli, that turned also into a “national” case by media due to the presence of asbestos in the houses for years.

In the process of data collection, the main problem is the overstatement of the investment costs, especially for the case of Feltrinelli, where the investment cost of 13M covered also the asbestos removal. The risk is to develop an assessment that is probably not as cost-effective as it could be a more “standard” intervention of energetic efficiency on a large residential building. In this regard the PAES does not provide detailed information, since it reports the cost of the interventions (13M in the case of Feltrinelli, 2.3M for S. Bernardo). Given these problems, it has been crucial the collaboration of the Arch. Fabrizio Manzoni, of the Technical Area of State Property Office and Municipal Assets, who provided more information for what concerns the case of Feltrinelli. Indeed, the net cost of the intervention has dropped to 10M, and it has also been possible to quantify (and therefore to remove it from the total investment) the cost for removing the asbestos (1.3M). Instead for San Bernardo a public notice was officially made in 2017 and the cost of intervention are available and more accurate.

The savings of these measures are the energetic savings thanks to the conversion from gas oil to methane and district heating. Their unit costs in 2018 are considered for the analysis and are assumed to remain constant, but it is possible to explore some variations with a sensitivity analysis. One other indication concerns the maintenance costs, that are not calculated because of the lack of enough reliable information, but are not expected to be higher than in the past. This depends on the fact that the two building were in a compromised condition and that other interventions have some positive benefits. For example a thermal coat (realized in Feltrinelli) generally has a life-cycle of 25 year before a restoration and requires only visual-control every some years (InfobuildEnergia 2017), increasing the energetic efficiency and reducing the degradation of the facades. No “performance gap” (Gossop 2018) are considered because there are not studies and calculations available.

Despite the two intervention are classified under two different voices in the Documento di Piano (P2.1 and P2.2), in the analysis they are considered together in order to achieve a combined result, more significative and representative of an average intervention of energetic efficiency on a social housing building.

P4 PURCHASE OF GREEN ELECTRICITY FOR MUNICIPAL BUILDINGS. The measure refers to the purchase of clean electricity for both municipal offices and buildings. Therefore it is regulated by a contract between the city of Milan and the provider A2A Energia, and all the indications related to the costs of this measure are found in the contracts between the two parts. In 2014, the municipality signed a contract for the year, with the possibility to save some millions if compared to the contract expired at the end of 2013. From June 2015 to June 2017 a new contract is signed, and the costs are reported in the Municipal deliberation of 30-12-2014. Since this contract was going from June 2015 to June 2017, for the first half of 2015 the contract expired in 2014 was extended for 6 months and its cost is specified in the deliberation, while for 2017 the cost expected for the first half of the year has been doubled. The net cost of the measure is basically the difference in the costs of the contracts: in 2014 there is a saving if compared to the previous years, while the annual costs for the years 2015-2016-2017 is higher than 2014.

The main assumption is that the more recent contract is extended without variations until 2030. Despite this is probably unrealistic (because this kind of contract is likely to be reviewed more often than every fifteen years, or simply because an increase in energetic efficiency could potentially reduce the future need of energy in municipal buildings), there are no other available data. It is also difficult to run a reliable sensitivity analysis, since there are many variables and conditions that affect the definition of a contract.

E1 REDUCTION OF INFRASTRUCTURE COSTS FOR ENERGETIC REQUALIFICATION OF PRIVATE RESIDENTIAL BUILDINGS. Since some years, the municipality has started promoting the energetic requalification also in private buildings, both residential and with other destination. One of the measure included in the PAES is an indirect incentivization through a discount in the payment of infrastructure costs. This reduction was estimated by the Documento of Piano in 10% of the total amount of infrastructure costs. Since it is a measure of incentivization, there is no a direct financial return for the municipality, and the benefits relapse on the private subjects that apply for this reduction.

Looking at the municipal balances of these year, it has been possible to calculate the 10% of the total amount of the infrastructure costs raised. This 10% per year represents the cost of the measure. From 2014 to 2017 the infrastructure costs reported in the municipal balance are validate, while for the years 2018-2020 the most recent balance presents only a forecast. The two assumption is that for the period 2020-2030 the incentive remains the same and also the infrastructure costs remain constant. The biggest challenge is to find an average value for the total infrastructure costs for the period 2021-2030. Firstly, the current value estimated for calculating the infrastructure costs were made in 2007 and were increased if compared to the previous estimation of 1991 (Masseroli 2007), therefore it is not easy to predict possible variations before 2030. Second, even accepting the indication of 2007 it is impossible to estimate how many new infrastructures costs will be generated in the next years. Third, from 2018 a national law regulates the application of infrastructure costs at the municipal level in a more restrictive way (Pompilio 2018), making them probably less attractive in the future (the Italian municipalities very often use the infrastructure costs in a distorted way for financing other expenditures that are not related to the nature of infrastructure costs). Fourth, in the future a reduction in the soil consumption could be at least desiderable if not expected, and also the demographic trends do not seem to show a tremendous increase in the population. Last but not least, there is not a clear recognizable trend in the fluctuation of infrastructure costs year by year. Summing up, the assumption for the year 2021-2030 is a total amount of infrastructure costs slightly lower than the forecast for 2020 (60 million instead of 74). Despite the possibility to run a sensitivity analysis with different values for the period 2021-2030, the measure will remain a costs for the municipality, given the nature of an incentive. In addition it is not considered the level of responsiveness of the private subjects toward the energetic efficiency, that could lead to a reduction of the 10% of discount in the case it is very high.

E2.1 NOTICE BE1 FOR ENERGETIC EFFICIENCY FOR PRIVATE BUILDINGS. The Municipality of Milan is also trying to encourage the energetic requalification of private buildings by designing some calls and public notices. A first notice (BE1) was presented initially in 2010, but it remained largely ineffective and unsuccessful. Some modifications in the rules and in the conditions of the notice have been recently adopted, making it more attractive. The investment cost represents the total fund made available to private subjects, and in the case of the BE1 the amount is 1.6 million.

The assumption is that the duration of the notice is extended from 2014 to 2030, with an average annual cost of almost 100.000€. The notice ends when the funds are exhausted and completed, therefore the main issue is to understand when the notice will end. In coherence also with previous measure, in the baseline scenario the notice expire in 2030. Even if it could be partially unrealistic, it can help the municipality in having an idea about its cost-effective. Furthermore, as already happened in the previous year, this notice remained unexploited for around eight years, so it is not unrealistic to think of a time frame of more than 10 years. An alternative option could be to replicate the notice at a certain point, simulating its successful application in the short term and its replication until 2030. In this new scenario the costs of the measure is doubled.

E2.2 NOTICE BE2 FOR ENERGETIC EFFICIENCY FOR PRIVATE BUILDINGS. This new notice works like the previous BE1 measure, with the differences that the funds available in this case are much bigger than the previous one (around 23 million) and that is has been set for starting in 2018. The time frame is the period 2018-2030, with an estimation of almost 600.000€ available per year. Even in this case it is possible to make a simulation in case of success of the public notice. Nevertheless, given the broader and more systemic approach of this second notice, it is unluckily to replicate it in the same way only after seven years. For this reason it appears more realistic in case of success (and anticipated conclusion), to extend the notice until 2030 with new funds, but with additional funds much lower than the initial 23 million.

L1.1 PLAN FOR THE EFFICIENCY OF PUBLIC LIGHTS. The measure includes the signature of a new contract with A2A that, starting from 2014, allows significant savings in the following years for what concern the public lighting. The municipal deliberation of 20-12-2013 points out the maximum costs available for the year 2014 and 2015, with already a significative savings in relation the previous contract. In order to make possible for the municipality to sign a more convenient contract, the provider had to develop a series of investments on the efficiency and performances of its assets, for a cost of 38 million. In the new contract the municipality of Milan has to cover this costs, transferring 2.8 million per year to A2A starting from 2016. Keeping the year 2030 as time frame of the analysis, the municipality presents an investment costs of 2.8 million per year until 2028 and 0.8 million for the years 2029-2030. The annual savings that come from the difference with the previous contract represent the financial benefit of the measure.

In these measure the extraordinary maintenance is not included, due to some missing information that do not make possible the comparison between the previous and the new contract. Nevertheless, the new plan of investment by A2A should at least in theory modernize the infrastructures, and therefore reducing the need of maintenance in the following years.

L1.2 REPLACEMENT OF TRAFFIC LIGHTS WITH LED SYSTEM. This measure consists of a plan for replacing the traffic light illumination with a led system, in many cases when the lights end their life-cycle or when there is a need of extraordinary maintenance. Therefore the net cost of the measure do not include the maintenance costs because they would have been anyway necessary. The indication of other costs provided concern the cost of the led, while the benefits are essentially the improved energetic efficiency due to this new technology. A precise number of the lights substituted until now is available and increase the precision of the estimations. In fact, the total cost for replacing a light with a led is estimated by the Documento di Piano in 500€. However its net cost is 370€, because the real cost of the measure is the difference between the replacement with a standard light (with average cost of 130€) and the replacement with a led light (with cost of 500€). The total number of lights that need to be changed are around 22.000, and it was possible to find that at February 2015 the light that needed to be changed were 11600, and at June 2017 were 9826. Since these two data are not at the same interval of times it has been assumed those value as reference for the whole respective years. Beside the investment costs, the financial benefits come from the reduction in energy consumption. Given the expected 8785 MW/h of energy saving per year once all the light would have been replace, it is possible to estimate the energy saving according to the rhythm of replacement of the lights. Therefore it results an energy savings of 2115mw/h for the years 2014-15, 348 mw/h for the years 2016-17 and 1285mw/h for the years 2018-19-20.

The main source of information is the Municipal Deliberation 2675/2013, and the only assumptions concerns the unitary cost of electricity, despite a sensitivity analysis can be run in order to test and evaluate different scenarios.

L2 PURCHASE OF GREEN ENERGY FOR PUBLIC LIGHTS. The measure concerns a difference in the purchasing of green energy thanks to the signature of a new contract with a different provider. The Documento di Piano reports an estimation on the ground of a Consip Convention signed in 2011 and estimates an increased costs in 66000€ per year. Nevertheless more recent sources reports a lower difference between the two contract (almost 30000€). Given this discrepancy an average value is considered. Initially, a value closer to the more recent source is adopted, considering the most recent source more precise. Nevertheless a sensitivity analysis could test different variation between the two ranges. The only assumption is that this difference between the two contracts (that represent the cost of the measure) remains constant until 2030.

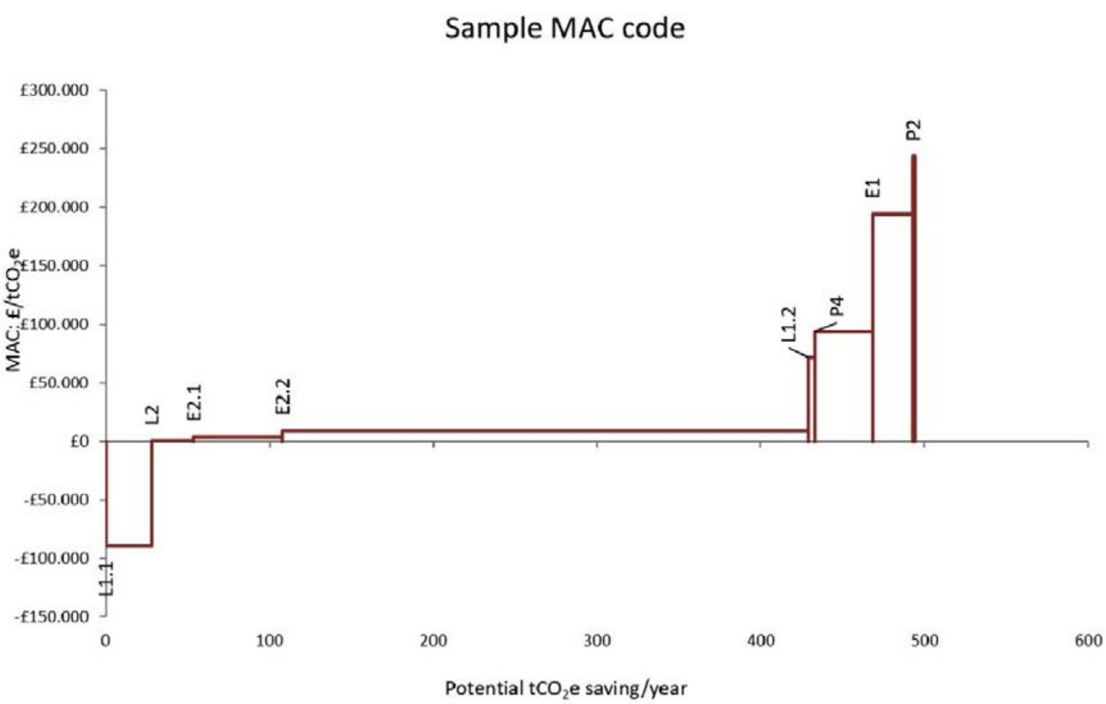
4.2 Summary of the data collection and calculation

The table below reports the application of the standard MAC curve, with a social discount rate of 3%, that as already stated in the previous chapter, represent the average value found in literature for the social discount rate in Italy.

Table 3: Summary of the results of standard MAC curve

MEASURES	NPV	CO2 abatement potential (kton/year)	STANDARD MACC VALUE	RANKING
P_2	4,969,787.29 €	1,2	243,617.02 €	8
P_4	52.639.057,59 €	35,1	93,720.52 €	6
E_1	81,570,908.38 €	24,7	194.262,70 €	7
E_2.1	968,026.31 €	54,4	1.046,74 €	3
E_2.2	15,832,118.65 €	321	3.793,94 €	4
L_1.1	-42,351,151.21 €	28	-88.973,01 €	1
L_1.2	5,003,320.87 €	4,1	71.783,66 €	5
L_2	348,973.49 €	24,7	855,33 €	2

Graph 1: Standard Marginal Abatement Cost Curve



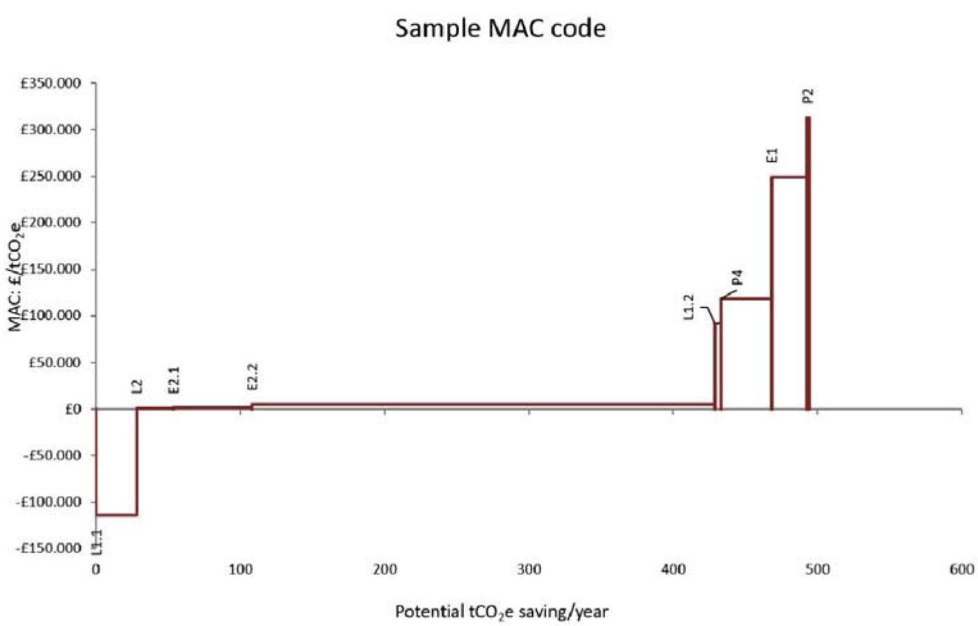
In order to deal with the social discount rate, a sensitivity analysis is also presented proposing other values found in literature (Percoco 2007, Florio and Sirtoni 2013). Beside the 3%

proposed in the curve, two other alternatives are proposed, with a social discount rate of 1.5% and 5 %. The table below reports the results, then the 2 new curves are shown:

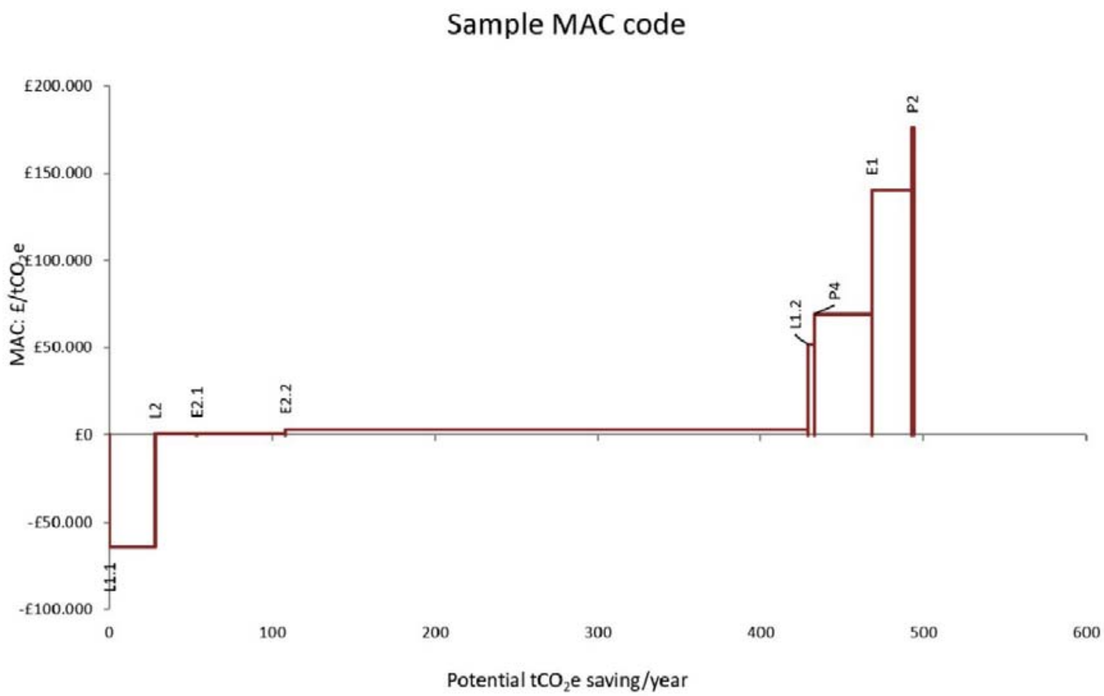
Table 4: Results with different discount rate

	3%	1.5%	5%
P_2	305,319.40€	312,620.70 €	175,680.02 €
P_4	93,720.52 €	118,527.72 €	68,904.54 €
E_1	194,262.70 €	249,286.44 €	140,089.04 €
E_2.1	1,046.74 €	1,343.23 €	754.84 €
E_2.2	3,793,94 €	4,591.09 €	2,954.70 €
L_1.1	-88,783,66 €	- 114,174.30 €	- 64,161.28 €
L_1.2	71,783,66 €	92,116.13 €	51,765.49 €
L_2	855,33 €	1,081.61 €	628.78 €

Graph 2: Standard MACC with discount rate 1.5%



Graph 3: Standard MACC with discount rate 5%



As it is possible to see from the three curves, the most cost-effective measure is the L1_1 (Plan for the energetic efficiency of public illumination), while massive intervention on public residential buildings in order to achieve higher energetic performances result the most expensive if compared to the abatement potential (measure P_2). Between these two extremes, there are other measures (like the notices E_2 for fostering private actions of energetic efficiency, and the purchase of green electricity, P_2 and L_2) that show a good potential reduction in front of not unsustainable costs, and therefore demonstrating a good cost-effectiveness. The sensitivity analysis related to the discount rate do not change the overall trends. In fact, despite a different discount rate leads to a different MACC value, it does not change neither the ranking of the measures nor the proportions among them.

4.3 Application of alternative methodologies

As saw in the literature review, there are different methodological approach to the design of marginal abatement cost curves. Considering this case study, it is not possible to apply the two proposals advanced by Taylor and Ward, because these methodological approaches are explicitly made for prioritize in a different way only the measures that present a negative value (those that have a positive return). The problem is that at the state of this research there is only one action that is negative, the L1.1 (the plan for the efficiency of the public light), therefore any comparison following these 2 methods is at the moment not possible. If any further negative measures will be added, it will become possible to apply this methodology.

A possible source of methodological comparison can be found in Tienda, Hernandez et al., (2016), with the proposal of the Gain maximizing method. Nevertheless a modification has to be changed for adapting it to the measures of this work. The formula applied in this research divides the economic benefits (in negative) with the costs, then multiplying for the abatement potential. In the original formulation, the free variable *e* with values between 1 and 0,001 is summed to the denominator, with the scope of avoiding division by zero in the case of measure with no costs. Since in the present analysis some measures do not present any benefits, the formula has been symmetrically changed: the free variable e is added to the numerator (the economic benefit), while the denominator was is considered negative.

Box 1: Formula for the application of the MAC curve

Tienda's proposal:

$$GMm = \frac{-\Delta Bm}{\Delta C_m + \varepsilon} * \Delta E_m$$

Adapted proposal:

$$GMm = \frac{\Delta Bm + \varepsilon}{-\Delta C_m} * \Delta E_m$$

Looking at the results, the rank is different from the Standard Approach, but the formula does not prefer the measure with the highest reduction potential, like it was expected to be.

Table 5: Methodological comparison

MEASURES	RESULTS (Gain Max. Method)	RANKING (Gain Max. Method)	CO2 abatement potential (kton/year)	Ranking (Standard MAC curve)
L_1.1	-79,57894811	1	28	1
P_2	-0,259943834	2	1,2	8
L_1.2	-0,005018099	3	4,1	6
L_2	-4,55357E-05	4	25,5	3
E_2.1	-0,000034	5	54,4	2
E_2.2	-1,38065E-05	6	321	4
P_4	-4,47151E-06	7	35,1	5
E_1	-1,83201E-07	8	24,7	7

The curve is not show, because the chart presents measures with values very different among them, and a good graphical representation would have been out of scale. From the data it appears correct that all the results are negative, like in Tienda's proposal (therefore avoiding the problem of having positive and negative measures with different treatment), The resulting value is not the cost-effectiveness of the measure but simply the outcome of the method for allowing the prioritization of the measures. The lowest values, or the most negative actions, are considered the ones to prefer (in an hypothetical chart, the measures on the left have to be choose as preferred). However, making a comparison with the respective abatement potential, it results that the apparently more preferred actions are not the most impacting in reducing the CO_2 emissions.

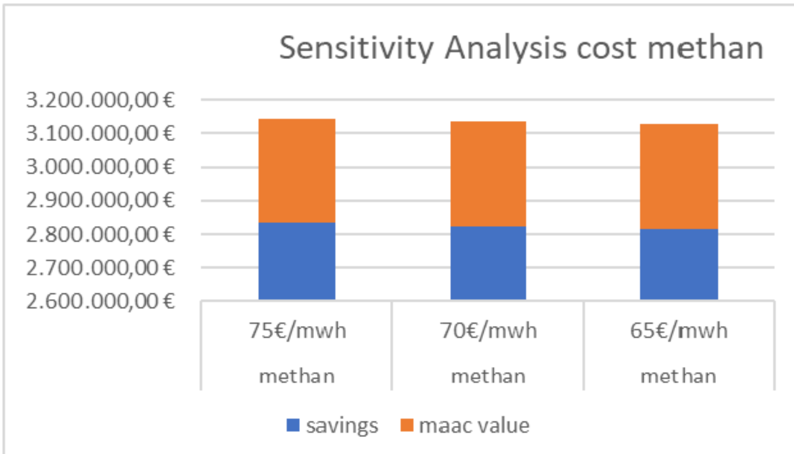
4.3 Variations in the values of some indicators and sensitivity analysis

In the analysis of the measures it has been to necessary to apply a series of assumptions, many of the them related to the impossibility to collect the data (in many cases because the data are not available or do not exist at all). In other cases, given a time horizon of 2030 for the development of the curve, it is necessary to predict and assume a future value for some of the indicators (usually it is assumed that the value remain constant along the period considered). Studying the variation of some indicators and how these variations could affect the final results of the MACC can contribute to understand under which conditions a measure could increase or decrease its cost-effectiveness, In this regards, running a sensitivity analysis for identifying the "critical variables or parameters" (EU Directorate General Regional Policy 2008) could be an extremely useful operation also for the same municipality, because knowing that some measures are more effective than others under certain conditions could lead to a better selection and prioritization process of the actions to do in the next years. Following the indication provided by the "Guide to Cost-effectiveness analysis of investment projects" (2014) the parameters that can be objects of sensitivity analysis are related to some price dynamics (like energy prices), some investment costs (in many cases not all the data are related to the investment costs are available and this increase the uncertainty of the assumptions), and operating costs (like the price of electricity and other fuels). More refined and advanced parameters (like some accounting prices and other quantitative paraments for costs and benefits) are not included in the analysis, due to the absence of reliable data and high level of difficulty of a potential collection.

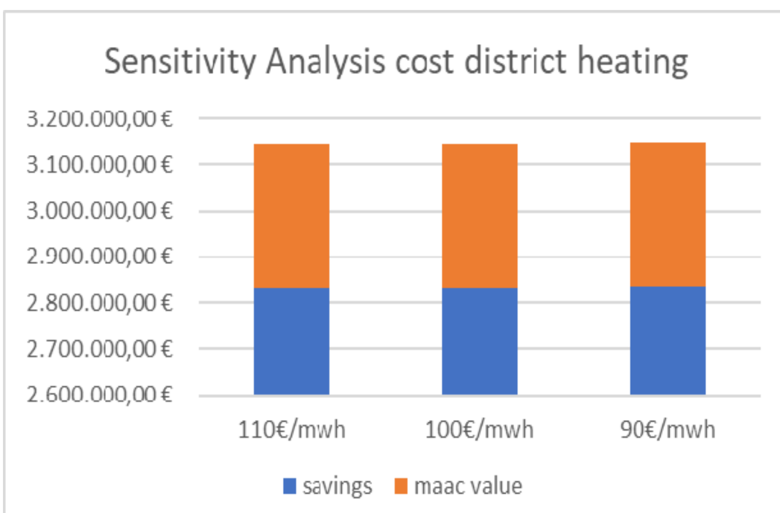
In addition, since as already shown, there is not significant differences in the variation of the social discount rate, the current sensitivity analysis are conducted keeping the average value of 3% for the social discount rate. The chart below reports how the standard MACC value of some measures could change at the variation of some parameters. In the cases in which there are few data available, the sensitivity analysis is not run because changing a parameter would have not changed the ratio with the abatement potential: taking as example the measure E1.1 (Reduction of infrastructure costs for promoting energetic efficiency in the private sector), running a sensitivity analysis concerning the size of the incentive (10% in the baseline scenario, 5% or 15% in an hypothetical sensitivity analysis), would have had as a consequence a increase or decrease of 50% both in costs and in the reduction of CO_2, without affecting the MACC value and the cost-effectiveness of the measure. The same happens for the two notices set for promoting energetic requalification in the private sectors (measures E2.1 and E2.2), because the ratio between costs and emission savings would not change.

P2 ENERGETIC REQUALIFCATION OF PUBLIC RESIDENTIAL BUILDINGS. For these measures the parameters that can be object of sensitivity analysis are the unit cost of energy, because the data about the cost investments are official, and the estimations about the energy saving have already been made and presented in the Documento di Piano. In the baseline scenario the unit cost of methan, gasoil and district heating is respectively 75€/mwh, 132€/mwh and 110€/mwh (AIEL 2018). Looking at the standard MACC the measure does not seem to be cost-effective, and it appears hard that a variation in the estimation of the unit costs could transform this measure in an effective one. With the current data, the only condition that could increase the energy savings is a lower cost of methan and of district heating. The sensitivity analysis is run considering these two parameters, because of the trend in the city of Milan to convert old heating systems (mainly in gasoil to methan or district heating). It will be up to next studies to evaluate how many public residential building need to be converted, which source of energy is promoted, and also the cost and the abatement potential. Looking at some macroregional data, the cost of methan in Milan is already lower than in other cities, therefore it does not seem realistic to predict a very strong decline. A stronger reduction could be expected in the cost of district heating, that in itself is considered cheaper as a whole service and that could expand its diffusion in the next years. Nevertheless, looking at the result, a reduction in the unit costs of energy does not seem enough for increasing the cost-effectiveness of the measure in term of ratio cost/CO2 avoided.

Graph 4: Sensitivity Analysis unit cost of methan



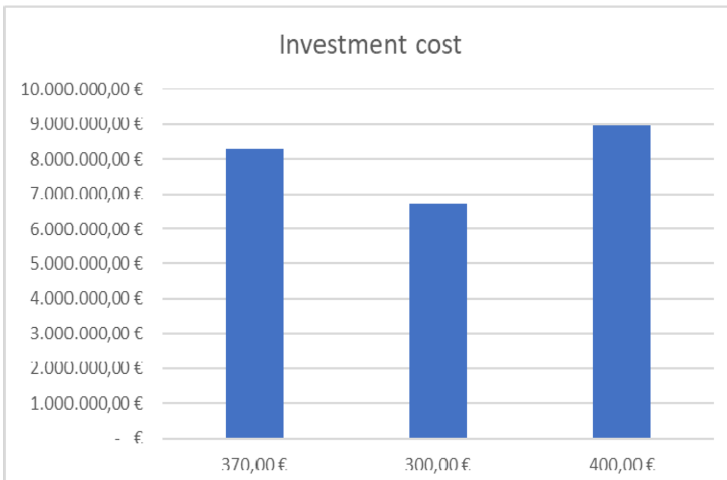
Graph 5: Sensitivity analysis unit cost of district heating



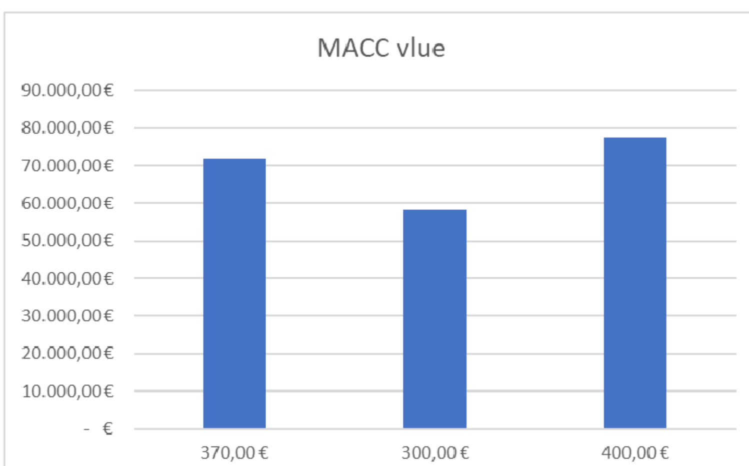
As it is possible to see from the graphical representation, the variations in the costs of the unit price of methan and district heating do not lead to relevant discrepancies in the final result, and most of all do not affect the cost-effectiveness of these interventions in Via Feltrinelli and in Via S. Bernardo. From the data available it results that the investment cost is very high, not much in comparison to the saving but especially for what concerns the potential of CO_2 abatement.

L1.2 SUBSTITUTION OF TRAFFIC LIGHTS WITH LED SYSTEM. The most impacting parameter in defining the cost effectiveness of this measure is the cost of a led light, estimated in the current scenario at 370€. This number represents a net value between the substitution of a normal light (with an average cost of 130€) and the installation of a led light (with estimated cost of 500€). In this sensitivity analysis the variation of the cost of the led are assumed to be 300€ and 400€. For the next years, it would be likely to see a further reduction in the cost of the led light, therefore the reduction proposed is more consistent that the increase in the price.

Graph 6: Sensitivity analysis of the investment costs for LED system installation



7: Different MACC value according to the previous sensitivity analysis



Especially looking at the chart of the MACC values, a reduction in the cost of the led show a not irrelevant impact in the cost-effectiveness of the measure, despite the measure presents anyway a cost for the municipality. The fluctuations in the cost of led can be monitored in the next years, and could open more possibility for new measures based on the led technology.

L2 PURCHASE OF GREEN ELECTRIC ENERGY FOR PUBLIC ILLUMINATION AND TRAFFIC LIGHTS. The sensitivity analysis for this measure concerns the uncertainties about the additional costs that comes from the signature of a new convention with Consip for what concerns the purchase of green electricity. In fact, there is a discrepancy between the Documento di Piano that states additional 66.000€ per year and the Report about the advancement state, which states only 27.00€ additional per year. In the baseline scenario a value in between was assumed, but closer to the most recent source. The current sensitivity analysis try to analyse both the indications as extreme cases of a potential range.

Table 6: Sensitivity analysis of the additional cost of the new contract

Additional cost of the new contract	MACC value
66000 €	1612,00 €
35000 €	855,33 €
27000 €	659,82 €

Even in this case, although it does not overturn the results, there are some variations in the final value, potentially able to change the ranking position in a more numerous marginal abatement cost curve.

4.4 Synthesis of the main results

In this chapter, the data collected have been elaborated, and the marginal abatement cost curve has been developed.

The first step has seen the development of a traditional Standard MAC curve. Looking at the results, the most effective measure from a financial point of view is the plan for the efficiency of the public lights (L1.1, while in terms of CO_2 the two most effective measures are the public notices for promoting energetic requalification in the private sector (measures E2.1 and E2.2). At the contrary, the less cost-effective measure in absolute term results the measure P2, related to the physical intervention of energetic requalification an efficiency on public residential buildings.

The first standard curve has been realized by adopting a social discount rate of 3%, after a literature review. However, two other curves have been realized, with different social discount rate (respectively 1.5% and 5%). Nevertheless there are no significant alterations in the curve, and this could lead to the conclusion that the variations in the social discount rate do not represent the most sensitive parameters in the MAC curves.

Furthermore, different methodological approach has been questioned. Unfortunately, given the absence of a set negative measures (that is to say measures with a financial benefit) it has not been possible to test Taylor and Ward's method update. An adapted test has been made with Ponz-Tienda, Prada-Hernandez et al., (2016) Gain Maximizing Method: however the results do not seem to significantly prefer those measure with an higher abatement potential, as the authors showed.

In the last part of the chapter, a sensitivity analysis has been run in order to test the variability of some parameters and their power to affect the final rank of the curve. Despite some intrinsic limitation due to the absence of enough data, the more significant paraments seems to be the investment costs (that in the eight measure can assume different forms in terms of the kind of investment proposed). Other parameters, like the unit cost of energy, or the energy savings do not seem able to alter the results in a very significant way.

Despite the specificity of the context of the research and the limitation faced, it is anyway possible to draw some conclusions.

Chapter 5: Conclusions and recommendations

After the work of data collection and data analysis it is possible to come back to the initial research questions and see which answers this research has provided. Furthermore a new reflection on the literature review and some recommendations are provided.

5.1 Answering the research questions

The main question that has moved this work has been to identify which of the measure included in the SEAP and object of analysis in this research present the most cost-effective value in term of financial cost of the action and reduction of CO_2. Despite the several difficulties in the collection of data and in the proposal of an analytical approach that has found few application at the municipal level in Italy, a marginal abatement cost curve related to eight measures of SEAP has been designed and applied. The choice of working on the SEAP is the result of a shared decision and a collaboration with the municipality of Milan, that in 2018 has been engaged in its approval and adoption.

The result show that the most-cost effective measure in absolute term is the Plan of efficiency in public light (L1.1), the only measure that presents a negative cost, and therefore a financial benefit for the municipality due to an investment plan that increase the level of efficiency in a significant way. Nevertheless it is also important to look at the abatement potential of the measures. In this regards, the publication of the two notices for fostering energetic requalification in the private sector seem to be the most effective and promising (especially the second notice, BE2). Also the measure L2 (purchasing of green electricity for public illumination and traffic lights) presents a good result. More problems in term of cost-effectiveness are found especially in the substitution of traffic light system with led and in the massive energetic requalification of some public residential buildings (measures L1.2 and P2). Indeed, beside a not irrelevant costs for the realization of the measures, the abatement potential achieved calls at least for further investigations about the effectiveness and relevancy of these actions.

For what concerns the indicators that play a more significant way in the alteration of the MACC values, the most relevant one seems to be the investment cost. Looking also at the sensitivity analysis, despite the small proportions, the variation in this parameter (for example the cost of purchasing led lights in the measures L1.1) seems more able than others to change the final values. At the contrary, other parameters that do not play a very decisive role are the variation in the discount rate, the energy savings and the unit costs of energy. This last point seems also to be coherent with some findings in literature, like in Faber, Behrendes et al., (2011). A specific attention has to be paid to the operating costs, in this research often difficult to isolate but in general expected to decrease after the implementation of a new measure (Olbrish, Haites et al., 2011). A last remark concerns a more structural parameter, the choice of the time frame, that should usually take into account the expected life-cycle of the actions proposed and that is potentially able to drastically change the final prioritization ranking.

Moving to a more general conclusion, it also emerge that the largest part of the efforts in the field of climate mitigation will be probably played in the private level, while significative results in term of CO_2 emissions reduction in the public sector are more difficult to achieve and often rather symbolic. More in detail, the tool of public notice (as designed by the municipality) seems to result also the most complete, not only for its capacity to work as stimulus for the energetic requalification in the private sector, but also for its capacity to create a virtuous circle of co-benefits for the local economy and the urban quality. About the role of the private and public in these kind of initiatives, Sudmant, Gouldson et al., (2017) write how the public has to rely on the private sector, especially for collecting the necessary capitals and resources, while the public should play more a role of catalysation of new flows toward low-carbon investments.

5.2 Links with literature and potential new refined methodology

As already presented during the work, one of the reason of the growing popularity of the marginal abatement costs curves is represented by the clarity of their results and their easy communicability. Nevertheless a call for caution is necessary, like suggested by some authors (Ekins and Kesicki 2012). Beside the unavoidable assumptions, also some rigidities in the analysis cannot be avoided and can potentially provide a not correct result. First of all the final outcomes of the analysis naturally depend on the quality and reliability of the data collected. This research has tried to find the most possible information, dealing between the need of collecting data and the necessity to keep the level of validity and reliability as high as possible. However probably not all the measures present all the possible costs and savings they could have, and of course a different analysis could lead to different result. Secondly, this kind of approach deals with only two main variables, the cost of the measures and their abatement potential. In this regards, an interesting attempt was made by Tienda, Hernandez et al., (2016) by proposing an alternative model that was supposed to prioritize those measures which present higher level of CO_2 emissions. In this research Tienda's method has been applied and adapted to the current data of this work; however from the result it does not seem that the measure with higher abatement potential are preferred or prioritized in the MACC.

This issue remains quite important, since there are some measure that despite their effective environmental benefit (they indeed effectively contribute to reduce the emission of CO_2) they should not be preferred to others because of their higher costs. In order to tackle this problem, it seems there is the space for new methodological proposals, built on the previous methods found in literature. The idea could be to re-propose Tienda's method (Gain Maximizing method), attributing to the variable Ɛ of the formula a specific value within a range and depending on the performances of some indicators. In this work the proposal has not developed yet because of the lack of enough reliable data and because the range of the value that the variable can assumes need to be redesign and restudied in a way that they can effectively alter the final MACC value. These indicators that summed up will determine the value of the variable Ɛ could lead toward a multicriteria analysis and try to capture other benefits under some new parameters, like for example the co-benefits for adaptation, the creation of potential new jobs, the ease of implementation or the impact in term of urban quality. With this perspective, further more qualitative, it could become possible to evaluate some interventions under a different light. A special attention probably should be deserved to the aspect of implementation of the measure, that often can cause delays and increased costs. In the case of the municipality of Milan, providing actions in public residential buildings or in the public system of lighting probably is easier than promoting energetic efficiency in the private sector (indeed the municipality has set up a series of incentives that should promote the private sector). Measure that can foster the physical regeneration of obsolete structures. For what concerns the estimation of the potential new job, a reference could be found in Wei, Patadia et al., (2010) and in his attempt to individuate direct employment, indirect employment and induced employment. Not very significative could be the potential co-benefit for adaptation, since in the context of this research the goal of the plan was entirely focused on mitigation; nevertheless in the future or in the development of new measures it is a measure that is worthy to be considered.

Another interesting alternative is found in Bockel, Sutter et al., (2012). Given as accepted the impossibility to deal with co-benefits and ancillary effects (considered too problematic to be included in a MAC curve in a reliable way, a treatment of externalities is proposed. In fact, before the realization of the curve, an externality assessment matrix (Bockel, Sutter et al., 2012, p. 9) is applied to all the options that could be part of the MACC analysis. Those measures that present a no proportioned number of environmental, economic or social externalities not aligned with the political objective of the administration, are excluded from the MACC analysis from the beginning.

5.3 Recommendations

As final remark, some recommendation can be helpful for further researches and for refining the current work. In first instance, if new data will become available the current curves designed here could be updated, like it will always be possible to introduce new measures. The Marginal abatement cost curves have the quality of the incremental work and process: despite their sometimes rigid and univocal outcomes, they can always and quite easily reviewed, updated or modified. Secondly, focusing on the aspect of the process, as Kesicki suggests (2011, 2013), a very meaningful scope of the MAC curve is to bring together different stakeholders in order to explore which are effectively the possibility that seem to be more cost-effective. In other words, what Sudmant, Gouldson et al., (2017) call the "landscape of opportunities". In this regards, the most advanced curves keep together and calculate costs and savings for a plurality of actors and not only for a subject like happened in this research; in this regards a significative distinction in literature is found in Bockel, Sutter et al., (2012) between the public costs and a broader "leverage effect" that includes also the consideration of the private dimension. Certainly, moving to this perspective, some of the measures that in this work results not cost-effective (mainly the incentives in favour of private subjects), would become more attractive if considering that beside the cost for a municipality there are private subjects who are having a financial saving. Furthermore, it is important to stress that the research has focus its analysis on the SEAP that was been implemented in this period. But the SEAP represented the context (both temporal and for climate policy) where to develop the case study, not the boundaries of the application of the MACC. Other sectors and their respective plans (especially the mobility with the PUMS and the waste management) are relevant areas that a team of experts can try to look with the lens of the cost-effectiveness of their actions.

Ultimately, the motivation that lays behind the realization of this work is the ambition to show the application of this specific kind of cost-effectiveness analysis at the urban level, as a tool that properly enforced (and overtaken the main limitations here faced) can for sure become a relevant support for the decision making in the battle against the climate change at the municipal level.

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Annex 1: Overview of data collection

The tables below report the main data collected during the research period and used to build the marginal abatement cost curve. The timeframe of the analysis is the period 2014-2030.

P2 ENERGY RENOVATION OF PUBLIC RESIDENTIAL BUILDINGS				
P2.1 Requalification Via Feltrinelli 16				0,5 kton CO2/year
P2.2 Requalification Via San Bernardo 48-50				0,7 kton CO2/year
				1,2 kton CO2/year
Unit cost (€/MWh)	methan		75 €	
	gasoil		132 €	
	district heating		110 €	
Estimated consumption (MWh)	Feltrinelli (before interv.)		1849,05	
	Feltrinelli (after interv.)		215,72	
	S.Bernardo (before interv.)		679,06	
	S.Bernardo (after interv.)		90,99	
Energy savings	Feltrinelli	1.839.192,80 €		
	San Bernardo	993.740,04 €		
Investment cost	Feltrinelli		-8.679.513,61 €	
	San Bernardo		-2.367.720,38 €	
TOTAL INVESTMENT	**11.047.233,99 €**			
TOTAL SAVINGS	**2.832.932,84 €**			
DISCOUNT RATE	**3%**			
NPV	**6.377.462,34 €**			
MACC	**312.620,70 €**			

P4 PURCHASE GREEN ELECTRICITY FOR MUNICIPAL BUILDINGS

35,1 kton CO2/year

Average annual cost of the contract			
	previous (until 2014)	-	23.584.077,00 €
	new (from 2015)	-	29.138.466,67 €

TOTAL INVESTMENT	**84.470.234,67 €**
TOTAL SAVINGS	**0 €**
DISCOUNT RATE	**3%**
NPV	**66.565.166,82 €**
MACC	**118.527,72 €**

E1.1 REDUCTION OF INFRASTRUCTURE COSTS FOR INTERVENTIONS OF ENERGY EFFICIENCY

24,7 kton CO2/year

Total of annual 10% discount on infrastructure costs (2014-2030)	134.824.282,77 €

TOTAL INVESTMENT	**134.824.282,77 €**
TOTAL SAVINGS	**0**
DISCOUNT RATE	**3%**
NPV	**81.570.908,37 €**
MACC	**194.262,70 €**

E2.1 NOTICE BE1 FOR PROMOTING ENERGETIC EFFCIENCY IN THE PRIVATE RESIDANTIAL SECTOR

54,4 kton CO2/year

TOTAL INVESTMENT	**1.600.000,00 €**
TOTAL SAVINGS	**0 €**
DISCOUNT RATE	**3%**
NPV	**968.026,31 €**
MACC	**1.046,74 €**

E2.1 NOTICE BE1 FOR PROMOTING ENERGETIC EFFCIENCY IN THE PRIVATE RESIDANTIAL SECTOR

321 kton CO_2/year

TOTAL INVESTMENT	**23.250.000,00 €**
TOTAL SAVINGS	**0 €**
DISCOUNT RATE	**3%**
NPV	**15.832.118,65 €**
MACC	**3.793,94 €**

I1.1 PLAN FOR INCREASING THE EFFICIENCY OF THE PUBLIC ILLUMINATION

28 kton CO_2/year

Annual cost of the previous contract	until 2013	37.000.000 €
Annual savings from the new contract	2014	5.000.000,00 €
	2015	6.000.000,00 €
	2016-2030	9.000.000,00 €
Investment cost	2016-2030	38.000.000,00 €

TOTAL INVESTMENT	**11.047.233,99 €**
TOTAL SAVINGS	**2.832.932,84 €**
DISCOUNT RATE	**3%**
NPV	**6.377.462,34 €**
MACC	**312.620,70 €**

I1.2 SUBSTITUTION OF TRAFFIC LIGHTS WITH LED SYSTEM			
			4,1 kton CO2/year
Cost of a led light	500,00 €		
total number of lights to be changed	22378		
unit cost of electricity	0,175 €/MWh		
total expected MW/h saved	8785 €/MWh		
Investment cost (led replacement)	2015	3.987.860,00 €	
	2017	656.380,00 €	
	2018-2020	3.635.620,00 €	
Annual energy savings	2014-2015	370,21 €	
	2016-2017	431,20 €	
	2018-2030	656,16 €	

TOTAL INVESTMENT	**8.951.200,00 €**
TOTAL SAVINGS	**10.132,94 €**
DISCOUNT RATE	**3%**
NPV	**337.764,67 €**
MACC	**71.783,66 €**

I2 PURCHASE OF GREEN ELECTRIC ENERGY FOR PUBLIC ILLUMINATION AND TRAFFIC LIGHTS		
		25,5 kton CO2/year
Annual additional cost of the new contract	35.000 €	

TOTAL INVESTMENT	**560.000,00 €**
TOTAL SAVINGS	**0**
DISCOUNT RATE	**3%**
NPV	**348.973,49 €**
MACC	**855,33 €**