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A Parsimonious Analytic Hierarchy Process methodology for the evaluation of climate policies

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A chi non ha ancora un posto nel mondo,
a chi si batte ogni giorno per i propri diritti,
a chi sbaglia, cade e si rialza.
A chi spera.

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1. Introduction

The climate of our planet has evolved during the years since the past. According to Nasa the last 800,000 years have been subject of eight cycles of ice ages and warmer periods with the beginning of the modern climate era 11,700 years ago (Climate Change Evidence, n.d.-a).

Year 2021 has been considered one of the most challenging years in terms of climate disasters causing a record of $ 20 billion-plus weather disasters (Masters, 2022). Everyone will remember the bushfires in Australia due to the dry season in 2019 with 18 million hectares burned and 9000 buildings and homes devastated and 400 deaths; the floods of Indonesia in 2020 that caused many destructions; the Coronavirus pandemic with the first case in China, in December 2019 (Kumar, n.d.).

According to a recent study conducted by Legambiente in 18 state capitals, Italian cities are still far from the goal fixed by 2030 aimed to reduce by 55% the net emissions. All the cities have been subject to a detailed analysis and what has been discovered is that the future limits for the air quality are in delay. Too many cars on the street and the air is unbreathable, despite this bad result, 1 citizen out of 4 is ready to leave the car (Repubbica.it, 2023). Another study found out that 29 Italian cities out of 95 have exceeded the daily PM10[1] limits (Legambiente Veneto, 2023). There is scientific evidence about the warming of the climate system, and this is certain (Climate Change evidence, n.d.-a).

There are two numbers that we must know when we talk about climate change: the first one is 51 billion, and the second one is zero (Gates, 2021). 51 billion are the tons of greenhouse gases typically emitted into the atmosphere on an annual basis around the world, zero is the number we need to aim for, to stop global warming and to avoid the worst effects of climate change, we must stop releasing greenhouse gases into the atmosphere (Gates, 2021). Greenhouse gas emissions increased sharply since the eighties because of human activity that involved the use of fossil fuels (Gates, 2021).

Human activity has been considered the principal reason for climate change with the burning of fossil fuels (coal, oil, gas). This leads to the consequence that the Earth now is

[1] PM10 stands for Particulate Matter. It refers to ambient air quality trends for particle pollution settled by Environmental Protection Agency. PM10 refers to inhalable particles of 10 micrometres (EPA, 2023).

1.1° C warmer above pre-industrial levels in 2019 (United Nations, n.d.-a). The reason we need to go carbon neutral is simple. Greenhouse gases trap heat, causing the average temperature on the earth's surface to rise, the greater the presence of gas, the greater the increase in temperature will be (Gates, 2021).

Recently has been published the Sixth Intergovernmental Panel on Climate Change Report (2023). What has been observed is that global greenhouse gases emissions have raised bringing with itself huge changes in the atmosphere, ocean, cryosphere, biosphere. Experts underlined that continuing with greenhouse gas emissions, we could reach 1.5C°. To work together toward the 2030 goal, we need the commitment of citizens, but the hugest action is enabled by finance, technology, and international cooperation (IPCC, Summary for Policymakers, 2023). Nowadays, there are many agreements and plans that have been settled to fight climate change: the Sustainable Development Goals, the United Nations Framework Convention on Climate Change and the Paris Agreement. The Sustainable Development Goals were absorbed by the United Nations (UN) in 2015 with the aim to act against poverty and environmental protection by 2030 (United Nations, n.d.-b). The UN Framework Convention on Climate Change had the idea to regulate greenhouse gas concentrations to avoid dangerous interference with the climate system (United Nations, n.d.-c). The Paris Agreement, an international climate change treaty that went into effect in 2016 with the goal of preventing a rise in temperature of 1.5°C above pre-industrial levels, is the last but certainly not least significant. (United Nations, n.d.-d).

The main effort now is based on taking action and adapting in order to reduce and prevent climate change impacts for the future. There is a huge effort coming from the European Union to fight climate change. The goal is making Europe the first climate neutral continent in the world, report the European Commission (n.d.-a). This can also be a good opportunity to build a new economic model. All the 27 EU member States are working together in order to achieve climate neutrality by 2050 (European Commission, n.d.-b).

Before this step, there is another important goal that must be achieved by 2030: reduce emissions by at least 55% compared to 1990 levels, and this is the core topic of this work. The benefits that we could have from this reduction are huge: reducing emissions, reducing external energy dependency, improving wealth and wellbeing, creating jobs and work opportunities. All these plans are incorporated into the European Green Deal

presented by the Commission in December 2019. The possibility of achieving a cut in the emissions by 2030 represents a good opportunity for policymakers and investors to achieve climate neutrality (European Commission, n.d.-b).

On 14 July 2021 the European Commission established the rules in order to accomplish the task by 2050, involving also the guidelines to reach the emissions reduction by 2030 (European Commission, 2021). Those policies include the EU ETS[2], Effort Sharing Regulation, transport, and land use legislation (European Commission, 2023). To make that possible, the European Commission settled the Fit for 55 legislative proposals involving areas such as climate, energy, transport with the aim to make possible the 2030 target.

The EU Emission Trading System (EU ETS) is a keystone of the EU's policy to combat climate change. As reported by the European Commission, since the EU ETS was introduced in 2005, emissions have been cut by around 41% in the sectors covered by emission trading. The EU ETS covers around 40% of the total EU emissions as cited by the European Council (n.d.). The Fit for 55 package of proposals aims to make the EU '55% ready' and deliver the necessary transformative changes in the economic, social, and industrial spheres (European Commission, 2021). The 2030 climate target plan has assessed the opportunities and costs of the green transition and has shown that if we can find the right policy mix, the balance will be positive (European Commission, 2021). This is based on the awareness that what is good for the planet is also good for citizens and the economy, as evidenced by the fact that since 1990 there has been an economic growth of over 62% and a drop in emissions of 25% (European Commission, 2020). The current generation is the last one that can take action on time and this decade is the most important one if we want to respect the Paris Agreement. There are still many things to do. Despite some positive political interventions, emissions are increasing and because of that the possibility of reaching the target by 2030 will be more and more complicated (Midulla, 2023).

The interest of this work is to analyse through a Multi-Criteria method how to reduce the emissions by 2030. The idea is to consider different alternatives and criteria in order to prioritize some actions compared to others to achieve the target. Decision-making could

[2] EU ETS refers to European Union Emission Trading System. The goal is to rescue carbon emissions (European Commission, n.d.-c).

be useful to understand and facilitate responses to climate change also because the options available may represent a strategy of action (Intergovernmental Panel on Climate Change, Summary for Policymakers, 2023).

The work will start by introducing the topic to the reader together with some insights about the theoretical concepts that states behind Multi-Criteria Decision Analysis (MCDA) methods, in particular concerning the Parsimonious Analytic Hierarchy Process (PAHP), that is the method chosen for this thesis.

Secondly, through a literature review alternatives and criteria have been identified and given the complexity of the phenomenon, groups of experts and non-experts have been involved to assign ratings to alternatives and criteria. Once the data have been collected, we will show how to apply them on the model and how results can be interpreted.

Finally, to provide a practical application of the results a methodology on portfolio choices is introduced. The method used and its technicalities will be explained in the last part of this dissertation.

To summarize, with this work, we want to show how MCDA methods can be used to create a basis to define and arrange projects in real life, showing how this can help in finding among different alternatives, which ones are more suitable to reach the goal and how can find a practical application.

2. Literature review

2.1 Introduction to the problem

The 2030 environmental, energy, and climate targets, that represent the focus of the European Commission so far, are at the core of this work. This involves defining a set of policies able to reduce greenhouse gas emissions and encourage the spread and use of sustainable and environmentally friendly energy sources. Since this is a very complex issue that involves efforts coming from everyone, from citizens to the highest political offices, in the following chapters we will try, using a mathematical method (Analytic Hierarchy Process, AHP), to define which strategies to prioritise in order to achieve the target fixed by 2030. After a brief introduction to the Multi-Criteria Decision Analysis methods and in particular to the Parsimonious Analytic Hierarchy Process, we will proceed with an analysis of the literature that already used Multi-Criteria methods to address environmental issues. At the end of this analysis, it will be possible to define more precisely which policies can be more effective and which ones need to be pursued in order to achieve a reduction in greenhouse gas emissions by 2030.

2.2 Multi-Criteria Decision Analysis

All of us in our daily lives are inclined to make decisions based on our ideas or intuitions (Ishizaka and Nemery, 2013). For instance, students in choosing the university are considering the rankings, or recruiters are valuating candidates based on their experience or performance during the interview. Ishizaka and Nemery (2013) underlined how decision problems have existed since classical times involving ranking, choice, and sorting problems, that are complex and include different criteria. In considering a decision problem, most of the time there is no perfect solution that embraces all the criteria and for this reason a compromise solution needs to be found: Multi-Criteria Decision Analysis (MCDA) methods have been created to support the decision maker in this process (Ishizaka and Nemery, 2013). However, there are more complex and delicate circumstances in which appropriate methods must be used to evaluate a problem to support the decision. Complex decisions lead to evaluating the phenomenon from different points of view, which we will henceforth commonly refer to as 'criteria' and for this Multi-Criteria Decision Analysis (MCDA) methods can be useful. The main task

performed by this methodology is to match possible alternatives with different criteria (Abastante et al., 2019). According to Ishizaka and Nemery (2013), there are four types of decisions to consider: the choice problem (the aim is to choose the best option or reduce the number of options available); the sorting problem (options are organised into groups, called categories); the ranking problem (options are coordinated from the best to the worst); the description problem (the idea is to define the options and the consequences to them correlated). Obviously, there is no option that fits all criteria, but we can find a compromise solution that is not the optimal one but is the preferred one according to the preference of the decision maker. In order to be able to solve these problems, MCDA proposes different methods depending on one's needs: given the huge number of MCDA methods that can be used, the decision maker has to select the appropriate tool (Ishizaka, Nemery, 2013). The literature (2013) suggests different ways to identify which is the most suitable method to be used, one way is to consider the data and others input information available; in case the perceived utility function is available and the MAUT (Multi-Attribute Utility Theory) method can be used. Building a utility function is not easy and when it is too difficult, it is possible to use a pairwise comparison between criteria and alternatives, and this is supported by Analytic Hierarchy Process (AHP) and Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), as explained by Ishizaka and Nemery (2013). In this analysis we will start from the Analytic Hierarchy Process (AHP) as this is the one, I used in my academic career, focusing to a new proposal, the Parsimonious Analytic Hierarchy Process (PAHP). In this way we will try among different alternatives to find out the optimal ones able to contribute to a reduction of 55% in the emissions by 2030.

2.2.1 The Analytic Hierarchy Process

The Analytic Hierarchy Process was developed by Saaty[3] (Abastante et al., 2019). The application of this method requires the accomplishment of four steps. First, we have to structure the problem, then we have to prioritise the alternatives (based on a pairwise comparison), third weights the criteria (defining the importance of each criterion based on a number) and lastly rank the alternatives (Abastante et al., 2019). The Analytic

[3] Thomas L. Saaty (1926-2017) was the inventor and primary theoretician of the Analytic Hierarchy Process.

Hierarchy Process (AHP) is built in a hierarchical way, where the goal is located at the top of the hierarchy, while the alternatives are at the bottom; moreover, the criteria on which we are evaluating the alternatives are in the middle between the goal and the alternatives (Abastante et al., 2019). In the AHP we compare each couple of alternatives in order to indicate which is the preferred one and express the preference towards a nine-point scale known as the Saaty scale (Abastante et al., 2019). The meaning of the scales are the following:

- 1: equal importance
- 3: moderate importance
- 5: strong importance
- 7: very strong importance
- 9: extreme importance

where 2, 4, 6, 8 represent the intermediate values. This procedure is fundamental because thanks to this pairwise comparison we can construct the pairwise comparison matrix (Abastante et al., 2019).

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

where a_{ij} represents the pairwise comparison between element i (row) and element j (column). The general rule is:

$a_{ij} > 0$; $a_{ij} = 1/a_{ji}$; $a_{ii} = 1 \ \forall i$ (Berrittella et al., 2007) (2)

Once the matrix is constructed, we can calculate the priorities by computing the main eigenvector *w* of the matrix A using the software R[4]:

$AW = \lambda_{max} W$ λ_{max} is the largest eigenvalue of the matrix A (3)

After, we choose the dominant eigenvalue (largest one) and select the eigenvector associated with the principal eigenvalue. When the pairwise comparison matrix fulfil transitivity for all pairwise comparisons it is consistent and verifies the following relation:

[4] R is a programming language that provides through lines of codes statistical computations and graphics (The R project, n.d.).

$a_{ij} = a_{ik}a_{kj}$ $\forall i,j,k$ (Berrittella et al., 2007) (4)

Saaty was underling that the number of factors considered must be less or equal to 9 to maintain consistency when deriving the priorities. The consistency of the matrix can be determined through the consistency ratio (Berrittella et al., 2007):

CR = CI/RI where CI is the consistency index and RI is a Random Index (5)

Saaty calculated the random indices shown in the Table below (Ishizaka and Nemery, 2013).

n	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 1: Random indices from Saaty (1997)
Source: Ishizaka and Nemery (2013)

Saaty (1977) explained that a consistency ratio higher than 10% indicated a set of judgements that are inconsistent and in this case the decision maker should revise the evaluations (Abastante et al., 2019). At the same time the authors (2019) remarked that sometimes a value of the CR greater than 10% doesn't always implies inconsistency, in case of a problem involving a large number of criteria and alternatives, the analyst could admit a CR higher than 10%.

The consistency index (CI) for a matrix of order n is defined as:

$(\lambda_{max} - n)/n-1$ (6)

Usually, a consistency ratio equal or lower than 10% is considered acceptable. If the value is higher, it is not acceptable and we have to go back to the decision maker (Berrittella et al., 2007).

2.2.2 Reduction of pairwise comparisons in AHP: the new proposal

Miller (1956) explained that when we apply the Analytic Hierarchy Process (AHP), we have to provide $\binom{n}{2} + n\binom{|A|}{2}$ pairwise comparisons ($\binom{n}{2}$ pairwise comparisons between importance of criteria and $\binom{|A|}{2}$ pairwise comparisons between alternatives on each considered criterion) (Abastante et. al, 2019). When we are building a problem, we could ask to the decision maker many information and in this way, it could be too complicated, for instance in a problem composed by 10 alternatives and 5 criteria, the DM has to provide 145 pairwise comparisons: $\binom{10}{2} + 10\binom{5}{2}$ (Abastante et. al, 2019). To overcome this problem a new method has been introduced, in which the AHP is applied, to prioritize a lower set of reference levels of the considered criteria, the idea is to reduce the number of pairwise comparisons of alternatives in relation to each of the criteria (Corrente, Greco and Ishizaka, 2016). The Parsimonious Analytic Hierarchy Process (PAHP) was created by Abastante et al. in 2019[5]. The use of this new alternative to the classical AHP, involves the application of five steps:

1) First, for each criterion g_j, we ask the decision maker to give a rating to the alternatives, using a common scale 0-100 (Abastante et al., 2019).
2) The decision maker together with the analyst decide to fix some reference levels (γ_{j1}, ... , γ_{jtj}) (Abastante et al., 2019).
3) The decision maker applies the AHP to the reference evaluations defined in the previous step following Corrente et al. (2016).
4) Some checks have to be performed: the consistency of the pairwise comparisons through the consistency ratio (CR) and check for the monotonicity (Abastante et al., 2019).
5) The ratings of the evaluations not part of the reference evaluations are computed by the interpolation of the normalised evaluations from the previous step (Abastante et al., 2019).

The difference between the classical Analytic Hierarchy Process and the Parsimonious Analytic Hierarchy Process is that, in the first method, we ask the decision maker to

[5] Abastante et al. (2019): Francesca Abastante, Salvatore Corrente, Salvatore Greco, Alessio Ishizaka, Isabella M. Lami from the Politecnico di Torino (Turin), Department of Economics and Business (Catania), Portsmouth Business School (University of Portsmouth-UK).

provide a pairwise comparison among all the alternatives on the criteria that constitute the case study. In contrast, in the second method, we first ask the DM to provide a rating of the alternatives on the criteria chosen and then apply the AHP on a lower number of reference evaluations. i.e., we only ask to compare the reference levels on each criterion pairwise. In the classical AHP, no ratings are involved, and no reference points are considered (Abastante et al., 2019). Abastante et al. (2019) conclude that the Parsimonious AHP give us the opportunity to use the Analytic Hierarchy Process even if the considered problem involves a large number of alternatives and criteria, permitting the decision maker to compare the reference objects considered as most representative according to him.

In this specific case study, where we are trying to evaluate how to reduce emissions by 2030 by applying the MCDA, given the large number of alternatives that have been selected as the most relevant ones, we decided to apply the Parsimonious AHP to avoid the DM to pairwise many alternatives on the selected criteria.

2.3 Practical cases

Much research related to environmental issues has already been conducted over the years. We reviewed main studies on how multicriteria methods can be used to approach environmental issues. The articles that have been subject of the analysis adopted the same procedure: introduction of the problem object of the research, identification of the main goal, construction of the assessment scheme (goal, criteria, and alternatives) and lastly application of the Analytic Hierarchy Process to find out the optimal solution to the problem.

The building industry can have an important impact on the natural environment. This can be supported by the fact that the construction of infrastructures is linked with an increase in the CO_2 emissions and into an increase in the energy demand. The Malaysian government, for instance, decided to recover existing buildings in order to reduce the emissions and energy consumption, and provide its contribution to the achievement of the emission reduction goal fixed by 2030 (Kamaruzzaman et al., 2018).

Aeroplanes, trains, cars and in general the whole transport sector are contributing to greenhouse gases emissions and in this way, they are affecting climate. According to a

research published by Il Sole 24 Ore, the 13% of the emissions are caused by the transport sector, of which the 2% is caused by the aviation sector (Da Rold, 2019). To understand and identify a set of transport policies useful to solve the problem, the Analytic Hierarchy Process has been applied. Incentivising public and environmentally friendly transports are a valid option (Berrittella et al., 2007). Another important sector that is extremely linked to climate change is food security. Changes in the temperatures and irregular seasons affect the yield of fields. A reduction in the production is linked to an increase in food prices (Birgani et al., 2022). Agriculture plays an important role in fighting climate change, for example, trees on agricultural land absorb carbon from the atmosphere. At the same time, the agricultural sector is responsible for around 10% of emissions, in particular coming from methane and nitrous oxide (European Commission, n.d.-d).

Population growth is directly translated into an increase in the energy demand. This is the reason why we need to move towards cleaner energy resources such as solar, wind, biomass, and mini-hydro energy (John et al., 2021). 3.5 billion people live in regions that are very sensitive to climate change, and the energy industry is responsible for 75% of global emissions (United Nations, n.d.-e). Through the literature review, what has been discovered is that EU's industry, services, transport, and energy sectors will face considerable investment challenges in order to meet the 55% emissions reduction objective (European Commission, 2020).

In the following section we will translate the theory into practice. To apply the AHP, as mentioned above, it’s important to identify the goal, alternatives and criteria related to the scope. A survey, in which alternatives and criteria have been collected, was submitted to some experts and non-experts in order to build the framework. Criteria and alternatives have been identified and supported by the literature and by a deep analysis of the main issues interlinked with climate change.

3. Methodology

3.1 Climate change today

Climate change is the result of more than a century of unsustainable energy and land use, behaviours, and patterns of consumption, explains the Introduction and Framing Chapter of the Sixth Intergovernmental Panel on Climate Change[6] (2022). Global greenhouse gases emissions continued to growth until 2019 and since the AR5 (Fifth Assessment Report of IPCC, 2014) there has been an increase in the social awareness and sensitivity in the fight to stop climate change, as can be read in the IPCC (Introduction and Framing Chapter, 2022). In the European Union, emissions have increased of 6.5% in 2021 after a very low level that has characterised the pandemic period, even if emissions decreased of 5% in comparison to 2019 (Di Donfrancesco, n.d.). The commitment to reduce the emissions since the Paris Agreement (2015) requires a shift to low carbon intensive activities and an industrial transformation in which each sector of the economy can contribute: countries can reduce their emissions while growing their economies, but at the same time a transition to a low-carbon economy involves different drivers and constraints (IPCC, Introduction and Framing Chapter, 2022). The relation between power, politics and economy is the reason why some activities are not translated into urgent actions; both public and private financing are influencing low-carbon investments, and a global cooperation can be a positive way to accelerate the diffusion of low-carbon technologies and help to do not leave behind developing and poorer countries (IPCC, Introduction and Framing Chapter, 2022). The last report published by the Intergovernmental Panel on Climate Change (2022) explains that different solutions to limit global warming and to reduce the GHG emissions by 2030 are available and come from different sectors: positive aspects are still available with a decrease in the costs of renewable energy, and today, half of world emissions are covered by laws and policies (Skea, 2022).

Recently COP28 took place in Dubai (United Arab Emirates) from 30 November until 21 December 2023 (United Nations, 2023-f). The United Nations Climate Change conferences, commonly denoted by COPs, take place every year. These meetings are an occasion where representatives coming from every part of the world are gathering to agree

[6] The Intergovernmental Panel on Climate Change, commonly denoted by IPCC, was created in 1988 and it is the United Nations body for assessing the science related to climate change (IPCC, n.d.-a).

on ways to address climate crisis (United Nations, 2023-f). The UN Climate Change Executive Secretary at COP28, Simon Stiell, opened the conference with a speech in which he underlined the importance of taking climate action as fast as possible, stressing that 2023 has been the hottest year ever in humanity and that we are playing with people's lives and livelihoods (United Nations, 2023-g). The main points underlined by the Secretary are involving a safer and resilient planet, fund a transition, and commit to a new energy system leaving fossil fuels production and consumption, as explained in the United Nations website (2023-g).

Immediately after the opening ceremony of COP28 came important and long-awaited news: the adoption of a loss and damage fund to help the most vulnerable countries affected by climate change, whose resources should come from richer countries (Barolini, 2023). The European Union will pledge USD 225 million, followed by the United Arab Emirates with 100 and 76 by the United Kingdom. From the United States, only 17.5 will come (Barolini, 2023).

At the end of the UN Climate Change Conference (COP28), the need for global cooperation to bring 'the beginning of the end' to the use of fossil fuels was repeatedly emphasised by the Executive Secretary, Simon Stiell (2023). It ends by underlining the extreme importance of reducing greenhouse gas emissions, thus limiting global warming to 1.5°C (Worth, 2023). Countries will now have to get to work to present major action plans to reduce emissions by 2025 (Worth, 2023).

The United Nations Framework Convention on Climate Change (UNFCCC), which highlights the fact that 11 nations have submitted national adaptation plans (NAPs)[7] in the fight against climate change, is sending out a positive signal. The Green Climate Fund (GCF) plays a significant role in this, supporting the implementation of national adaptation plans. As of 2023, 83 adaptation projects have been approved and converted into USD 5.3 billion, thanks to funding from the GCF (Nield, 2023).

The Next Generation EU and the Multiannual Financial Framework for 2021–2027, which together account for over 1.8 trillion euros, can aid in achieving the green and digital transition that Europe aims for. The European Commission is committed to

[7] National adaptation plans (NAPs) were introduced during COP17 (South Africa, 2011) aimed for providing ways to reduce impacts of climate change, build adaptive capacity, facilitate climate change adaptation (United Nations, n.d.-h).

Europe's 2030 climate ambition (European Commission, 2020). Improving the transition has the potential to significantly transform the EU economy and give residents access to a more contemporary, resilient, and sustainable environment. According to 2020 European Commission report, the transportation and building sectors are the highest emitters. Reducing emissions in these industries can directly improve the well-being of citizens. Moreover, the Commission (2020) underlined that interventions include the agricultural and food sector: consumers should shift towards sustainable healthy diets and foods, reducing in this way the sector emissions and improving health, while reducing health costs and food waste. All these interventions can provide positive impacts on GDP and in the EU employment, providing durable and new green jobs, even if the situation is not the same in all Member States, where everyone has different national situations and not all states have the same capacity to fight against climate change (European Commission, 2020).

To conclude, the EU's climate ambition for 2030 will provide both economic opportunities and a cleaner and more sustainable environment: for instance, the EU's energy system is mainly covered by imports and renewable energy generated in EU could increase security in the supply (European Commission, 2020).

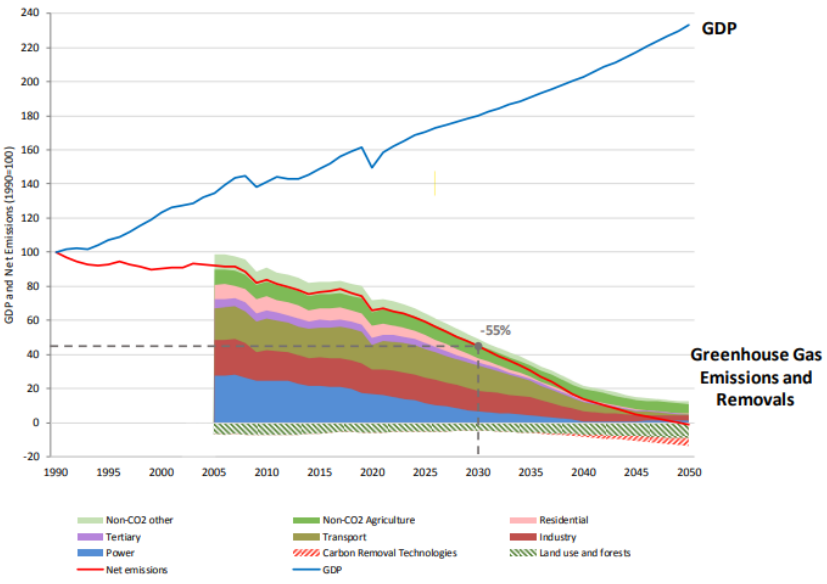

Figure 1: The EU's pathway to sustained economic prosperity and climate neutrality, 1990-2050

Source: European Commission (2020) Stepping up Europe's 2030 climate ambition

In the following section a detailed analysis of different solutions is provided. This section is based on the work done by the Sixth Assessment Report provided by the Intergovernmental Panel on Climate Change (2022) and by the European Commission strategies adopted to fight against climate change, known as the EU 2030 targets. The Intergovernmental Panel on Climate Change is a group of experts, belonging whether to United Nations or World Meteorological Organization (WMO), that work together to identify drivers of climate change, impacts, risks, and adaptation policies (IPCC, n.d.-a). The EU 2030 climate targets are a series of proposals adopted by the European Commission (July 2021) to reduce net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (European Commission, n.d.-b).

3.2 Identification of alternatives

As can be seen from the scheme below, ten different alternatives to contribute to the reduction of GHG emissions by 2030 have been identified and all of these alternatives have been observed in comparison to three different criteria: economic, environmental and wellbeing, that will be briefly explained in the next paragraph.

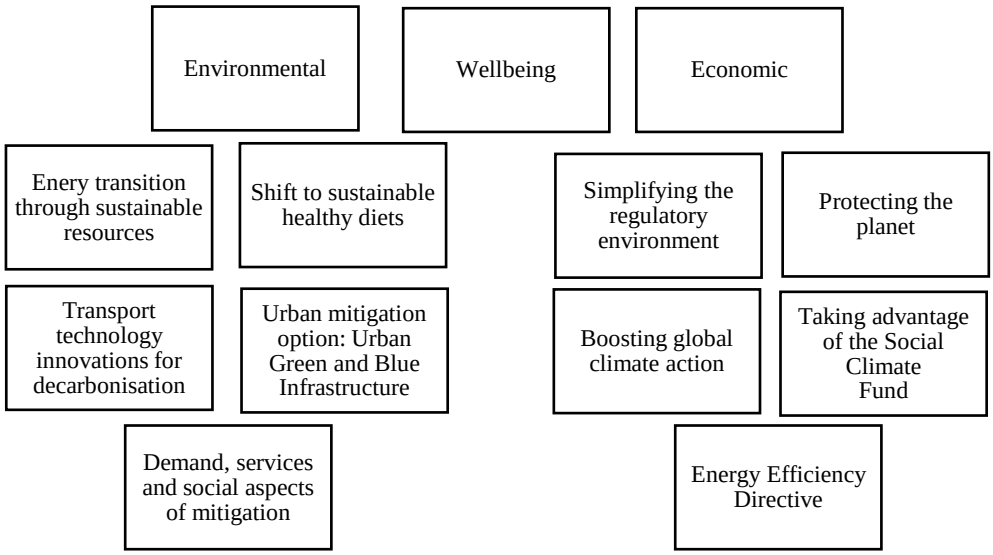

Table 2: Proposed Assessment Scheme for a reduction in the global GHG emissions by 2030

3.2.1 Energy transition through sustainable resources such as Solar PV and Wind

We have to reduce CO_2 and GHG emissions, given that the energy sector is the largest contributor of carbon dioxide emissions. We have to intervene in the energy system with sustainable sources such as Solar PV and Wind that in many areas are cheaper than fossil-generated electricity (IPCC-Chapter 6, 2022).

The increase in the temperature cannot be stopped without some important interventions in our energy system and with a reduction in carbon dioxide and greenhouse gas emissions (IPCC-Chapter 6, 2022). Working for limiting the increase in the temperature above 1.5C° will be linked to a reduction of 35-51% in net CO_2 and 38-52% in GHG emissions (IPCC-Chapter 6, 2022). To achieve these results, there is need to work in different directions: reducing fossil fuel consumption, increase use of alternatives electricity resources able to produce no carbon dioxide emissions, and remove it from the atmosphere (IPCC-Chapter 6, 2022). The Intergovernmental Panel on Climate Change in the Energy System chapter (2022) observed how in the energy sector both the demand and the emissions have continued to grow: from 2015 to 2019 this increase was of 4.6% for CO_2 and 2.7% in the total greenhouse gas emissions. On the other hand, prices have reduced thanks to different energy mitigation options such as solar photovoltaics, wind power and batteries: these prices decreased by 56%, 45% and 64% respectively from 2015 to 2020 as cited in Chapter 6 of IPCC (2022). Between 2015 and 2019, there was a growth in wind and solar photovoltaics, which can also be attributed to lower costs, a desire to decrease fossil fuel generation, and low interest rates. These resources made up 21% of all low-carbon electricity generated in 2019 and 8% of all electricity generated overall. However, if we keep investing in fossil fuel infrastructure like coal, the energy system will be unable to contain rising emissions and keep global warming below 2°C (IPCC-Chapter 6, 2022). In this way climate change will affect different areas and regions and the impacts are uncertain. We already have different options to mitigate the emissions as reported in the Energy System Chapter (2022): in many locations wind and solar PV are cheaper than fossil-generated electricity and nuclear power and hydropower are already established technologies, a tenth of the global primary energy is represented by bioenergy. The IPCC (2022), in the Energy Chapter, underlined that all these actions need to be linked with other factors: socio-cultural, economic, technological, institutional, geophysical. If from one hand we have to work towards an electricity transition, today there are still people in the world that have no access to electricity; the war in Ukraine

and the global economic uncertainty are contributing to this path with instability of energy prices. To ensure access to electricity and achieve the Sustainable Development Goal[8] number 7 we have to invest in electrification and in renewable energy sources (United Nations, n.d.-i). Given that the energy sector is the largest contributor of carbon dioxide emissions, a reduction in this sector is extremely important to limit global warming (IPCC-Chapter 6, 2022). The energy sector as a whole is composed by physical and societal elements. In the first case we refer to infrastructure and equipment that transport and convert energy in order to provide energy services to the community, while in the second case we are referring to another relevant component, where humans use energy to transport themselves and the goods they are using. The energy system is in this way an important component for the supply of goods and services. All energy users can change their behaviours investing in infrastructure able to reduce the energy needs, invest in technologies (such as rooftop solar) or store energy (such as batteries) (IPCC-Chapter 6, 2022). As we already said, energy emissions will continue to grow, and the temperature will not be limited below 2°C according to the Energy System Chapter of the IPCC (2022). Between 2015 and 2019 global energy CO_2 emissions from fossil fuels increased by 4.6%. In 2020 with the global Covid-19 pandemic, the energy sector CO_2 emissions decreased. As we can see from the figure below (Figure 2a), observing the global energy sector CO_2 emission by fuel, coal was the largest contributor in the last years accounting about 44% of the total emissions in 2019 followed by oil (34%), natural gas (22%). Figure 2b underlines the emissions by sectors: the largest contributor of emissions is the energy sector (36% in 2019), followed by industry (22%) and immediately after we have the transport sector, excluding aviation and shipping (22%). The increasing level of the emissions is also linked to an increase in the population, this effect is also enhanced by the economic growth (IPCC-Chapter 6, 2022).

[8] The Sustainable Development Goals (SDGs) have been adopted by the United Nations in 2015. They are constituted by 17 goals that represent an urgent ambition for all countries to ensure peace and prosperity for planet and people by 2030 (United Nations, n.d.-d).

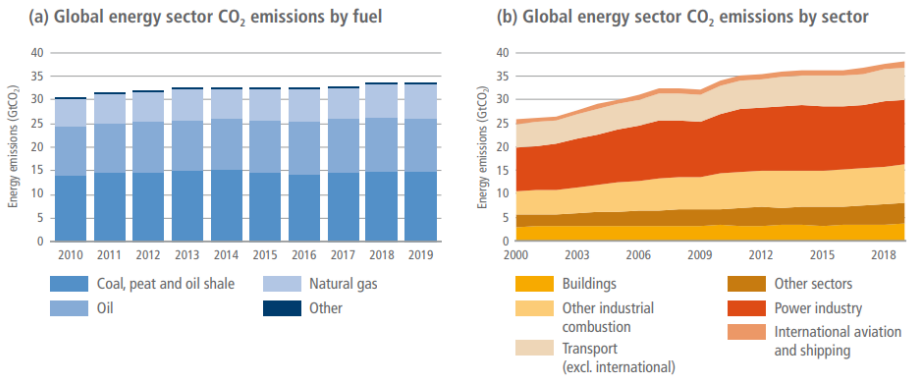

Figure 2: Global energy sector CO_2 emissions

Source: IPCC-Chapter 6 (2022)

In other to reduce the emissions by 2030 a change is needed. One option is to look for alternative energy sources and energy conversion systems such as solar energy and wind. Solar energy is considered as a form of renewable energy in which sunlight is converted into electricity or other forms of energy use and it is the energy source that grows quicker (Mwaura and Krol, 2023). From solar photovoltaics (PV) we can convert sunlight into usable energy: solar PV are able to absorb energy coming from sun lights and convert it into electric current and release electrons. The cells that constitute the system are built in a manner such that all the electrons are moving in the same direction creating in this way energy able to power electric cars, homes, etc. (Mwaura and Krol, 2023). The costs of this source of renewable energy have declined by 62% in 2015 and are anticipated to decline by 16% in 2030, as cited by the Intergovernmental Panel on Climate Change, Chapter 6 (2022). In numerous regions across the globe, the expense of power produced through photovoltaic cells is less than that of fossil fuels: the cost of PV electricity has decreased by 89% since 2000 and by 69% since the last Report (AR5, 2014) as explained in the AR6 Report in the energy section (2022). Several factors, including automation, increased efficiency, and various incremental improvements, are associated with the reduction in costs, although it will be challenging for CSP to compete with PV, the technical potential for concentrating solar power (CSP) costs has also decreased - Figure 3 (IPCC-Chapter 6, 2022).

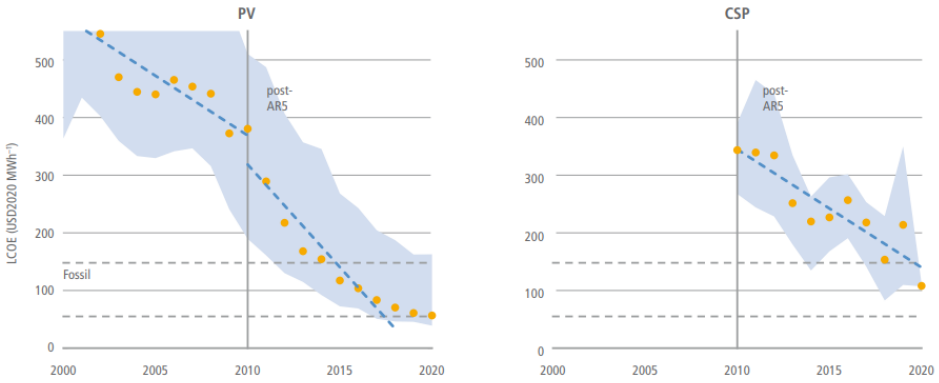

Figure 3: Levelized costs of electricity (LCOE) of solar energy technologies 2000-2020
Source: IPCC-Chapter 6 (2022)

To reduce the impact that PV has on the environment, recycle materials, and make smart land-use decisions is necessary. Another aspect that can be taken into consideration is the conversion of land to collect solar energy: this can have an impact on the biodiversity and land use. A solution could be to combine PV with agriculture (agrivoltaics) and PV installations floating on water. Motivations for people to adopt PV are financial gains, environmental benefits, more self- sufficient and peer expectations (IPCC-Chapter 6, 2022).

Another option is represented by wind energy. It is a form of renewable energy that is created by the movement of wind across wind turbines. These turbines are not a producer of greenhouse gas emissions, making wind a carbon-free energy source (Howland et al., 2023). Costs have declined by 18 and 40% since 2015 with an expected reduction for the next years. The energy that comes from wind is abundant and the potential of this resource is able to cover the total amount of energy necessary to keep the warming below 2°C, observed the IPCC in Chapter 6 (2022). The use of wind is unequally distributed around the world, but any region is characterised by a quantitative measure of wind energy available. There are two types of wind power: onshore and offshore wind energy. The first one is wind energy that is created by wind turbines that are on land and moved by the air, usually constructed on fields, where there is less population and buildings that could negatively impact the air flow; the second one is energy generated by wind blowing across the sea and those are considered more efficient than onshore because of a less invasive interference on land and higher speed of wind (National Grid, 2022). Electricity

generated from onshore wind is less expensive than electricity generated from fossil fuels, wind power plants have a low environmental impact but can have an ecological effect (IPCC-Chapter 6, 2022). Wind turbines don't produce waste or pollutants and the Life Cycle Assessment (LCA) for wind is influenced by quality of wind resources, size of the turbines and wind power technologies compensate their carbon footprint in less than a year (IPCC-Chapter 6, 2022). Wind energy is an efficient solution also for the achievement of SDGs proving access to electricity for millions of people, create jobs and income opportunities (Sustainable Business, 2023).

3.2.2 Shift to sustainable healthy diets

A sector that also needs to be considered is represented by Agriculture, Forestry, and Other Land Uses (AFOLU). This sector cannot only reduce emissions but also remove and store carbon dioxide. There is a need to conserve ecosystems and improve the food system. Given that AFOLU are strictly linked to the food production and consumption, a shift to sustainable healthy diets can reduce the sector GHG emissions (IPCC-Chapter 7, 2022).

Agriculture, Forestry and Other Land Uses (AFOLU) affect climate change but at the same time offer different opportunities to mitigate the phenomena while delivering food, respecting biodiversity, and avoiding forms of malnutrition in the population, especially in developing countries, explains Chapter 7 of the IPCC (2022). The AFOLU sector is responsible for 13-21% of global total greenhouse gas emissions between 2010 and 2019 of which, the three mains are carbon dioxide, methane, and nitrous oxide; but at the same time there are ways to mitigate the increase in the global temperature: an intensification in the agricultural system with a shift to more healthy diets, together with a reduction of food waste can help, as cited in the last IPCC Report Chapter 7 (2022). Some countries face some barriers that most of the time are represented by financial obstacles: achieving these results requires government sources and funding sources that most of the time are not sufficient. The continued loss of biodiversity is linked to less resilient ecosystems and can increase the difficulties in AFOLU policies to fight climate change (IPCC-Chapter 7, 2022). Agriculture Forestry and Other Land Uses provide different mitigation options to reduce GHG emissions or to improve the quantity of carbon sequestration. On demand-side measures one solution can be represented by a shift to sustainable healthy diets, this

term refers to a change in the behaviour of individuals to enhance and promote wellbeing while having a lower environmental impact. The reduction in the consumption of animal-based food and an increase in the consumption of plant-based can represent a benefit for forests, and land used for feeding animals, increasing at the same time the conservation of biodiversity (IPCC-Chapter 7, 2022). In the long term these measures could reduce by 29% GHG emissions providing others benefits for climate, observed the AFOLU Chapter of the IPCC (2022). Moreover, the experts in their Report (2022) examined a case study in New Zealand where a shift in the diet can be translated, not only in a food system GHG emissions reduction by 4-42%, but also a reduction in the healthcare system costs (NZS 14-20 billion). In conclusion, a shift to sustainable healthy diets can have a positive impact for population health and for the environment but requires at the same time not only financial resources, but also non-financial, including changes in consumers behaviours and sensibilization campaigns (IPCC-Chapter 7, 2022).

3.2.3 Transport technology innovations for decarbonisation

Transport sector has the capacity to actively contribute to a reduction in the emissions. Transport and in particular road transport, such as cars, play an import role in our daily life and for this reason is important to improve car performance and use low-carbon fuel innovations (IPCC-Chapter 10, 2022).

As reported in the official website of the European Commission (n.d.-b), there is strong evidence about how the transport sector is working to fight climate change and to find out affordable and effective solutions for a greener mobility and accessible transport systems available for all European citizens. The idea is that by 2035 all new cars and vans in Europe will be zero emissions but this goal requires that by 2030 the emissions for the car sector will be reduced by 55% until reaching zero emission for the mobility sector in 2050 (European Commission, n.d.-b). If we look at the emissions coming from the transport sector, according to Chapter 10 of the IPCC Report (2022), 23% of the total global energy related CO_2 emissions come from the transport sector (70% from road vehicles). The evidence is clear and the need for an immediate change too: there is huge need for a change in consumers behaviours as consequence to an infrastructural change, cities could reduce transport fuel consumption approximately around 25% by combining less car dependent behaviours together with appropriate infrastructures such as bike

pathways and pedestrian areas, explains the Transport Chart of IPCC (2022). To fight the emissions, a solution could come from battery electric vehicles (BEVs) characterized by lower GHG emissions when charged with low-carbon electricity sources, but at the same time there is need to reduce greenhouse gas emissions footprint for battery production. These technologies are facing obstacles concerning costs, capital, and infrastructure availability, but at the same time without action, emissions coming from the transport sector could rise between 16 and 50% by 2050 (IPCC-Chapter 10, 2022).

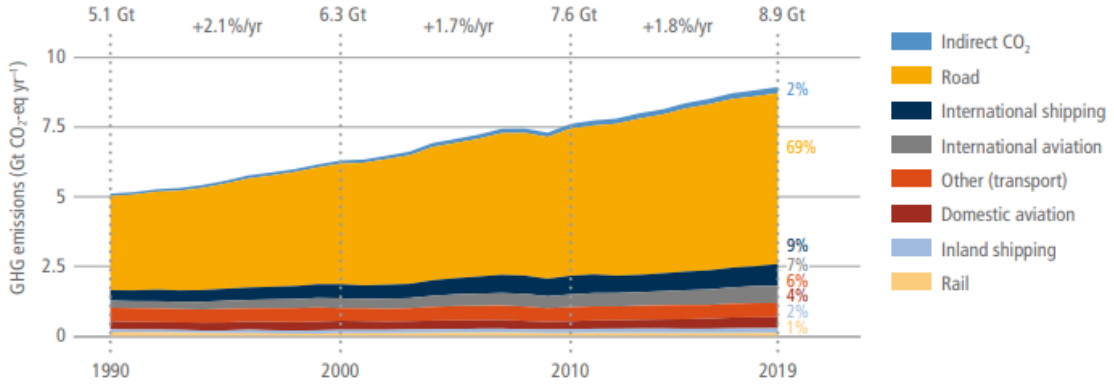

Figure 4: Global transport greenhouse gas emissions trend

Source: IPCC-Chapter 10 (2022)

Transport was the largest contributor of GHG emissions in 2019 and as can be seen from Figure 4 above, the highest percentage came from road transport (69%). There are different strategies aimed to change the situation such as, minimising travel distance, develop an efficient transport system (also in terms of pricing), and introduce lower emitting transport modes requiring efficient transport infrastructure investments, as underlined by the Sixth IPCC Report on Chapter 10 (2022). If from one side there is huge intervention coming from government and institutions, on the other hand there is need for a behavioural and mode choice change. Behaviour is linked to people preferences, personal values, and environmental values also play a role in people's decisions. Researchers find out that income and price have an important impact on people but at the same time shifting the demand is crucial for decarbonising the sector (IPCC-Chapter 10, 2022). Cars play an important role in today life and because of that, meliorate cars performance is extremely important for a decarbonisation in the transport sector,

explained the IPCC Chapter 10 (2022). What is suggested by the Report (2022), as solutions for transport technology innovations for decarbonisation, are vehicles technologies and low-carbon fuel innovations. Reducing the emissions of CO_2 from internal combustion engine vehicles (ICE) with low-carbon or zero-carbon fuels is essential: alternative fuels involve natural gas-based fuels, biofuels, ammonia, and other synthetic fuels (IPCC Chapter 10, 2022). Another aspect is the electrification of transport nodes to reduce the emissions but depends at the same time on an appropriate electric energy storage system. Since the Fifth Assessment Report (2014), electrochemical storage (for instance batteries) upgraded strongly with the rise in lithium-ion batteries. In terms of costs, by 2020 there has been a reduction to USD137 per Kwh in the average battery cost pack (IPCC Chapter 10, 2022). All these technologies represent solutions that can help to promote the electrification of the system, reduce costs, and lastly lead to a huge environmental benefit. Promoting the spread of electromobility is not only related to developed countries, in fact, transports in low- and middle-income countries such as Africa, South-East Asia, and South America are characterised by gas-powered motorcycles that are negatively affecting the air pollution. Currently in Bulawayo (Zimbabwe) there is a project based on trackless trams paired with solar energy able to decarbonise and enable low transport costs: investing in climate could represent an opportunity to invest in developing countries, concluded the Sixth IPCC Report for transport (2022).

3.2.4 Urban mitigation options: urban green and blue infrastructure

The construction of new urban infrastructures will increase emissions. A solution is represented by urban green and blue infrastructure, as explained in Chapter 8 of the IPCC (2022).

Nowadays, more than half of the population lives in cities and another 2.5 billion of people are planning to move by 2050 (United Nations, 2017). The increasing urbanization in cities, together with an income increase and higher consumption levels, are influencing climate change, as reported in Chapter 8 of the IPCC (2022). The Intergovernmental Panel on Climate Change explained that urban infrastructures and activities are responsible of two-thirds of the emissions, but at the same time some cities already introduced some mitigations options, because solutions are available: in London for instance, fees have

been implemented to vehicles in order to fight pollution in the city centre, while Paris banded diesel cars (World Economic Forum, 2022). The population increase is linked with an increase in the construction and renovation industry that through 2030 will be translated into an additional increase in the global emissions: there is need to address urban mitigation strategies in cities to fight climate change (IPCC-Chapter 8, 2022). Urban green and blue infrastructure can be a solution to store carbon, reducing emissions and reducing energy use at the same time, providing in this way different benefits, but of course these strategies depend on different factors such as, city land, size, level of urbanisation etc., as explained in the Sixth IPCC Report-Chapter 8 (2022). Urban green and blue infrastructure include streets, parks, green roofs, and vertical forests showing how can help in addressing SDGs (see Figure 5). Urban forests and streets trees are the best option, given their capacity to store and sequester carbon in relation with a low energy demand (IPCC-Chapter 8, 2022). For instance, by planting among 245 world cities the maximum number of streets trees, these could be translated into a reduction of electricity use by 0.9-4.8% annually; while in Europe by turning in green surfaces the 35% of urban surfaces, carbon sequestration potential would be estimated 25.9 MtCO2 yr^{-19} with an energy saving of 92 TWh yr^{-110} as explained in the IPCC, Urban System and other Settlements Chapter (2022). Urban trees are also able to reduce UHI effect[11], improving the air quality together with a better health and well-being for citizens, efficient transport nodes in a greenspaces could reduce GHG emissions by cycling (in Copenhagen, the cost of cycling is six times lower than car driving) (IPCC-Chapter 8, 2022).

To conclude, urban efforts to implement carbon lock in can effectively reduce the emissions, electrification of urban energy systems can reduce emissions and urban areas can also help the achievement of Sustainable Development Goals; there is need to reduce or change energy and materials use by moving to a more sustainable production and consumption, shift to low carbon infrastructures and enhance carbon sequestration with urban green and blue infrastructures, as suggest by the IPCC (Chapter 8, 2023).

[9] MtCO2 yr−1 stands for million tonnes of carbon dioxide per year. This unit measures, in a given period of time, the amount of carbon dioxide that is removed or emitted (Gov.ie, n.d.).
[10] TWh yr^{-1} stands for terawatt-hour per year. It is usually used to measure the electrical energy generated by a power plant. It is one trillion watts of power used for one hour in a year (Clark, 2023).
[11] Urban Heat Islands effect (UHI) happens with an increase in the temperature of the environment, significant in urban areas with an important concentration of energy sources (Taha, 2004).

Figure 5: Key mitigation benefits, adaptation co-benefits, and SDG linkages of urban green and blue infrastructure

Source: IPCC-Chapter 8 (2022)

3.2.5 Demand, services, and social aspects of the mitigation

Emissions reductions may be possible through a mix of better infrastructure, technologies, and effective policies that influence behavioural change (IPCC-Chapter 5, 2022).

This is the first report in which the Intergovernmental Panel on Climate Change (2022) introduces a part related to demand, services, and social aspects of mitigation. It shows how a change in demand in each sector can reduce greenhouse gas emissions. The IPCC in Chapter 5 (2022) explained how a change in the demand is linked to a change in behaviours, ways of living, in the production and consumption system, and in service provision strategies, providing in this way good levels of well-being, improved quality of life, happiness and sustainable human development. To reduce the emissions, different types of strategies can be used: avoid (if not needed to achieve the result), shift (move to alternatives technologies and or services) and improve (improve in existing technologies) with a general key concern on decent living of standards (IPCC-Chapter 5, 2022). In demand-side mitigation it is extremely important an active participation coming from all sectors: economic growth is linked with emissions increase, underlines the Report (Chapter 5, 2022). People needs are satisfied with the provision of services and if associated with a low energy demand, can contribute to a reduction in the carbon emissions (IPCC-Chapter 5, 2022). In a global perspective, basic needs are delivered using different amount of energy according to the society: today about one-third of the population is energy poor and many others do not have access to energy, the capita energy requirement for a decent standard of living range around 5 to 200 GJ (gigajoules per person per year, it refers to a unit energy consumption per capita per year) cap^{-1} yr^{-1} (IPCC-Chapter 5, 2022), moreover total energy consumption is related to inequalities across the world: the poorest are responsible only for 10% of the emissions consumptions, while 50% of the global GHG emissions are under the responsibility of 10% richest people, as reported in the AR6 Chapter 5 (2022), a reduction in the inequalities together with an efficient service provision system between developed and developing countries can help in the emissions reduction. To obtain a higher well-being and low-carbon-demand, societies individuals' behaviours, culture, institutions, infrastructure, and investments play a role (IPCC-Chapter 5, 2022). Consumers can change their behaviours only if they are committed to this change and have the capacity to change, because this implies a change in personal values, routines, and the willingness to change can be

enhanced by a focus on personal wealth and finance (IPCC-Chapter 5, 2022). Secondly according to the same Chapter (2022), socio-cultural drivers of climate mitigation can help to change ideas or social practices to achieve a reduction in the emissions, in this case trust plays an important role together with local initiatives. Another influence comes from businesses and corporate organisations that influence global warming by investing in new technologies and other energy efficient resources, another role is played by institutional drivers and lastly by technological and infrastructural drivers (IPCC-Chapter 5, 2022). The last IPCC Report in demand, services and social aspects of mitigation section (2022) suggests that engineers, urban planners and researches can help towards the decarbonisation: for instance, architects can design infrastructures to facilitate low carbon mobility implemented by walking and cycling; consumers (10% richest group) can move and experiment a more sustainable consumption. To conclude, solutions able to reduce fossil demand and use, reducing in this way greenhouse gas emissions, provide better services and well-being for all.

3.2.6 Simplifying the regulatory environment

A simple, predictable, and clear regulatory environment is key to promote investments but at the same time another important pilar, of the Green Deal Industrial Plan, is the need to extend and accelerate access to funding in order to invest in sectors and technologies (European Commission, 2023).

The European Union (EU) is dedicated for achieving a world with zero emissions. Thanks to a strong industry built by scientists and researchers, the EU is a leader in innovation, the spread of sustainable products, and contemporary technologies (European Commission, 2023). In February 2023, the Commission published a communication on the Green Deal Industrial Plan, which stated that in order to help companies access to financing, the European Union needs to develop a strong point within the single market. According to the Commission (2023), the goal of the Green Deal Industrial Plan is to guarantee a predictable and simplified regulatory environment with quicker access to financing. The Commission made the decision to control regulations in order to avoid needless burdens and to move toward a straightforward regulatory system to encourage investment.

One of the proposed regulations aims to provide more clarity on how to achieve the goals of climate neutrality by outlining in plain terms how to support the industrial production of key technologies. In particular, as the Statement (2023) mentions, setting targets for industrial capacity by 2030 and reducing the authorization period by establishing a single channel for investors and industry stakeholders. The European Commission established regulatory sandboxes to test and experiment with new technologies in order to foster innovation. The EU Commission reports that investments in clean energy have increased by 10% in 2022 over 2021. Within the NextGenerationEU[12], EUR 250 billion are made available for green measures and decarbonisation of industry; Horizon Europe (EU programme for research and innovation) devotes EUR 40 billion to research; cohesion policies make EUR 100 billion available for the green transition. To date, these EU resources have been earmarked for research and innovation and the deployment of sustainable energy (European Commission, 2023).

State aid is one way through which funding can be provided (European Commission, 2023). The Commission approved EUR 51 billion in aid in 2022 to support the decarbonization of industry throughout the EU and the advancement of renewable energy. The Commission now wants to provide member states more flexibility in providing aid: first by simplifying support for renewable energy, the decarbonization of industry, proportionality of subsidies, and more focused support for production projects (European Commission, 2023). EU funding will need to be increased by 2030 in light of the goals the EU has set. EU aid will also come with an additional EUR 20 billion brought to the Recovery and Resilience Facility (RRF) by the REPowerEU initiative, reported the Commission (2023). REPowerEU is an answer to the market energy crisis founded by the European Commission (European Commission, n.d.-e). Public investment is not enough, so a substantial part will have to come from private investment (European Commission, 2023).

To conclude, in recent years the European single market has increased the Union's annual GDP by about 8-9%, as indicated by the Commission's statement (2023). The idea is to make the Green Deal Industrial Plan a way to simplify, accelerate and align incentives to

12 It is an investment plan valid for all EU countries, and among its objectives one part is devoted to environmental protection (Fiordaliso, 2020).

preserve competitiveness and attractiveness for zero-emission investment (European Commission, 2023).

3.2.7 Protecting the planet

We should work with nature to protect our plant and wealth. Restoring nature and protecting the biodiversity is a cheap and effective solution to store and absorb carbon (European Commission, n.d.-f).

Why does the topic of climate change matter so much? We all want to see turtles, polar bears, and leopards in their natural habitats. Additionally, the production of coffee and the upkeep of a clean water system may be impacted by climate change, with the increase in global temperatures potentially playing a significant role in exacerbating the already dire situation of water scarcity (WWF, n.d.). Since everyone on the earth is impacted by climate change, everyone has a right to breathe clean air, regardless of where they live (WWF, n.d.).

The European Union Biodiversity Strategy for 2030, released by the European Commission in May 2020, aims to prevent ecosystems from being destroyed and to promote their preservation for the benefit of people, environment, and climate (European Commission, n.d.-f). Nature is extremely important in our life: not only for physical and mental health but also for the capacity of our society to cope with global changes, health threats and disasters (European Commission, 2020). Many sectors are strongly linked with nature, and more than half of the world's GDP depends on it: construction industry, agriculture, food, and beverage sector are the most important ones in our economy, as can be read from the EU Biodiversity Strategy (2020).

The preservation of biodiversity has the potential to yield significant advantages. For example, the preservation of marine stocks could boost fishing industry profits by over 49 billion euros, while the insurance industry could avoid losses of roughly 50 billion euros if coastal areas are protected (European Commission, 2020). The five primary causes of biodiversity loss were identified by the European Commission in the Biodiversity Strategy for 2030 as follows: changes in land sea use, excessive exploitation of resources, climate change, pollution, and invasive exotic species. There has been a 60% fall in just over 40 years in the planet wildlife (Grooten et al., 2018). The loss of

biodiversity reduces agricultural and fishing industry productivity and at the same time increases economic losses, as a result of floods and other disasters, as underlined by the Commission in its Strategy (2020). For instance, each dollar invested in marine area will lead to a return of just under 3 dollars benefits (Brander et al., 2020) and those investments could lead to about 500 000 new jobs (European Commission, 2020).

In summary, the Biodiversity Strategy statement for 2030 (2020) outlines the following primary goals: strictly protect at least one third of the EU's protected areas; legally protect at least 30% of the EU's land surface and 30% of its seas; manage the protected areas effectively, establishing precise goals and procedures for an efficient conservation under ongoing monitoring. According to the Commission's 2020 report, the plan calls for a minimum 50% reduction in the use of chemical pesticides by 2030. Nature restoration is an important commitment if we want to impact the global worming by capturing and storing carbon, reports the European Commission on its official page: we have to force the removal of net carbon and boost carbon sink: the goal is to reduce 310 million tonnes of CO_2 by 2030 as can be seen from the chart below (European Commission, n.d.-b).

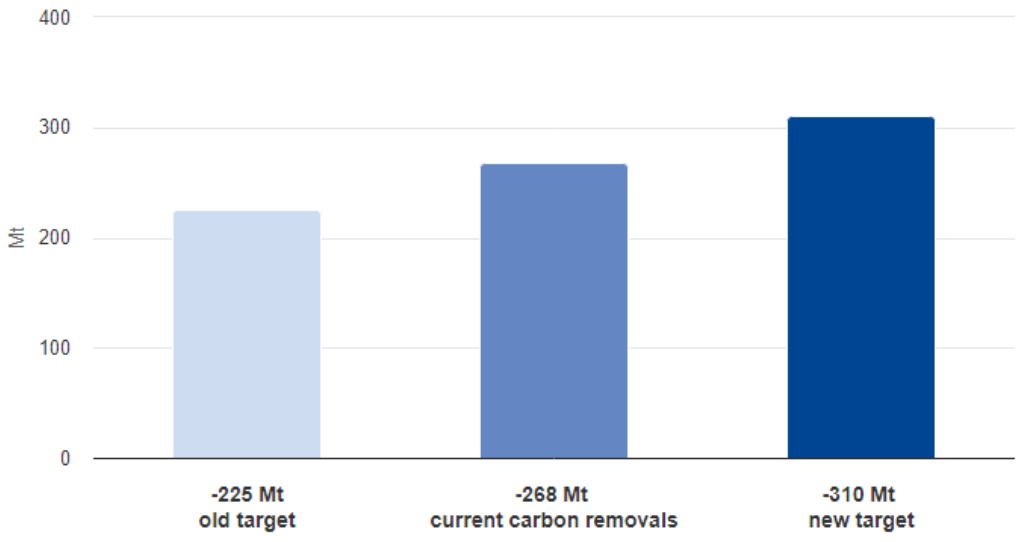

Figure 6: New targets for natural carbon removals

Source: European Commission (Retrieved November 2023)

3.2.8 Boosting global climate action

The European Commission (n.d.-b) explains that climate change is affecting everyone and everywhere, from developed countries to less developed ones and because of that we can only win the war against climate change if we cooperate and work together with international partners.

Global climate action at the international level is therefore required to move toward a low-carbon economy because climate change is a phenomenon that affects all of us. States must collaborate closely to address the targets defined during the Paris Agreement (COP21) on December 12, 2015 (United Nations, n.d.-d). According to UN reports on SDG number 13 (Climate Action), if we do nothing, the global temperature will rise by more than 3°C, having an adverse effect in the industry (United Nations, n.d.-j).

Furthermore, in order to achieve Sustainable Development Goal number 17 (Partnerships for the Goal), partnerships between public and private sectors, civil society, and both developed and developing countries must be formed. To do this, all available resources must be mobilized. Recurrent controls must be applied to nations in order to guarantee that everyone is using the same line (United Nations, n.d.-b). The European Union, its Member States, and the European Investment Bank are the largest contributors financing developing economies with € 23.04 billion in 2021 (European Commission, n.d.-g). The Commission highlighted the possibility of still limiting global warming to 1.5°C and attempting to meet the targets of the Paris Agreement at the United Nations' COP27 in Egypt in 2022 (European Commission, n.d.-b). The fight against climate change becomes achievable when governments, civil society, and the private sector make choices aimed at reducing risk while preventing justice and equity, but this obviously requires financial resources and actions integrated with timescales and sectors (IPCC-Summary for Policymakers, 2023). More recently, during COP28, the UN Climate Change Executive Secretary, Stiell, mentioned the need for faster progress and ambitious national plans in line with a 1.5°C pathway and the decision to active the loss and damage fund to help most vulnerable countries (United Nations, 2023).

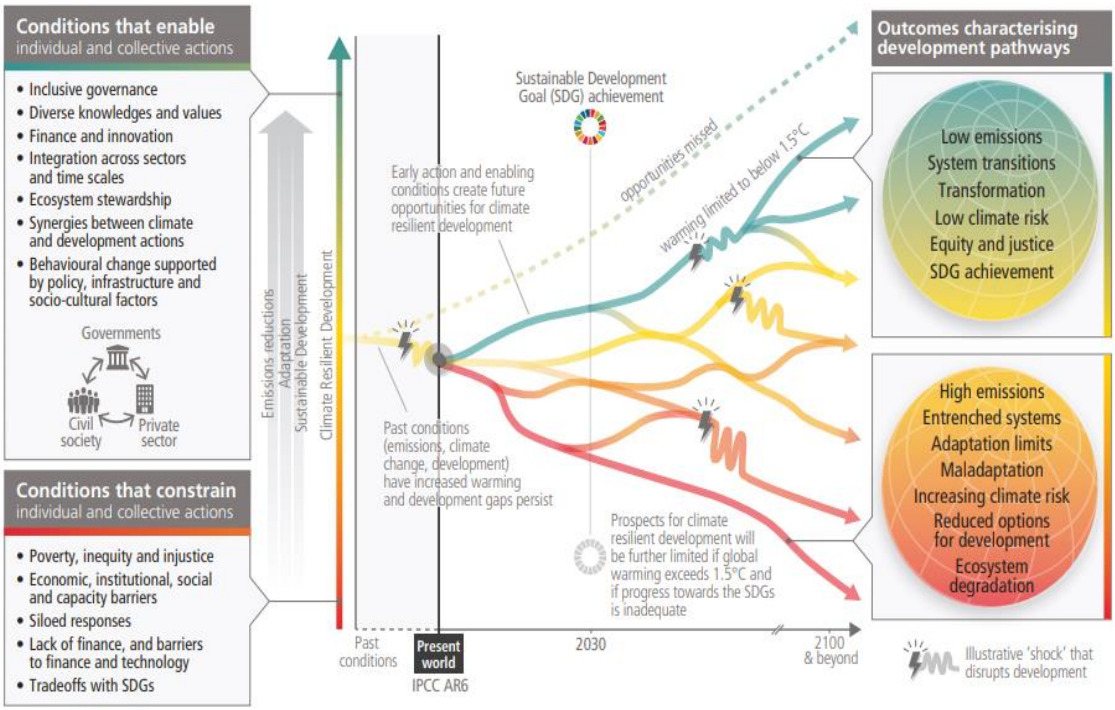

Figure 7: Multiple interacting choices and actions can shift development pathways towards sustainability

Source: IPCC-Summary for Policymakers (2023)

As can be seen from the picture above, there are still opportunities to win this challenge and the Summary Report of the Intergovernmental Panel on Climate Change (2023) presented an illustrative example: integrating choices and actions can improve climate development and a shift towards sustainability with some limited applications for human and some natural systems, explained the Summary for Policymakers Report of the Intergovernmental Panel on Climate Change – IPCC (2023).

3.2.9 Taking advantage of the Social Climate Fund

A Social Climate Fund (also known as "the Fund") is established in order to address the social and distributional effects, on the most vulnerable people, that result from the emissions trading from the buildings and road transportation sectors (European Commission, 2021).

Another tool that has been introduced to win the challenge against climate change is the Social Climate Fund per the period 2026-2032, under proposal of the Commission, the

European Parliament and the Council of the European Union, on 10 May 2023, have published the regulations of the Fund (Official Journal of the European Union, 2023). The plan will provide financial help in terms of investments and effective measures to the Member States, as reported by Article 1 Regulation EU 2021/2060. The same article also points out that the measures of the plan have to provide benefits to households, micro-enterprises and transport users that are defined as vulnerable and affected by greenhouse gas emissions coming from the transport and building industry, in particular those who live in energy and transport poverty conditions (Official Journal of the European Union, 2023). Article 2 of the same regulation explains the definition mentioned above, clarifying that energy poverty is referring to households that are suffering from a lack of energy access, negatively influencing their living of standards and health. Transport poverty means difficulty to face the costs of private and public transport, or a lack to the access of these. Article 3 remarks that the Fund should be able to contribute and support vulnerable micro-enterprises, households and transport users through income support and other measures of investment, aimed at increasing energy efficiency in buildings and improve access to a zero and low emission mobility and transport (Official Journal of the European Union, 2023). To benefit of the Fund, Member States have to present to the Commission their Plan, which needs to contain measures and investments that are effective and coherent, able to meet and enhance the climate targets of the Union, as explained in article 4. These measures and investments will be considered valid if able to accomplish building renovation, decarbonise, introduce renewable energy sources, and increase a low emission mobility and transport. A maximum amount of EUR 65 billion is made available for the period from the 1st of January 2026 to 31st of December 2032, mention article 10 of the Regulation (2023).

3.2.10 Energy efficiency directive

The energy efficiency directive has been proposed to give Member Sates guidelines to use energy more efficiently in all the phases of the energy chain, from transportation to distribution and consumption (European Commission, 2011).

To achieve energy efficiency, for the first time in 2012 the Energy efficiency directive (Directive on Energy Efficiency 2012/27/EU) has been introduced to set the rules and obligations regarding energy. The directive has been renovated in 2018 and in 2023

(European Commission, n.d.-h). As we have already mentioned in this work, the energy sector is highly contributing to greenhouse gas emissions but at the same time is able to provide solutions to meet the EU's 2030 intent to reduce the emission by at least 55%. In relation to this ambition, the directive has been recently updated (European Commission, n.d.-h). The Energy Efficiency Directive (EU/2023/1791) remarks, as fundamental principle, the energy efficiency, in a sense that all countries should take decisions and investments in the energy and non-energy sectors.

Directive EU 2023/1791, of the European Parliament and of the Council on 13 September 2023, has been published in the Official Journal of the European Union. As defined by article 1 of the Directive (2023) the goal is to implement energy efficiency solutions in all sectors able to overcome barriers in the energy market that impede an efficient energy supply, transmission, storage, and use. The achievement of energy efficiency can provide a reduction in energy prices and GHG emissions and enhance a shift towards an electrified system, hydrogen, e-fuels, and other technologies. The Directive explains that (2023) improvements in energy efficiency can be considered in all energy stages (energy generation, distribution, and storage) providing in this way huge environmental benefit, such as, air quality and public health, with the final aim to reduce the costs for energy services covered by households and companies. This can lead to an increase of jobs and economic activity. It is fundamental to settle improvements in the energy efficiency when these are more efficient on the side of costs compared to other supply-side solutions and this can be applied in all sectors of the economy: transport, buildings, healthcare, water management, water purification, waste management, energy distribution, infrastructures, education etc. (Official Journal of the European Union, 2023). In summary, Member States are required to guarantee a minimum 11.7% decrease in energy consumption by 2030. This will help the Union meet its primary energy consumption target of 763 Mtoe for final energy and 992,5 million Mtoe for primary energy by 2030 (EU Directive, 2023). The EU member states have embraced the challenge of contributing to the goal's accomplishment by indicating national contributions that take into account factors specific to their own countries, like GDP, energy intensity, and potential for energy savings. Accordingly, Member States must save a minimum of 0.8% of their final energy consumption each year in 2021–2023, 1.5% between 2026 and 2027, and 1.9% between 2028 and 2030 (European Commission, n.d.-h).

3.3 Identification of the criteria and summary table

All of these ten alternatives have been analysed under three different criteria: economic, wellbeing and environmental. The first criterion (economic) has to be intended as all the effects, both in terms of value and in terms of benefits, that can positively influence the economy while addressing the environmental issues. Wellbeing is strictly linked to our daily life. For instance, how an alternative can positively affect people by creating new jobs, by providing health and well-being. The last criterion, environmental, is explaining which are the environmental benefits that this solution is able to provide in the short and long term. For a more detailed explanation see the table below (Table 3).

	Environmental	Wellbeing	Economic
Energy transition through sustainable resources such as Solar PV and Wind	Alternative sources able to reduce CO_2 and GHG emissions	Energy transition improves human welfare and the creation of green jobs	Wind and Solar PV are cheaper than fossil generated electricity
Shift to sustainable health diets	Preservation of biodiversity	Promotion of individuals health and wellbeing	Reduction of the expenses caused by food waste and healthcare
Transport technology innovations for decarbonisation	Vehicle-technologies and low-carbon fuel innovations	Change in people behaviours and patterns	Investments to promote an efficient transport system
Urban mitigation option: urban green and blue infrastructure	Increase store of carbon, emissions reduction, and energy use	Improving quality of life with better health and well-being for citizens	Energy savings
Demand, services and social aspects of mitigation	Services with low energy demand can contribute to a reduction in GHG emissions	Reduction in inequalities. People willingness and capacity to change	Investments in new technologies and other energy efficient resources
Simplifying the regulatory environment	+ 10% increase in investments in clean energy	New jobs and strong single market	Facilitate access to finance with a simplified regulatory environment
Protecting the planet	Protection of ecosystems	Nature plays a key role in our life	Biodiversity conservation can implement profits and reduce costs
Boosting global climate action	Global cooperation to reduce the emissions	The benefit of a single person can be a benefit for the whole	Developing products and expertise from which the world can benefit
Taking advantage of the Social Climate Fund	Energy efficiency and low-zero carbon emission system	Help vulnerable people affected by GHG emissions	Financial help to promote investments
Energy efficiency directive	Overcome barriers in the energy market	Improving hair quality and public health	Reduced costs for energy

Table 3: Summary of alternatives and criteria to achieve a reduction in greenhouse gas emissions by 2030

4. Practical application

4.1 Introduction

Nowadays climate change is part of our lives, and everyday media and news, report about extreme weather events or other environmental issues, impacting Europe but also the entire world (European Commission, 2019). The work of Europe started with the European Green Deal and in specific, with the goal fixed by the President of the European Commission:

"I want Europe to become the first climate neutral continent in the world by 2050"
(Ursula Von Der Leyen, 2019).

Aiming to create a just and inclusive transition, a clean, affordable, and secure energy supply, a modernized industry, a clean and circular economy, biodiversity protection, sustainable mobility, and a fair and healthy food system, the European Commission announced the European Green Deal on December 11, 2019, making the European Union the first continent to be climate neutral, as a green answer also to the Coronavirus Pandemic (European Commission, 2019).

To achieve the climate neutrality the first step is based on a reduction in the emissions of at least 55% by 2030, as outlined by the President of the European Commission (2019). The financial resources to make that possible come from the NextGenerationEU Recovery Plan, and the EU's seven-year budget, that together constitute one third of the €1.8 trillion devoted to the European Green Deal (European Commission, 2019).

As already mentioned, the European Union is committed to lowering greenhouse gas emissions (GHG), which are thought to be the primary cause of climate change. Although there may be other gases in the atmosphere, carbon dioxide (CO2) is the most well-known type of GHG (European Parliament, 2023). In 2021, methane accounted for 12% of the total greenhouse gas emissions in the European Union, while carbon dioxide accounted for 80% (European Parliament, 2023). Even though human activity encourages their buildup, greenhouse gases are a naturally occurring phenomenon in the atmosphere. Essentially, they trap heat from the sun that is generated on the surface of the Earth and absorb it, keeping the planet's temperature higher than it otherwise would be (European Parliament, 2023).

The United States, China, India, and the European Union accounted for the top four greenhouse gas emitters in 2019. Within the EU, the top emitters in 2019 were Germany, France, Italy, Poland, and Spain. The effects of rising temperatures and biodiversity loss vary depending on the location (European Parliament, 2023).

4.2 Building the framework

The diagram below summarizes the steps followed in the research.

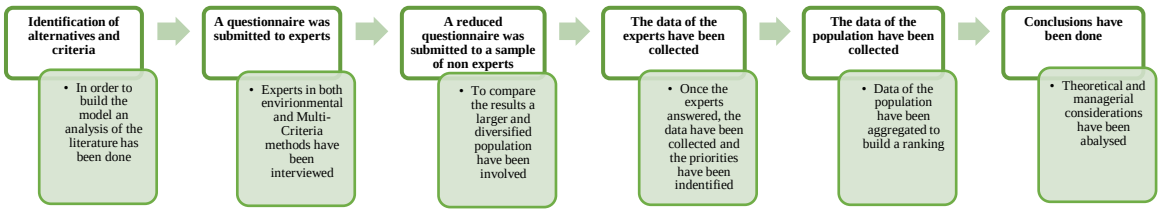

Figure 8: The stages of the analysis

Once the criteria and objectives have been identified, in order to be able to understand which alternative would be best to reduce emissions by 2030, it is necessary to move from theory to practice in order to apply the Analytic Hierarchy Process.

In having to analyse problems that require the use of Multi-Criteria Decision Analysis methods, there are several aspects to be considered that can be complex and therefore it is best to divide them into two parts: structuring the problem and elicitation of priorities through pairwise comparisons (Ishizaka and Nemery, 2013). The first phase, structuring the problem, was described in the previous chapter: after doing much research, we looked at the work done by Europe and the scientific contribution provided by the Intergovernmental Panel on Climate Change (IPCC) in order to understand in detail which sectors were the most sensitive and impacted in the fight against emissions. The literature provides quite detailed explanations: the European Commission has identified several measures to reduce emissions by 2030 and to achieve climate neutrality by 2050. Through the analysis, we have identified 10 alternatives involving different sectors (from

transport to energy, from investments to European funds) that can make their contribution in the fight against climate change. Instead, in this chapter we will analyse how to elicit priority thanks to a Multi-Criteria Decision Analysis method.

Given the complexity of the phenomenon, to have a more valid and meticulous analysis, we decided to ask for the support of experts so that we could confront ourselves with them and get their point of view. Usually, experts are asked to rate the alternatives and provide their reference evaluations, these are the first two steps that are followed in the methodology (Abstante et al., 2019). Hence the decision to administer a questionnaire. The idea was to first get their opinion on the ratings that were given to the 10 alternatives. In order to base the analysis on reliable data, we asked scholars to indicate whether they agreed or disagreed with the percentages we assigned and secondly to define (using a conventional 1-9 scale) their preferences in relation to the criteria. In this way, the questionnaire was rather time-consuming, but such a lengthy structure was necessary in order to build a solid base and get their opinions. The experts were selected with the idea of involving people who have both knowledge in environmental issues and in the use of MCDA methods. Some of the experts were selected from my university department and other lecturers I researched on the university portal. My lecturer provided me with invaluable assistance in this, helping me to select additional experts.

The initial idea of this work was to use the classical AHP to study the case, but given the large number of objectives that were selected (10 alternatives and 3 criteria), all these pairwise comparisons would have required too much effort and work for the decision maker. For this reason, the decision to use the Parsimonious Analytic Hierarchy Process (PAHP), a new method that differs from the most commonly used and can be an innovative approach to implement the knowledge acquired in my university career (Abastante et al., 2019).

After this decision I investigated how to use the PAHP proposed by Abstante et al. (2019) and Corrente et al. (2016) and which are the differences between the classical AHP, that I used during my university course, and the PAHP, trying to understand how to apply it to my case. It was necessary to go back to the literature and study the cases in which scholars already used this approach and which are the procedures they followed.

As explained in the second chapter, to apply the PAHP, we first need to evaluate the objectives in relation to three criteria (environmental, economic and wellbeing) using a

common rate 0-100; identify the reference levels (usually lowest, middle, and highest) to split the sample proportionally and lastly compare pairwise criteria and reference levels (Hamadneh et al., 2022). After, performing checks (such as consistency and monotonicity) are computed and the rate of objectives that are not reference levels are obtained by interpolation (Hamadneh et al., 2022).

Once the theoretical model was clear, we started to create the questionnaire, whose phases are deeply outlined in the next paragraph, and we thought which could be the most suitable experts to who submit the survey.

One questionnaire was sent to experts and secondly a shorter and simplified questionnaire was submitted to a sample of 20 random people. The decision to use two different targets (from one hand scholars and on the other a random group of people) was to compare and see different perceptions and ideas. Moreover, we also aimed to test if it was possible to extend the use of the PAHP with a shorter questionnaire trying to overcome one of the main limitations of the methodology.

In the following paragraph the first questionnaire will be explained, followed by the report on the analysis of the data.

4.3 The questionnaire submitted to the experts

The first questionnaire administered to the experts consisted of 7 pages[13]. In the first part there was a brief explanation of the problem being analysed, in which criteria and alternatives are explained. In this way the reader can have a general overview of the problem and of my analysis. For each alternative we selected, we left the reference sources so that any expert could access them if needed. The questionnaire was constructed with the use of the Open Office Word test document and then addressed to the experts via my institutional email address. Given the length and structure of the questionnaire, we thought it would be easier and more effective to read and subsequently fill in using a text document rather than a multiple-choice tool such as Google Form or similar ones.

In the second part, there was a table showing the ratings given for each alternative in relation to the criteria. Here, the experts' first task was to decide whether they agreed or

[13] See Appendix 1.

disagreed with the ratings and eventually give their opinions (see Table 4 below). Ratings are assigned from 0% to 100% taking the following three aspects into account. First, a rate of 100% means that the alternative can provide huge environmental benefits since the sector is an active contributor of current emissions and quick intervention is needed, but also a rate of 100% means no obstacles (in terms of financial resources, time, etc.) and no possible negative effects. Second, a rate of 50% means that the positive effects impacting the achievement of the goal are relevant, but its application faces important obstacles, or the intervention in that field is not the most important from which we should start and/or is not the biggest contributor to the emissions. Last, a rate of 0% means that the alternative is neutral and doesn't provide either positive or negative effects, so its application is unnecessary.

The last part of the questionnaire asked to pairwise compare the criteria in terms of their importance using a nine-point scale (Saaty, 1994). Here the first matrix was introduced (3x3 matrix) asking to assign values between environmental, wellbeing and economic, and this first matrix is the one in which we used the classical Analytic Hierarchy Process. After, three matrices (5x5) were created to compare pairwise the five reference levels (0%, 25%, 50%, 75%, 100%) to the three criteria using the same 1-9 scale, using in this case a new typology of comparison that characterizes the PAHP.

Once the questionnaire was built and sent, out of 15 experts, four answered, of who three completed the entire questionnaire and one, only agreed about the ratings assigned to the objectives and only completed the first matrix. These experts (that in the following session will be identified by Expert nr 1, Expert nr 2 and Expert nr 3) have knowledge in either MCDA methods or environmental issues.

The decision to submit the questionnaire to the scholars was important to have an idea coming from valid authorities and in particular from people involved and with knowledge in MCDA and environmental issues.

Criteria Alternatives	Environmental	Wellbeing	Economic
Energy transition through sustainable resources such as Solar PV and Wind	100%	100%	95%
Shift to sustainable healthy diets	50%	40%	60%
Transport technology innovations for decarbonisation	80%	80%	60%
Urban mitigation option: urban green and blue infrastructure	70%	70%	40%
Demand, services, and social aspects of mitigation	50%	20%	20%
Simplifying the regulatory environment	95%	80%	95%
Protecting the planet	60%	50%	40%
Boosting global climate action	50%	40%	60%
Taking advantage of the Social Climate Fund	50%	50%	50%
Energy efficiency directive	30%	50%	30%

Table 4: Rating of alternatives concerning each criterion

4.4 Practical analysis of the data of the experts

The practical analysis of the data collected by the experts was done in line with the application procedures of the Parsimonious Analytic Hierarchy Process outlined in the literature review section (see Chapter 2).

The calculations were made using R software. This is a free software for statistical calculation and graphics. It is highly extensible and gives the possibility of writing codes by hand and processing the results. The main advantage of this software is the possibility of obtaining well-delineated, editorial-quality graphics with symbols and formulae (The R project, n.d.). It includes an extensive data management and storage facility, several operators for calculations on arrays such as matrices (The R project, n.d.). The decision to use this programme was because, firstly I was already familiar with it since it has been

used during my studies, and secondly because it was well suited for the necessary analysis. In software R, thanks to the skills I acquired during my studies, I learnt how to write the necessary codes to write the matrices and to study the desired data set.

Once we received the completed questionnaire from the experts, using R software we reported the data to calculate the results. For each of the four matrices that defined each questionnaire, the procedure followed was the same: firstly, after defining the matrix, we calculated the eigenvalues and eigenvectors (see Chapter 2), then we separated the dominant eigenvalue and the dominant eigenvector from the matrix, and we calculated the priorities. Lastly, we carried out consistency and monotonicity checks for each matrix.

To conclude the analysis, without the use of the software, we calculated the ratings of the evaluations that are not reference evaluations. In this way we were able to rank the results from the most preferred and efficient policies until the less preferred one. In the next paragraphs the results for each expert are deeply explained.

4.4.1 Analysis of Expert 1

Regarding the analysis of the first expert[14], having confirmed the percentages assigned to the objects (see Table 4 above), we proceeded with the construction of the first matrix. The first matrix compares the three criteria with each other. For example, expert number 1 assigned a value of 5 (strong importance) to economic and wellbeing in relation to the environmental criteria, and a value of 1 (equal importance) in the comparison of the economic and wellbeing criterion. The consistency index and the consistency ratio were calculated giving acceptable values. It should be noted that the consistency index is the difference between the maximal eigenvalue and the number of rows, divided by the number of rows minus 1. Low values of consistency index points to low inconsistency, but high values signal a problem (Ishizaka and Nemery, 2013). The consistency ratio is given by the difference between the consistency index and a random index, and if less than 10%, the matrix is of an acceptable consistency (Ishizaka and Nemery, 2013).

After the expert confirmed the five reference levels set, the same calculation was made with the other matrices. Regardless the values attributed by the first specialists, it is interesting to note that the values assigned in the matrices are close the same or the

[14] See Appendix 2 for the answers.

difference is minimal. For instance, according to the environmental criteria, the scholar assigned value 7 to the row representing the fourth reference level (75%) and the column representing the first reference level (0%), meaning that there is very strong preference for an alternative with a rating of 75% to an alternative with a rating from 0%. For the same pairwise comparison, the expert assigned value 8 in relation to the wellbeing criteria and 6 for the economic criteria. Considering the three matrices together there are no important differences to be underlined, the values differ of 1 point above or below among them.

For all these matrices, the CI and CR were acceptable, and the monotonicity of the priorities was also verified, as a fundamental step of the methodology followed in the PAHP (Abstante et al., 2019). The derivation of priorities is crucial in the application of the AHP method, otherwise rankings could not be produced (Ishizaka and Nemery, 2013). In this case, priorities were identified as the ratio of the dominant eigenvector to the sum of the vectors.

The overall results are summarized in Table 5 below. In the second row, the priorities are referring to the first matrix that the expert completed (comparison among the criteria) and the last two columns represent the relative consistency index and ratio. The other three priorities are referring to the matrices asking to compare pairwise the reference levels to criteria, for this reason we have five priorities, that refer to the five reference levels.

Criteria	**Env**	**Wellb**	**Econ**			**Monot**	**CI**	**CR**
Priority	0.09	0.455	0.455				0%	0%
Env	y1=0%	y2=25%	y3=50%	y4=75%	y5=10%			
Priority	0.029	0.066	0.152	0.256	0.498	ok	12%	11%
Wellb	y1=0%	y2=25%	y3=50%	y4=75%	y5=10%			
Priority	0.029	0.079	0.143	0.264	0.485	ok	8%	7%
Econ	y1=0%	y2=25%	y3=50%	y4=75%	y5=10%			
Priority	0.036	0.071	0.142	0.258	0.494	ok	5%	5%

Table 5: Results of the analysis conducted for Expert number 1
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic and Monot for monotonicity).

The ratings of the non-reference alternatives are obtained by interpolation. For instance, valuating A_1 in terms of the economic criteria, given that the rating 95% belongs to the

reference evaluations [75%, 100%] is computed using the following formula (Abstante et al., 2019).

$$U_{ECONOMIC}(A_1) = U_{ECONOMIC}(75) + \frac{UECONOMIC(100) - UECONOMIC(75)}{100-75} * (95\text{-}75) \quad (7)$$

$$U_{ECONOMIC}(A_1) = 0.2575 + \frac{0.4939 - 0.2575}{25} * 20$$

$$U_{ECONOMIC}(A_1) = 0.4466$$

Once all these values are obtained for each of the criteria, the final valuation is obtained by multiplying the ratings (values in the centre of the Table 6) for the priorities of the three criteria (see the last column of Table 6 for the results). What has been discovered for the first expert was that the preferred alternative, to achieve a reduction in the emissions, would be an Energy transition through sustainable sources such as Solar PV and Wind (alternative number 1). This alternative is ranked first and immediately followed by alternative number 6 (speeding up access to finance), transport technology innovations for decarbonisation. These three constitute the podium of the ranking, after we can find urban sector, with the same ranking healthy diets and global climate action, to conclude we have the social climate fund, protecting the planet, energy efficiency directive and the last one demand, services, and social aspect of mitigation.

	Env	**Wellb**	**Econ**		**Env**	**Wellb**	**Econ**		**U(-)**
A1	100%	100%	95%		0.498	0.485	0.447	A1	0.469
A2	50%	40%	60%		0.152	0.118	0.188	A2	0.153
A3	80%	80%	60%		0.304	0.308	0.188	A3	0.25
A4	70%	70%	40%		0.235	0.240	0.114	A4	0.182
A5	50%	20%	20%		0.152	0.06	0.064	A5	0.074
A6	95%	80%	95%		0.449	0.308	0.447	A6	0.384
A7	60%	50%	40%		0.194	0.143	0.114	A7	0.134
A8	50%	40%	60%		0.152	0.118	0.188	A8	0.153
A9	50%	50%	50%		0.152	0.143	0.142	A9	0.144
A10	30%	50%	30%		0.083	0.14	0.085	A10	0.112

Table 6: The table shows alternatives evaluations (left), ratings (centre) and comprehensive valuation (right)
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic)

4.4.2 Analysis of Expert 2

The second expert[15] also kept the ratings of the reference objects unchanged. In this case the expert assigned a value equal to 3 (moderate importance) in the comparison between the economic criteria and wellbeing. The comparison between economic and wellbeing in relation to the environmental criteria obtained value 1 (equal importance). Here is important to underline the first difference between Expert nr 1 and Expert nr 2: the first one attributed strong importance in the comparison among economic and wellbeing, while the second specialist attributed moderate importance (3), moreover, in the first analysis the expert attributed strong importance between economic and environmental, while in this second case it was assigned equal importance (1).

Despite these differences with respect to the values attributed by expert number 1, the values attributed in the other matrices are similar. It is interesting to note that, the second expert, attributed the same values to the three matrices regarding the compare pairwise in relation to the reference levels. This means and confirms an equal importance among the criteria. As for the first expert, the consistency index, consistency ratio and monotonicity have been checked and priorities are summarized below (see Table 7).

Criteria	**Env**	**Wellb**	**Econ**			**Monot**	**CI**	**CR**
Priority	0.319	0.221	0.459				6%	12%
Env	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.042	0.075	0.141	0.266	0.477	ok	0.8%	0.7%
Wellb	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.042	0.075	0.141	0.266	0.477	ok	0.8%	0.7%
Econ	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.042	0.075	0.141	0.266	0.477	ok	0.8%	0.7%

Table 7: Results of the analysis conducted for Expert number 2
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic and Monot for monotonicity)

As in the previous paragraph, the same procedures are followed and at the end energy transition through sustainable sources such as Solar PV and Wind has been confirmed the most efficient alternative, also according to expert nr 2 (see Table 8 below).

[15] See Appendix 3 for the answers.

	Env	Wellb	Econ		Env	Wellb	Econ		U(-)
A1	100%	100%	95%		0.477	0.477	0.434	A1	0.457
A2	50%	40%	60%		0.141	0.115	0.191	A2	0.158
A3	80%	80%	60%		0.308	0.308	0.19	A3	0.254
A4	70%	70%	40%		0.241	0.241	0.115	A4	0.183
A5	50%	20%	20%		0.141	0.068	0.068	A5	0.091
A6	95%	80%	95%		0.434	0.308	0.308	A6	0.348
A7	60%	50%	40%		0.191	0.141	0.115	A7	0.145
A8	50%	40%	60%		0.141	0.115	0.19096	A8	0.158
A9	50%	50%	50%		0.141	0.141	0.1412	A9	0.141
A10	30%	50%	30%		0.088	0.141	0.0878	A10	0.099

Table 8: The table shows alternatives evaluations (left), ratings (centre) and comprehensive valuation (right)
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic)

By looking at the whole ranking, the second and the third preferred ones are alternative number 6 and 3, speeding up access to finance and transport sector, as for the first expert. The fourth alternative is urban mitigation option, followed by shift to sustainable healthy diets and global climate action with the same rank. The last four positions are protecting the planet, social climate fund, energy efficiency directive and demand, services and social aspects of mitigation.

4.4.3 Analysis of Expert 3

Looking at the results of expert 3[16], the first aspect to underline is in the ratings. For the first alternative, energy transition through sustainable sources such as Solar PV and Wind, the expert suggested to change the rating of 95% attributed to the economic criteria, with a value of 70%, supported by the fact that obstacles can be different. Another consideration regards the Social Climate Fund (alternative number 9). The expert suggested higher values supported with a significant impact but, given that the Fund will not be available until 2026, for the short term the ratings remained unchanged. Looking more in a long-term perspective, certainly the Fund will be able to provide huge benefits, and, in this case, higher ratings can be considered.

[16] See Appendix 4 for the answers.

In defying the importance among the criteria, the third expert assigned strong importance in the comparison among the economic criteria in relation to wellbeing, value 2 (intermediate) between economic and environmental, and 3 (moderate importance) between wellbeing and environmental. In this case, the relation between economic and wellbeing assumed equal importance for the first specialist, moderate importance for the second specialist and for this last one strong importance. The first expert attributed strong importance to the comparison between economic and wellbeing while the others attributed equal importance and moderate importance respectively.

The tables regarding the comparison among reference levels are fulfilled as reported in the Appendix.

Criteria	**Env**	**Wellb**	**Econ**			**Monot**	**CI**	**CR**
Priority	0.155	0.238	0.607				23%	23%
Env	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.032	0.050	0.138	0.267	0.513	ok	9%	8%
Wellb	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.033	0.063	0.129	0.262	0.513	ok	6%	5%
Econ	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.033	0.063	0.129	0.262	0.513	ok	6%	5%

Table 9: Results of the analysis conducted for Expert number 3
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic and Monot for monotonicity)

It is interesting to see, in this case, how a change in the ratings provide different results. For the last expert, in fact, the most favourable alternative turns out to be number six, speeding up access to finance (see Table 10 below). The second most preferred one is, as for the two cases above, alternative number one with the energy transition. The third alternative is represented by the transport sector. Another difference is the rank number four, in this case characterised by alternative number two and eight with the same percentage (healthy diets and global climate action), while for expert 1 and 2 these two alternatives were ranked at the fifth position. Immediately after we find urban green and blue infrastructure. The last ones are social climate fund, energy efficiency directive, protecting the planet and demand, services, and social aspects of mitigation respectively.

	Env	Wellb	Econ		Env	Wellb	Econ		U(-)
A1	100%	100%	70%		0.513	0.513	0.235	A1	0.344
A2	50%	40%	60%		0.138	0.103	0.182	A2	0.156
A3	80%	80%	60%		0.316	0.312	0.182	A3	0.234
A4	70%	70%	40%		0.241	0.235	0.103	A4	0.156
A5	50%	20%	20%		0.138	0.039	0.039	A5	0.055
A6	95%	80%	95%		0.463	0.312	0.463	A6	0.427
A7	60%	50%	40%		0.190	0.129	0.103	A7	0.123
A8	50%	40%	60%		0.138	0.103	0.182	A8	0.156
A9	50%	50%	50%		0.138	0.129	0.129	A9	0.131
A10	30%	50%	30%		0.068	0.129	0.142	A10	0.128

Table 10: The table shows alternatives evaluations (left), ratings (centre) and comprehensive valuation (right)
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic)

To conclude, regarding the ratings assigned to the reference objects, all experts agreed except from the last one. The importance among the criteria saw some differences: for the first case the highest values (5-strong importance) was in the comparison between economic and wellbeing with respect to environmental, while for the others two the values where 1 (for both economic and wellbeing respect to environmental) and 3 and 2 for the last scholar in the same comparisons. The second expert kept equal importance among all criteria, while moderate importance between economic and wellbeing. The last one attributed strong importance between economic and wellbeing instead.

In the comparisons of the reference levels there are no huge differences in the values attributed.

According to the expert analysis, the best ways to reduce the emissions by 2030 come from the energy sector and the financial sector. An energy transition through alternative and sustainable energy sources with an easier and quicker access to financial sources, could be the solution. At the same time, alternative number 5, demand, services, and social aspect of mitigation obtained the lower values, so it can be considered the less efficient solution.

To compare the results with a larger sample of non-experts, a shorter and simplified questionnaire was submitted to a diversified group of people. To this sample, we asked only to compare pairwise criteria and the reference levels. The results are explained in the next paragraph.

4.5 The questionnaire submitted to the population

With the scope to have a larger idea of the opinion that common people can have about climate change, in specific regarding the target fixed by 2030, we decided to extend the questionnaire to a sample made by 20 random people[17]. People have been selected among students that belongs to my university department and have already practiced with MCDA methods, students from other departments and/or universities and people that either never have used it or have never heard about this method before such as friends, parents, and relatives.

In this work, for the first time in the literature, we are testing a new type of approach, in which we are using the ratings that have been suggested by the experts and apply them to the pairwise comparisons that we obtained by asking the opinion to a sample of non-experts.

Regardless of people's knowledge and skills, the questionnaire has been simplified as much as possible and we tried to use some examples to help people in understanding the reasoning behind it. The whole version of the questionnaire can be found in the appendix (Appendix 5). The questionnaire in this case, given the lower length, was provided with the use of the platform Qualtrics[18] because was the most efficient to report matrices and to spread among the population.

Once we built the questionnaire on this platform, I sent people a message with the link of the survey asking them to fulfil it, and in case of any dubs or clarification I remained available. After each enquiry completed, Qualtrics automatically registered and reported the results in my account. In this way at the end, it was easier to download the individual questionnaires and to see the overall results.

The overall sample completed the survey in about two weeks. Most of the people were able to complete the whole set of questions without need of clarification, but some needed some help in understanding the matrices, in particular the last three that were asking to compare pairwise the reference levels according to criteria. The difficulty can be linked to two reasons: first some of the people interviewed never worked with matrices and especially, in big matrices (5x5), can be challenging to understand and follow the

[17] See Appendix 5.
[18] Qualtrics is a platform that gives the possibility to create surveys and collect answers (Qualtrics.com, n.d.).

reasoning behind it; other may have already worked with matrices and Multi-Criteria Decision Analysis methods but never worked with the Parsimonious Analytic Hierarchy Process. In both cases after a brief and more detailed explanation, they have been able to complete the survey.

The questionnaire constituted of three parts. In the first part of the questionnaire, we explained that the object of the research is to investigate which are the most effective policies to achieve a reduction in the emissions by 2030. Secondly, some general questions have been provided to understand the target of the people answering (age, nationality, occupation) and then we asked some general questions regarding climate change and MCDA methods.

4.5.1 Analysis of the population results

The sample is constituted by 38% male, 57% female, and 5% non-binary people, of which, the age is ranked between 22 and 66 years old, providing in this way a quite diversified category of respondents. It is interesting to have a group of people that is not limited to the national borders, because some of the respondents belong to Romania, Albania, Austria. The occupation of the interviewees arranges between students, unemployed, entrepreneurs, doctors, housewives, graduated students.

The first part was constituted by some multiple choice and open questions. The first question that has been asked was if you are interested in climate change and other environmental issues to better understand the sensitivity that people can have on the topic: 95% answered yes, while 5% was neutral. This was a good result since the questionnaire is based on reducing the emissions and improve the environment, confirming in this way an interest into the problem. After, we asked if people think that climate change is a today problem that requires immediate action, the majority (90%) answered “strongly agree” and only the 10% “somewhat agree”. The last question regarding climate change was if people are doing something in their daily life for the environment (such as using sustainable transport modes, healthy diet etc.): 19% answered yes, 67% yes but they could do more and only 14% answered no, but they would. Also, in this case there was a positive result, because the highest percentage of the respondents are already doing something in their life for our earth and health and/or are willing to do more. The first part is concluded with a question regarding MCDA methods. We asked if people have ever heard of this

method: 24% answered yes and have also used it, 24% answered yes but never used it and many of the respondents answered no (52%).

In the second part of the questionnaire, we introduced which are the alternatives and criteria that have been identified as solutions to the problem, and how to complete the matrices using the 1-9 scale. In the first matrix we asked to compare pairwise the criteria and in the last part to compare pairwise criteria in relation to reference levels using the same scale. For both matrices we provided a practical example to help people better understand which is the reasoning behind each value they will assign.

In the first matrix, most of the respondents assigned values between 7-9 in the comparison between the environmental criterion in relation to wellbeing, some attributed values between 2 and 5 but this applies only to a small portion of the sample. In the comparison between environmental and economic, as for the comparison between wellbeing and economic, most of the interviewed assigned value 7. It is interesting to observe how most of the respondents assigned value 7 (very strong importance) between environmental and wellbeing and 3 respondents out of 20 attributed an intermediate level of 2. In the comparison between environmental and economic, one person answered equal importance and one attributed an intermediate level of 2, even if the highest percentage gave 7. A similar situation happened also between wellbeing and economic.

Observing the questionnaires, what can be said is that 20 out of 20 enquiries have been completed and none left empty spaces, but the mistakes that have been found are mainly two. First, two people forgot that in completing the matrices the reciprocity rule needs to be followed such that $a_{ij} = \frac{1}{a_{ij}}$ where i and j are the alternatives of the matrix (Ishizaka and Nemery, 2013). Second, a person in completing the matrices of the reference levels assigned values from 1 to 9 also above the leading diagonal, for instance, by assigning an intermediate level of 2 to an alternative with an efficacy of 25% with respect to one of 100% is unbalanced. In both cases I corrected the results: in the first case the interviewed have been recalled and I asked them to correct their results keeping in mind the reciprocity rule; for the second case I switched the values to obtain a correct matrix.

Unlike the analysis done for the three experts (section 4.4), in this case due to the high number of participants, the values assigned to the matrices were not taken individually but were aggregated to form a single priority. According to Aczel and Saaty (1983), the

geometric mean is used to aggregate the weights of the participants, as the following equation illustrates:

$$f(x_1, x_2, \ldots, x_n) = \prod_{k=1}^{n} x_k^{\frac{1}{n}} \quad (8)$$

where x_1, x_2, …, x_n stand for entries (e.g., the AHP scale values), and n is the number of the participants (k = 1, 2, 3, …, n) (Hamadneh et al., 2022). There are different methods that can be used but this is the most common (Szabolcs, 2022).

Once the data have been aggregated, four matrices have been obtained and from these the analysis using software R has been done. First, the dominant eigenvector and the dominant eigenvalue have been found and secondly the priorities have been computed. Last the consistency index, the consistency ratio and the monotonicity have been checked. Table 11 summarizes the fundings.

Criteria	**Env**	**Wellb**	**Econ**			**Monot**	**CI**	**CR**
Priority	0.687	0.222	0.091				11%	18%
Env	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.028	0.050	0.104	0.245	0.573	ok	22%	20%
Wellb	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.029	0.051	0.113	0.252	0.555	ok	18%	16%
Econ	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.023	0.036	0.063	0.429	0.449	ok	63%	56%

Table 11: Results from the analysis of the population's questionnaire
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic and Monot for monotonicity)

After performing the practical analysis and checking for the consistency some problems have emerged. As we can see from Table 11 above, especially for the economic criteria, the consistency index and the consistency ratio are assuming extremely high values, 63% and 56% respectively, and this is a clear sign of inconsistency. To better understand where the problem lay, we decided to look at the questionnaires individually. For each of them, we reported each of the four matrices on R and performed the same steps explained before. First, we calculated the eigenvalues and eigenvectors, after which we identified the highest values and isolated the largest eigenvalue and consequently the respective eigenvectors. We were then able to calculate the priorities and check for the consistency index and ratio of each matrix.

By doing this type of analysis and looking at the data individually, we decided to remove from the sample those questionnaires that had at least two matrices with a consistency ratio greater than 30%. For this test of the methodology, we mainly thought about the possibility to apply the method, possibly other methodologies to reduce inconsistency could be adopted. In this way, six questionnaires were discarded from the analysis, some of which presented particularly anomalous values. By doing this the idea was to see how the aggregate data would have changed and if in this way they would have led to more consistent results. For example, among the six questionnaires kept out of the analysis, one matrix reported a consistency ratio of 36%: in the analysis, the respondent attributed a value of 3 (moderate importance) to an alternative with an effectiveness of 25% compared to an alternative with an effectiveness of 0%, while attributed a value of 2 (intermediate) when comparing an alternative with an effectiveness of 100% to 0%. The user also reported the same reasoning for other matrices, thus leading to inconsistent results. In my opinion, in fact, an alternative with 100% effectiveness should be preferred over one with 25% effectiveness because it would then be more efficient in solving the problem.

Some users gave identical values for several comparisons. For example, one person attributed 9 (extreme importance) in the comparison of the reference levels 25%, 50%, 75% and 100% with respect to the first reference level of 0%, attributing the same value for the comparison between 100% and the other reference levels (0%, 25%, 50%, 75%). This has been done by different interviewed, using different values ranged between 7 and 8. This brought to inconsistency, in fact the CR was between 37% and 50%.

The reasons that may have led to this type of results may be manifold. A first influence could be the length of the questionnaire, which is much shorter than the one administered by the experts, but at the same time rather demanding in terms of time, especially for the compilation part. Tiredness and loss of concentration in the concluding part might have prompted the users to fill in the matrix quickly without dwelling much on the reasoning. This could explain the reason for equal values in the first place and probably the reason for equal matrices, even if the latter hypothesis is unfounded because for some, the three criteria and their policies might be equally effective and preferable.

We then aggregated the data of the 14 questionnaires left using the geometric mean by Aczel and Saaty (1983), and the results are summarized in the following table (Tabe 12).

Criteria	Env	Wellb	Econ			Monot	CI	CR
Priority	0.682	0.216	0.102				8%	14%
Env	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.031	0.050	0.102	0.244	0.573	ok	16%	15%
Wellb	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.032	0.053	0.114	0.250	0.551	ok	13%	11%
Econ	y1=0%	y2=25%	y3=50%	y4=75%	y5=100%			
Priority	0.035	0.056	0.110	0.249	0.550	ok	11%	10%

Table 12: Results from the analysis of the population's questionnaire
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic and Monot for monotonicity)

By comparing Tables 11 and 12, we can say that the values have extremely improved and can now be considered acceptable. This is a signal of how important and impactive is the pairwise comparison and in particular the weight of the values we attribute for each case.

As performed in the analysis of the scholars, also in this case se computed the ratings of the non-reference levels by interpolation (Abstante et al., 2019). As suggested by expert number 3, we kept the rating of 70% regardless alternative number 1 in relation to the economic criteria. The final evaluation is obtained by multiplying the ratings with the priorities of the criteria. In this way we have been able to rank the alternatives from the most preferred one (see Table 13 below).

	Env	Wellb	Econ		Env	Wellb	Econ		U(-)
A1	100%	100%	70%		0.573	0.551	0.221	A1	0.532
A2	50%	40%	60%		0.102	0.089	0.166	A2	0.106
A3	80%	80%	60%		0.310	0.310	0.166	A3	0.296
A4	70%	70%	40%		0.216	0.223	0.088	A4	0.205
A5	50%	20%	20%		0.102	0.049	0.052	A5	0.085
A6	95%	80%	95%		0.507	0.310	0.490	A6	0.463
A7	60%	50%	40%		0.159	0.114	0.088	A7	0.142
A8	50%	40%	60%		0.102	0.089	0.166	A8	0.106
A9	50%	50%	50%		0.102	0.114	0.110	A9	0.1056
A10	30%	50%	30%		0.061	0.114	0.067	A10	0.073

Table 13: The table shows alternatives evaluations (left), ratings (centre) and comprehensive valuation (right)
(Env stands for environmental, Wellb stands for wellbeing, Econ stands for economic)

As we can see the most favourable alternative is the number one as for expert number 1 and 2, followed by alternative number 6, the most efficient according to expert number 3. The third rank is for alternative number three, transport technology innovations for

decarbonisation. At the foot of the podium, we find urban mitigation options followed by protecting the planet. In the last positions we have global climate action and healthy diets (also in this case with the same percentage), the social climate fund, demand services and social aspects of mitigation and to conclude energy efficiency directive.

Among the comments left in the questionnaires, people identified in the environmental criteria the primary advantage in the fight against climate change, able to provide important benefits. Another comment underlined the ceteris paribus condition to stress the difficulty in assigning values in the matrices. In economics, this latin phrase is used to consider economic or financial phenomena assuming that the other variables that could influence the analysis remain constant, of course this is not actually happening in the reality (Economy-pedia, n.d.). This condition can influence the comparisons between alternatives. For people with an economic background can be easier to consider the alternatives separately with respect to criteria, but giving a rate and trying to consider the benefits singularly can be challenging.

The goal of this practical analysis was to identify, using the PAHP how to prioritize alternatives based on criteria, to achieve a reduction in the emissions by 2030. The answers given in the survey were interesting. First, there was an unexpected interest to the topic and to the analysis conducted. Secondly, users demonstrated an ability to deal with matrices and in the use of the Saaty scale, despite some mistakes, we are satisfied by the results obtained.

In the next chapter the conclusions are drawn by focusing the attention on the most effective policies and to the possible constrains.

5. Discussion and conclusion

Once the rankings of the alternatives, whose computation is explained in the previous chapter, have been obtained, a methodology is proposed to select the alternatives with a higher priority. The idea is to build an optimization model and define, through estimates and parameters, which alternatives are feasible, given a certain amount of resources and time. Of course, it is very difficult to define the optimization model in a precise and completely realistic manner, given the large number of aspects to be considered and the limitation in the accessibility of information, so the final idea of this chapter is to demonstrate how the obtained ranking can be used to select the alternatives with the highest priority. To do this, priority based portfolio selection methodology is used (Barbati et al., 2023).

5.1 Priority Based Portfolio Selection (PBPS)

Through Multi-Criteria methods we can compare alternatives based on quantitative and qualitative criteria, from which a set of projects is created considering resources and constraints (Barbati et al., 2023). This methodology is called Priority Based Portfolio Selection (PBPS). The method starts from what has been done in Chapter 4. Once projects are ranked, a selection of projects can be proposed based on the prioritization obtained from the MCDA method's application. This explains why the methodology used is called priority-based (Barbati et al., 2023). This procedure follows two steps: first, a MCDA method is used to define the priorities, and second, a portfolio is built considering some constraints, such as the limited number of sources and budget at disposal (Barbati et al., 2023). One of the difficulties, in fact, is given by the quantification of the economic aspects that can have an influence on the problem, given the limited resources and information available. Moreover, it is challenging to think that all the projects will be funded and for this reason is essential to consider a limited number of them to be pursued (Barbati et al., 2023).

The foundation of the PBPS methodology is the integration of a ranking or sorting process with a portfolio decision problem, the relationship between MCDA and PBPS will be explained in the following (Barbati et al., 2023) and particularized for the case study object of this dissertation.

We have a set A = {A_1, …., A_n} of projects, a portfolio P that is a set of projects such that P ⊆ A and a set C of constraints that have to be satisfied by the portfolio (Barbat et al., 2023).

As mentioned, considering a Priority Based Portfolio Selection problem in real life can be extremely difficult, especially when there are many projects. For this reason, a solution to the PBPS needs to be found. The method starts with the set of projects A and their associated priorities, obtained by the application of the MCDA method. Secondly, to each alternative, a cost category will be assigned, considering that the decision to implement each policy requires a certain amount of money. Three categories of costs will be selected and will be explained deeply in the next paragraph.

To create the model, the decision variables, the objective function, and the constraints need to be defined. The decision variables are the variables that affect the system's performance, the objective function can be either based on maximise or minimise a function in relation to the decision variables, and the constraints are the restrictions we build on the decision variables (Brocklehurst, 2015/16).

The solution is found using a combinatorial optimization problem, formulated as a 0-1 knapsack problem with a set of constraints (Barbati et al., 2023). The alternatives (A) need to be ordered considering their priorities from the highest to the lowest and assigned to a cost category. After, we can assign x_i decision variable to each A. The value of x_i can be either 1 or 0. It has value 1 if the alternative is selected and we decide to implement it, instead, x_i is 0 if the alternative is not pursued. The priority-based portfolio then can be formulated as follows:

$$\max f(x) = \sum_i c_i x_i \text{ where } x_i = 0,1 \ \forall i \ \epsilon \ A_i \quad (9)$$

$$\text{subject to a set of constraints C, where } c_i = 2^{i-1} \quad (10)$$

We will now focus our attention in defining the constraints. For this model, the constraints are defined by assuming that each alternative belongs to a cost category. We assigned to each alternative a category of cost (g) where g = {1,2,3}, according to which $f_i^g = [0,1]$. The parameter f_i^g has value 0 if the alternative is not assigned to category g, while obtains value 1 if the alternative belongs to g. The final constraint formulation is the following:

$$\sum_i f_i^g x_i <=> \alpha \quad \forall g \tag{11}$$

where α is a constant representing the number of projects to be pursued for each category.

In our simulation study, we hypothetically define the number of projects to be implemented for each category. The decision is not simple and needs to be made considering different aspects such as the amount of money that we have at our disposal, the costs that this alternative involves, the efficacy, and the time that is requires. For instance, we can decide that we require at least or maximum two projects belonging to the category g_i to be implemented.

The following paragraph will provide a practical analysis tailored on our case study.

5.2 A portfolio choice problem for the evaluation of climate policies

Before building the model, we have to consider the ten alternatives that constitute the possible solutions to reduce emissions by 2030. The alternatives are assigned to a cost category based on qualitative criteria, since we considered the possible costs that each alternative may require for its implementation, in this way we can propose possible scenarios. We assumed to assign to each of these a category of cost g, where g assumes values between 1 and 3, whose values are attributed considering time, money, and affordability. We created a classification that is based on some assumptions and on the literature, of course it is not easy to provide a solid categorisation, but the goal of this method is to help the reader understand how rankings can be used to build a project assuming further constraints as the ones defined.

The criteria according to which cost categories are assigned can be summarized as follows: if an alternative belongs to category 1 this means that the alternative is expensive and requires huge intervention and, in this sense, can be extremely challenging its performance; if an alternative is part of category 3 is less expensive and is more achievable, while a category of 2 is assigned when it is neither expensive nor easily possible. The Table 14 below summarizes the hypothesis. For instance, energy transition through sustainable resources such as Solar PV and Wind has been assigned to category 3, given the incentives enhanced by the European Commission, available for the construction of photovoltaics (PMI, 2023). Alternative 3, transport technology

innovations for decarbonisation, has value 1, given that changing an entire transport system requires lots of money and time, it is not completely easy. Boosting global climate action (alternative 8) is assigned to category two, in this sense we thought a global cooperation is not extremely costly but may not be balanced because some countries could do less than others.

Alternative	**Category of cost**
Energy transition through sustainable resources such as Solar PV and Wind	3
Shift to sustainable healthy diets	2
Transport technology innovations for decarbonisation	1
Urban mitigation option: urban green and blue infrastructure	1
Demand, services, and social aspects of mitigation	1
Simplifying the regulatory environment	3
Protecting the planet	2
Boosting global climate action	2
Taking advantage of the Social Climate Fund	3
Energy efficiency directive	3

Table 14: Categories of costs

As mentioned, the model will be constructed in Excel. To solve a linear programming (LP) problem[19] we first have to check the presence of the Solver Add-In in the Data tab of the program[20]. This can be checked on the Data Tab and at the end, right side, we should see the Solver command. In the next sub-section, we will explore the applicability of the model taking into consideration the priorities obtained from the three experts and the results obtained from the sample of non-experts (see Chapter 4).

[19] A linear programming problem is an optimisation problem where the function f and constraints g are linear functions of the variable x_i (De Giovanni, n.d.).
[20] To install the command on Windows you have to go on file, select options, add ins, go and select Solver Add-In and click ok.

5.2.1 A portfolio choice problem based on the data of Expert 1

To study the case of expert 1, we first took back the ranking obtained from the questionnaire analysis (see Table 6 chapter 4). The priorities have been noted and classified from the highest to the lowest. Considering that alternative number 2 and 8 got the same ranking (0.153) we assume once that alternative 2 rank 5 and alternative 8 rank 4 and after the opposite. The constraint c_i is computed with the formula (10) presented at the beginning of the chapter and reported in the Table.

Priority	**Alternative**	**C_i**	
0,469	A1	512	10
0,384	A6	256	9
0,25	A3	128	8
0,182	A4	64	7
0,153	A2/A8	32	6
0,153	A2/A8	16	5
0,144	A9	8	4
0,134	A7	4	3
0,122	A10	2	2
0,074	A5	1	1

Table 15: Computation of the C_i

As explained before, each alternative has been assigned to a category of cost. We assume we want to implement at maximum two project belonging to category 1, two projects from category 2 and two from category 3. This decision is done by considering that as a first investment could be necessary to select at maximum two alternatives for each category of cost, to see which are the effects that provide in reaching the target of the research. This is done to identify among different combinations of projects which is providing the highest benefit to reduce the emissions. According to this, for the case of expert 1, alternative 1, 6, 3, 4, 7 and 8 will be pursued, remembering that alternative one was ranked first according to the preferences assigned by the first expert.

Alternative	Cost category	Cost category 3	Cost category 2	Cost category 1	Variable (x_i)
A1	3	1	0	0	1
A2	2	0	2	0	0
A3	1	0	0	1	1
A4	1	0	0	1	1
A5	1	0	0	1	0
A6	3	1	0	0	1
A7	2	0	1	0	1
A8	2	0	1	0	1
A9	3	0	0	1	0
A10	3	0	0	1	0

Table 16: Assignment of cost categories and definition the x_i variable

Once this has been decided, we need to define the objective function and the constraints for each category. The objective function is computed in excel with the sum-product command, where we multiply each c_i for x_i decision variable. In this case the Solver tool help us, because we need to select maximise (since we require a certain maximum number of projects per category) and select the decision variables as variables cells, after we define the columns subjects to the constraints that refers to the number of alternatives and its priorities. Remember to define the decision variables as binary and as resolution method Simplex LP. In this way the software computes the results. The category constraints are given in the same way considering in this case the sum-product of the decision variable (x_i) for the category of cost we consider individually. The model is below summarized.

$max \sum_{i=1}^{10} c_i x_i$ where $x_i = 0,1 \ \forall i \ \epsilon \ A_i$ (12)

The following three constraints, written in this way (with $\leq$) mean that we selected maximum two alternatives for each category of cost.

Constraint 1 $x_1 \leq 2$

Constraint 2 $x_2 \leq 2$

Constraint 3 $x_3 \leq 2$

1008 is the result of the maximization function where we maximize the number of projects that can be pursued. 1008 is the result of the sum of the c_i coefficients reproduced by the objective function.

Given that alternative 2 and 8 present the same priority, by changing their ranking (basically by switching their position), the objective function would be reduced to 1000.

To recap, the main decision in applying the PBPS to solve a LP problem states in defining the number and the type of projects we want to consider for maximising the results. In a real-world case, as the one of the European Commission, this decision may be based on more precise and clear reasons. We will now move forward and see how the methods can find application to the case of expert number 2.

5.2.2 A portfolio choice problem based on the data of Expert 2

As for expert number 1, here the same procedure has been followed. We first took the ranking, we ordered the priorities and we assigned to each alternative a category of cost, that remained unchanged. In the first case, we said that since we have two alternatives (2 and 8) that present the same ranking, to differentiate, before we assign the order A2-A8, and then the opposite, A8-A2.

Compared to the first case, we said that we wanted maximum two projects for each category. The reason of this choice could be to see which categories of costs provide the best results, where the number of projects taken from each category is equal. In this way, when we use the Solver tool, we keep computing a maximization function, expressed by the symbol $\leq$. To see how different combinations of projects perform, for this second case we will change the type of alternatives selected. For category of cost 3, we kept alternative 1 and 6 since got the highest ranking and are the two most effective policies according to expert 2; while for category of cost 2 we selected alternative 7 as before, but for this case we also choose alternative 2 (shift to sustainable healthy diets); for category 1, we selected alternative 5 and 4. The maximization function is expressed below together with the constraints.

Priority	Alternative	Cost category	Cost category 3	Cost category 2	Cost category 1	Variable (xi)
0,457	A1	3	1	0	0	1
0,158	A2	2	0	1	0	1
0,254	A3	1	0	0	1	0
0,183	A4	1	0	0	1	1
0,091	A5	1	0	0	1	1
0,348	A6	3	1	0	0	1
0,145	A7	2	0	1	0	1
0,158	A8	2	0	1	0	0
0,141	A9	3	1	0	0	0
0,099	A10	3	1	0	0	0

Table 17: Identification of the alternatives to be pursued

$max \sum_{i=1}^{10} c_i x_i$ where $x_i = 0,1 \; \forall i \quad \epsilon \, A_i$ (13)

Constraint 1 $x_1 \leq 2$

Constraint 2 $x_2 \leq 2$

Constraint 3 $x_3 \leq 2$

882 is the result of the maximization function of the decision maker from the decision variables.

If instead of implement alternative 2 (shift to sustainable healthy diets), we implement alternative 8 (boosting global climate action), the objective turns out to be 874.

5.2.3 A portfolio choice problem based on the data of Expert 3

For the case of expert 3, we kept the same constraints, but we choose a different combination of alternatives. The priorities are the results of the ranking, the alternative A2 and A8 are switched as before.

Priority	Alternative	Cost category	Cost category 3	Cost category 2	Cost category 1	Variable (xi)
0,344	A1	3	1	0	0	0
0,156	A2	2	0	1	0	1
0,234	A3	1	0	0	1	1
0,156	A4	1	0	0	1	1
0,055	A5	1	0	0	1	0
0,427	A6	3	1	0	0	1
0,123	A7	2	0	1	0	0
0,156	A8	2	0	1	0	1
0,131	A9	3	1	0	0	0
0,128	A10	3	1	0	0	1

Table 18: Identification of the alternatives to be pursued

For category 1 we selected alternative 3 and 4, transport technology innovations for decarbonisation and urban mitigation options, respectively. For category 2, we selected shift to sustainable healthy diets (A2) and boosting global climate action (A8). To conclude, for category 3, energy efficiency directive and simplifying the regulatory environment are taken. In this case it is not necessary to switch the ranking of A2 and A8 since both are selected as part of the category of cost 2.

$max \sum_{i=1}^{10} c_i x_i$ where $x_i = 0,1 \; \forall i \; \epsilon \; A_i$ (14)

Constraint 1 $x_1 \leq 2$

Constraint 2 $x_2 \leq 2$

Constraint 3 $x_3 \leq 2$

473 is the result of the maximization function of the decision maker from the decision variables. The objective function turns out to be 473 for expert 3. Comparing the three cases of the experts, we showed how the combination of different alternatives can provide different results. By looking at these three cases, we can suggest that a combination of policies, as the one chosen for expert 1, could be selected as a good model to reach a reduction on the emissions.

5.2.4 A portfolio choice problem based on the data of non-experts

The same procedure has been followed also after taking the ranking of the non-experts obtained by the aggregation of the questionnaires submitted to the population. The constraints can be summarized as follows:

Constraint 1 $x_1 \leq 1$

Constraint 2 $x_2 \leq 2$

Constraint 3 $x_3 \leq 3$

In this case we ranked alternative 8 at the fifth place and then we will propose an additional example where it is switched with alternative 2. In this case we selected transport technology innovations for decarbonisation and demand, services, and social aspects of mitigation, for category 1. For category 2 and 3 we selected respectively, protecting the planet and boosting global climate action, and simplifying the regulatory environment and taking advantage of the social climate fund. The objective function maximized gives us a value of 438, while by switching the rank of A2 and A8, the value change in 430.

In the case of non-experts, by changing another combination of projects that substitute alternative 9 with alternative 1, and alternative 5 with alternative 4, the objective function turns out to be 1008.

Priority	**Alternative**	**Cost category**	**Cost category 3**	**Cost category 2**	**Cost category 1**	**Variable (xi)**
0,532	A1	3	1	0	0	0
0,106	A2	2	0	1	0	0
0,296	A3	1	0	0	1	1
0,205	A4	1	0	0	1	0
0,085	A5	1	0	0	1	1
0,463	A6	3	1	0	0	1
0,142	A7	2	0	1	0	1
0,106	A8	2	0	1	0	1
0,1056	A9	3	1	0	0	1
0,073	A10	3	1	0	0	0

Table 19: Identification of the alternatives to be pursued

First conclusion that we can draw is that the parameters on which we build the constraints of the model are influencing the whole results. In real world, these constraints will be fixed according to a given and limited amount of money at disposal and/or based on some scientific evidence. What can be said is that to reach a reduction in the emissions by 2030, could be more helpful to consider alternatives that can provide quicker results instead of alternatives that could require larger amount of time and resources as the case of changing habits of the population or rearranging the entire transport system in a less carbonized manner.

An important aspect to be considered in the application of the model is the fact that in considering the alternatives that we are going to pursue, we do not rely completely on ranking because otherwise we would simply choose the alternatives with a higher priority. Instead, having defined the cost categories, the decision is made on the basis of this and thus we are required to select only two alternatives per category, showing in this way the applicability of the model.

6. Conclusion

The ultimate goal of this thesis is to propose an action plan to take action and achieve the goals signed during the Paris Agreement (2015) through the help of a mathematical methodology. This agreement aims to reduce emissions by 55% by 2030, until reaching the climate neutrality by 2050 (European Commission, n.d.-b). Given the numerous climate catastrophes that are affecting our planet, accompanied by abnormally hot weather and completely non-existent winters, the intention is to illustrate how MCDA methods can find application in real problems and come to our aid in defining a concrete plan of action. The findings obtained are the result of a literature review, research, and administration of questionnaires to a group of experts and non-experts, finally leading to the identification of two main policies, the energy sector and the financial sector as the most effective policies on which work.

The thesis also wanted to present a new, recently introduced model, the Parsimonious Analytic Hierarchy Process, to overcome the initial problem that had arisen, namely an excessive number of pairwise comparisons given the large number of alternatives. Another innovative aspect, used for the first time in the literature, was to use the ratings suggested by the experts, and apply them on the weights resulting from the comparisons obtained by the group of non-experts. In order to provide more insight into the practicality of the model, simulations based on portfolio choices were introduced. For instance, an efficient implementation project turns out to be the combination of an energy transition and a simplified regulatory environment, together with a more decarbonized transport system with urban mitigation options (such as urban green and blue infrastructure), enhancing the global climate action and a planet protection.

This thesis can represent a basis for developing further projects, considering resources and limitations present within the Union, in order to be able to understand, in even more detail, the actual practicality and limitations of the model, applying it not only to environmental issues but also to other projects and action plans involving different alternatives.

7. Appendix

Appendix 1

Global greenhouse gas emissions coming from human activities are at their highest level in human history but there is evidence of a slow decrease in the last decade. Without an effective intervention in all sectors, the possibility of limiting the global warming below 1.5°C will be out of reach (IPCC, 2022).

Dear Participant,

You are invited to participate in this research aimed at rating the alternatives that have been selected as the most relevant to help in the achievement of a "reduction of 55% in the greenhouse gas emissions by 2030". In the following questionnaire we would like to obtain your opinion as an expert through the following questions. Your information is extremely important for this work and your participation is very much appreciated. The length for answering the question is approximately ten minutes.

Please note that we will keep the information you provide confidential.

I sincerely hope you can help me with this study.

The alternatives represent actions that can help achieve the above target, and all of them will be evaluated according to three different criteria:

- Economic, has to be intended as all the effects, both in terms of value and in terms of benefits, that can positively influence the economy while addressing the environmental issues.
- Wellbeing is strictly linked to our daily life. For instance, how an alternative can positively affect people by creating new jobs, by providing health and well-being.
- Environmental explains the environmental benefits that an alternative can provide in the short and long term.

In the following pages, there is a brief explanation of the alternatives identified as most relevant for this research.

Energy transition through sustainable resources such as Solar and Wind

We have to reduce CO_2 and GHG emissions, given that the energy sector is the largest contributor to carbon dioxide emissions. We have to intervene in the energy system with sustainable sources such as Solar PV and Wind that in many areas are cheaper than fossil-generated electricity.

For more details: IPCC_AR6_WGIII_Chapter06.pdf

Shift to sustainable healthy diets

A sector that also needs to be considered is represented by Agriculture, Forestry, and Other Land Use (AFOLU). This sector cannot only reduce emissions but also remove and store carbon dioxide. There is a need to conserve ecosystems and improve the food system. Given that AFOLU are strictly linked to the food production and consumption, a shift to sustainable healthy diets can reduce the sector GHG emissions.

For more information: IPCC_AR6_WGIII_Chapter07.pdf

Transport technology innovations for decarbonisation

Transport can offer an efficient potential for reducing emissions. The European Commission set the target that by 2035 all new cars and vans will be zero emissions. In today's life, cars play an important role, and for this reason, is important to meliorate car performance by introducing vehicles technologies and low-carbon fuels innovations and change consumer behaviours and choices. This requires a reduction in GHG emissions footprint for battery production and at the same time the electrification of transport nodes depends on an appropriate energy storage system.

For more information: IPCC_AR6_WGIII_Chapter10.pdf

Urban mitigation options: Urban green and blue infrastructure

The construction of new urban infrastructures will increase the emissions. A solution is represented by urban green and blue infrastructure that can help through the carbon

sequestration process, emissions reduction and less energy use but also reducing urban energy and material use.

For more information: IPCC_AR6_WGIII_Chapter08.pdf

Demand, services and social aspects of mitigation

As we know our behaviour is strongly influencing the problem of climate change, but it can also offer a solution if associated with policies and adapted infrastructures. Demand side mitigation and the provision of services can help in GHG emissions reduction. As reported in the literature, changing demand, services, and social aspects is not easy and takes time. It also requires an important change in consumer behaviours, this is the reason of a low rating.

For more information: IPCC_AR6_WGIII_Chapter05.pdf

Simplifying the regulatory environment

Europe decided to create a plan aimed to invest towards a net zero emissions world, in which Europe all together, works to achieve innovation, inclusivity, and sustainability. The project named Green Deal is based on a predictable, coherent, and simplified regulatory environment and with a speed in the access for financing. Investments constitute an important starting point and are fundamental, this is the reason of a high rating.

For more information: COM_2023_62_2_EN_ACT_A Green Deal Industrial Plan for the Net-Zero Age.pdf (europa.eu)

Protecting the planet

Europe defined the Biodiversity strategy as a recovery path by 2030. The idea is to restore degraded ecosystems, in particular the ones that are able to store more carbon and to prevent natural disasters.

For more information: Biodiversity strategy for 2030 (europa.eu)

Boosting global climate action

To fight climate change and to accomplish the targets fixed by Europe we have to work with our international partners.

For more information: Biodiversity strategy for 2030 (europa.eu)

Taking advantage of the Social Climate Fund

This is a fund worth 86 billion euros which can be used for clean energy, direct aid to families while always maintaining the aim of reducing emissions. This aid will be provided as bonuses, tax incentives or interest-free loans, but the fund will not be active before 2026. Given the late release of the fund, the short-term effects may be slight and therefore a low rating is given.

For more information: resource.html (europa.eu)

Energy efficiency directive

The scope of the directive is to introduce a series of measures to accelerate energy efficiency practices. The directive refers also to energy poverty, countries are required to prioritise energy efficiency improvements for poorer customers, low-income households.

For more information: European Green Deal: Energy Efficiency Directive adopted, helping make the EU 'Fit for 55' (europa.eu)

Table 1 below summarizes the ratings assigned to each alternative concerning each criterion: after an analysis of the literature, I assigned the ratings considering both the advantages that the alternative can provide to each criterion (such as reducing emissions, improving people wellbeing, creating new jobs, reduce costs etc.) with the capacity to apply the alternative to the real world, considering the challenges associated, to be on time by 2030.

I kindly ask you to decide if you agree or not with the rating I have assigned to each of them, and in case not, please suggest a rating and briefly explain the reason for your choice.

Ratings have been assigned from 0% to 100% using as reference the following criteria and after a deep analysis of the literature:

- ➔ A rate of 100% means that the alternative can provide huge environmental benefits since the sector is an active contributor of current GHG emissions and quick intervention is needed, but also a rate of 100% means no obstacles (in terms of financial resources, time etc.) and no possible negative effects.
- ➔ A rate of 50% means that the positive effects impacting the achievement of the goal are relevant, but its application faces important obstacles, or the intervention in that field is not the most important from which we should start and/or is not the biggest contributor to the emissions.
- ➔ A rate of 0% means that the alternative is neutral and doesn't provide either positive or negative effects, so its application is unnecessary.

Do you agree with the ratings proposed in Table 1? Please in case of suggestions, use the last column of the table to add your comments and in the row "Experts rating" your own rating.

Alternatives Criteria	Environmental	Wellbeing	Economic	Comments from experts
Energy transition through sustainable resources such as Solar PV and Wind	100%	100%	95%	
Experts rating				
Shift to sustainable healthy diets	50%	40%	60%	
Expert rating				
Transport technology innovations for decarbonisation	80%	80%	60%	
Experts rating				
Urban mitigation options: Urban green and blue infrastructure	70%	70%	40%	
Experts rating				
Demand services and social aspects of mitigation	50%	20%	20%	
Experts rating				
Simplifying the regulatory environment	95%	80%	95%	
Experts rating				
Protecting the planet	60%	50%	40%	
Experts rating				
Boosting global climate action	50%	40%	60%	
Experts rating				
Taking advantage of the Social Climate Fund	50%	50%	50%	
Experts rating				
Energy efficiency directive	30%	50%	30%	
Experts rating				

Table1: Rating of alternatives concerning each criterion and additional comments if needed (right).

Given that for the ten alternatives a rating from 0 to 100 have been assigned, to conclude I ask you to decide whether you agree or not with the following reference levels for all alternatives evaluated on all the criteria that are:

First Level= 0%, Second Level= 25%, Third Level=50%, Fourth Level= 75%, Fifth Level=100%

By assigning this reference levels the Decision Maker is able to split the sample proportionally.

Do you agree?
If not, which reference levels do you think are more suitable?

Additionally, I ask you to use a nine-point scale (see the legenda below) to define the importance among the criteria, as follow:

- 1 equal importance
- 3 moderate importance
- 5 strong importance
- 7 very strong importance
- 9 extreme importance

  2,4,6,8 are intermediate levels

Ex: ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

I prefer the economic criteria with very strong importance compared to wellbeing criteria.

Please underline in yellow the value you attribute.

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 ENVIRONMENTAL

WELLBEING 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 ENVIRONMENTAL

Please use the same scale (1 to 9) to compare pairwise the reference levels selected above in terms of preference.

As in the example reported below, according to the criterion environmental, if I assign 5 to the row representing the second reference level of 25% and the column representing the first reference level of 0% it means that I strongly prefer an alternative with a rating of 25% to an alternative with a rating of 0% in relation to the environmental criterion.

Please fill in the spaces where there are missing values (indicated by the symbol -)

Environmental	0%	25%	50%	75%	100%
0%	1				
25%	5	1			
50%	-	-	1		
75%	-	-	-	1	
100%	-	-	-	-	1

Wellbeing	0%	25%	50%	75%	100%
0%	1				
25%	-	1			
50%	-	-	1		
75%	-	-	-	1	
100%	-	-	-	-	1

Economic	0%	25%	50%	75%	100%
0%	1				
25%	-	1			
50%	-	-	1		
75%	-	-	-	1	
100%	-	-	-	-	1

Demographics of the respondents

Position: Associate professor

Academic area (e.g. human resources, operations management, engineering, etc):

Work experience (year):

University/Educational institute:

Country:

What country do you feel culturally attached to for work?

Please if you want to give us an additional comment:

Appendix 2

Do you agree with the ratings proposed in Table 1? Please in case of suggestions, use the last column of the table to add your comments and in the row “Expert rating” your own rating.

Alternatives Criteria	Environmental	Wellbeing	Economic	Comments from experts
Energy transition through sustainable resources such as Solar PV and Wind	100%	100%	95%	
Expert rating				
Shift to sustainable healthy diets	50%	40%	60%	
Expert rating				
Transport technology innovations for decarbonisation	80%	80%	60%	
Expert rating				
Urban mitigation options: Urban green and blue infrastructure	70%	70%	40%	
Expert rating				
Demand services and social aspects of mitigation	50%	20%	20%	
Expert rating				
Simplifying the regulatory environment	95%	80%	95%	
Expert rating				
Protecting the planet	60%	50%	40%	
Expert rating				
Boosting global climate action	50%	40%	60%	
Expert rating				
Taking advantage of the Social Climate Fund	50%	50%	50%	
Experts rating				
Energy efficiency directive	30%	50%	30%	
Experts rating				

Table1: Rating of alternatives concerning each criterion and additional comments if needed (right).

Given that for the ten alternatives a rating from 0 to 100 have been assigned, to conclude I ask you to decide whether you agree or not with the following reference levels for all alternatives evaluated on all the criteria that are:

First Level= 0%, Second Level= 25%, Third Level=50%, Fourth Level= 75%, Fifth Level=100%

By assigning this reference levels the Decision Maker is able to split the sample proportionally.

Do you agree? YES
If not, which reference levels do you think are more suitable?

Additionally, I ask you to pairwise compare the criteria in terms of their importance using the nine-point scale (see the legenda below):

- 1 equal importance
- 3 moderate importance
- 5 strong importance
- 7 very strong importance
- 9 extreme importance

  2,4,6,8 are intermediate levels

Ex: ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

Economic criteria are more important than wellbeing ones. Moreover, Economic criteria are very strongly more important than Wellbeing ones..

Please underline in yellow the value you attribute.

ECONOMIC 9 8 7 6 5 4 3 2 <u>1</u> 2 3 4 5 6 7 8 9 WELLBEING

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 <u>5</u> 6 7 8 9 ENVIRONMENTAL

WELLBEING 9 8 7 6 5 4 3 2 1 2 3 4 <u>5</u> 6 7 8 9 ENVIRONMENTAL

Please use the same scale (1 to 9) to compare pairwise the reference levels selected above in terms of preference.

As in the example reported below, according to the criterion environmental, if I assign 5 to the column representing the second reference level of 25% and the column representing the first reference level of 0% it means that I strongly prefer an alternative with a rating of 25% to an alternative with a rating of 0% in relation to the environmental criterion.

Environmental	0%	25%	50%	75%	100%
0%	1	-	-	-	-
25%	5	1	-	-	-
50%	6	5	1	-	-
75%	7	5	3	1	-
100%	9	7	5	3	1

Wellbeing	0%	25%	50%	75%	100%
0%	1	-	-	-	-
25%	5	1	-	-	-
50%	6	4	1	-	-
75%	8	6	4	1	-
100%	9	7	5	3	1

Economic	0	25%	50%	75%	100%
0%	1	-	-	-	-
25%	3	1	-	-	-
50%	5	3	1	-	-
75%	6	4	3	1	-
100%	9	6	4	3	1

Demographics of the respondents

Position: Associate professor

Academic area (e.g. human resources, operations management, engineering, etc): Mathematics for economics

Work experience (year): 10

University/Educational institute: Università degli Studi di Catania

Country: Italy

What country do you feel culturally attached to for work? Italy

Please if you want to give us an additional comment:

Appendix 3

Do you agree with the ratings proposed in Table 1? Please in case of suggestions, use the last column of the table to add your comments and in the row “Experts rating” your own rating.

Alternatives Criteria	Environmental	Wellbeing	Economic	Comments from experts
Energy transition through sustainable resources such as Solar PV and Wind	100%	100%	95%	You did you the literature review, so you know it better than me
Experts rating				
Shift to sustainable healthy diets	50%	40%	60%	
Expert rating				
Transport technology innovations for decarbonisation	80%	80%	60%	
Experts rating				
Urban mitigation options: Urban green and blue infrastructure	70%	70%	40%	
Experts rating				
Demand services and social aspects of mitigation	50%	20%	20%	
Experts rating				
Simplifying the regulatory environment	95%	80%	95%	
Experts rating				
Protecting the planet	60%	50%	40%	
Experts rating				
Boosting global climate action	50%	40%	60%	
Experts rating				
Taking advantage of the Social Climate Fund	50%	50%	50%	
Experts rating				
Energy efficiency directive	30%	50%	30%	
Experts rating				

Table1: Rating of alternatives concerning each criterion and additional comments if needed (right).

Given that for the ten alternatives a rating from 0 to 100 have been assigned, to conclude I ask you to decide whether you agree or not with the following reference levels for all alternatives evaluated on all the criteria that are:

First Level= 0%, Second Level= 25%, Third Level=50%, Fourth Level= 75%, Fifth Level=100%

By assigning this reference levels the Decision Maker is able to split the sample proportionally.

Do you agree? It is subjective, so, yes.
If not, which reference levels do you think are more suitable?

Additionally, I ask you to use a nine-point scale (see the legenda below) to define the importance among the criteria, as follow:

- 1 equal importance
- 3 moderate importance
- 5 strong importance
- 7 very strong importance
- 9 extreme importance

  2,4,6,8 are intermediate levels

Ex: ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

I prefer the economic criteria with very strong importance compared to wellbeing criteria.

Please underline in yellow the value you attribute.

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 ENVIRONMENTAL

WELLBEING 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 ENVIRONMENTAL

Please use the same scale (1 to 9) to compare pairwise the reference levels selected above in terms of preference.

As in the example reported below, according to the criterion environmental, if I assign 5 to the row representing the second reference level of 25% and the column representing the first reference level of 0% it means that I strongly prefer an alternative with a rating of 25% to an alternative with a rating of 0% in relation to the environmental criterion.

Please fill in the spaces where there are missing values (indicated by the symbol -)

Environmental	0%	25%	50%	75%	100%
0%	1				
25%	2	1			
50%	4	2	1		
75%	6	4	2	1	
100%	9	6	4	2	1

Wellbeing	0%	25%	50%	75%	100%
0%	1				
25%	2	1			
50%	4	2	1		
75%	6	4	2	1	
100%	9	6	4	2	1

Economic	0%	25%	50%	75%	100%
0%	1				
25%	2	1			
50%	4	2	1		
75%	6	4	2	1	
100%	9	6	4	2	1

Demographics of the respondents

Position: Professor

Academic area (e.g. human resources, operations management, engineering, etc): operations rese

Work experience (year): 25

University/Educational institute: Neoma

Country: France

What country do you feel culturally attached to for work? UK

Please if you want to give us an additional comment:

Appendix 4

Do you agree with the ratings proposed in Table 1? Please in case of suggestions, use the last column of the table to add your comments and in the row "Experts rating" your own rating.

Alternatives / Criteria	Environmental	Wellbeing	Economic	Comments from experts
Energy transition through sustainable resources such as Solar PV and Wind	100%	100%	95%	95% per l'economia mi sembra molto ottimistico. Ridurrei a 70% perché gli ostacoli sono molti
Experts rating			70%	
Shift to sustainable healthy diets	50%	40%	60%	
Expert rating				
Transport technology innovations for decarbonisation	80%	80%	60%	
Experts rating				
Urban mitigation options: Urban green and blue infrastructure	70%	70%	40%	
Experts rating				
Demand services and social aspects of mitigation	50%	20%	20%	
Experts rating				
Simplifying the regulatory environment	95%	80%	95%	
Experts rating				
Protecting the planet	60%	50%	40%	
Experts rating				
Boosting global climate action	50%	40%	60%	
Experts rating				
Taking advantage of the social climate fund	50%	50%	50%	Benchè non avvenga nell'immediato, penso che l'impatto possa essere significativo
Experts rating	70%	70%	70%	
Energy efficiency directive	30%	50%	30%	
Experts rating				

Table1: Rating of alternatives concerning each criterion and additional comments if needed (right).

Given that for the ten alternatives a rating from 0 to 100 have been assigned, to conclude I ask you to decide whether you agree or not with the following reference levels for all alternatives evaluated on all the criteria that are:

First Level= 0%, Second Level= 25%, Third Level=50%, Fourth Level= 75%, Fifth Level=100%

By assigning this reference levels the Decision Maker is able to split the sample proportionally.

Do you agree? YES
If not, which reference levels do you think are more suitable?

Additionally, I ask you to use a nine-point scale (see the legenda below) to define the importance among the criteria, as follow:

- 1 equal importance
- 3 moderate importance
- 5 strong importance
- 7 very strong importance
- 9 extreme importance

  2,4,6,8 are intermediate levels

Ex: ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

I prefer the economic criteria with very strong importance compared to wellbeing criteria.

Please underline in yellow the value you attribute.

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING

ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 ENVIRONMENTAL

WELLBEING 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 ENVIRONMENTAL

Please use the same scale (1 to 9) to compare pairwise the reference levels selected above in terms of preference.

As in the example reported below, according to the criterion environmental, if I assign 5 to the row representing the second reference level of 25% and the column representing the first reference level of 0% it means that I strongly prefer an alternative with a rating of 25% to an alternative with a rating of 0% in relation to the environmental criterion.

Please fill in the spaces where there are missing values (indicated by the symbol -)

Environmental	0%	25%	50%	75%	100%
0%	1				
25%	3	1			
50%	5	5	1		
75%	7	7	3	1	3
100%	9	9	5	3	1

Wellbeing	0%	25%	50%	75%	100%
0%	1				
25%	3	1			
50%	5	3	1		
75%	7	5	3	1	
100%	9	7	5	3	1

Economic	0%	25%	50%	75%	100%
0%	1				
25%	3	1			
50%	5	3	1		
75%	7	5	3	1	
100%	9	7	5	3	1

Demographics of the respondents

Position: Full Professor

Academic area (e.g. human resources, operations management, engineering, etc): Planning Evaluation and Project Appraisal

Work experience (year): 22

University/Educational institute: Politecnico di Torino

Country: Italy

What country do you feel culturally attached to for work? Italy

Please if you want to give us an additional comment:

Appendix 5

A Parsimonious Analytic Hierarchy Process methodology for the evaluation of climate policies.

Dear Participant,

You are invited to participate in this research aimed at assessing criteria and reference levels that have been selected as the most relevant to help in the achievement of a reduction of 55% in the greenhouse gas emissions by 2030. In the following questionnaire we would like to obtain your opinion, as a student familiar with the Multi-Criteria Decision Analysis (MCDA) methods, thanks to your university background. Your information is extremely important for this work and very much appreciated. Please note that we will keep the information you provide confidential.

Question 1: Please confirm you consent the conditions stated above before proceeding to the survey:

- I consent to participate
- I do not consent to participate

Question 2: In which of the following categories you identify the most:

- Student
- Graduate student
- Other (please specify) :

Question 3: What is your gender:

- Male
- Female
- Non-binary
- Prefer not to say

Question 4: Please provide your age in years (e.g. 23):

Question 5: Which is your country of origin:

Question 6: Are you interested in climate change and other environmental issues?

- Yes
- Neutral

- No

Question 7: Do you agree or not that climate change is a today problem that requires important intervention?

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Question 8: In your daily life are you doing something for the environment: (for instance you could use environmental friendly transport modes, have a sustainable healthy diet etc.)

- Yes
- Yes, but I could do more
- No, but I would
- No and I am not interested to do something

Question 9: Have you ever heard of Multi-Criteria Decision Analysis (MCDA) methods?

- Yes and I have also used it
- Yes, but never used
- No

In order to give you a general overview of the research, below you can find some useful information about alternatives and criteria.

- Energy transition through sustainable resources such as Solar PV and Wind
- Shift to sustainable healthy diets
- Transport technology innovations for decarbonisation
- Urban mitigation options: urban green and blue infrastructure
- Demand, services, and social aspects of mitigation
- Simplifying the regulatory environment
- Protecting the planet
- Boosting global climate action
- Taking advantage of the social climate fund
- Energy efficiency directive

The alternatives represent actions that can help achieve the above target (emissions reduction by 2030), and all of them will be evaluated according to three different criteria:

1) Environmental explains the environmental benefits that an alternative can provide in the short and long term.
2) Wellbeing is strictly linked to our daily life. For instance, how an alternative can positively affect people by creating new jobs, by providing health and well-being.
3) Economic has to be intended as all the effects, both in terms of value and in terms of benefits, that can positively influence the economy while addressing the environmental issues.

After an analysis of the literature and thanks to the help of some experts, alternatives have been evaluated using a rating from 0% to 100% and five reference levels have been identified:

First Level=0%, Second Level=25%, Third Level=50%, Fourth Level=75%, Fifth Level=100%

Please use a scale (1 to 9) to compare pairwise the criterion explained above. I ask you to use a nine-point scale (see the agenda below) to define the importance among the criteria, as follow:

1 equal importance

3 moderate importance

5 strong importance

7 very strong importance

9 extreme importance

2, 4, 6, 8 are intermediate levels

Ex: ECONOMIC 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 WELLBEING, by assigning a value equal to 5, I prefer the economic criteria with strong importance compared to wellbeing criteria.

Question 10: Please use the 1-9 scale to compare pairwise the following matrix in relation to the three criteria explained above. Note that the comparison of the criteria for itself will always have value 1 (diagonal of the matrix).

	ENVIRONMENTAL	WELLBEING	ECONOMIC
ENVIRONMENTAL			
WELLBEING			
ECONOMIC			

Please use the same scale (1 to 9) to compare pairwise the reference levels in terms of preference. For instance, considering the environmental criteria, if I assign 5 to the column representing the second reference level of 25% and the column representing the first reference level of 0%, it means that I strongly prefer an alternative with a rating of 25% to an alternative with a rating of 0% in relation to the environmental criteria.

Question 11: Please use the scale (1 to 9) to compare pairwise the reference levels in relation to the environmental criteria.

Environmental	0%	25%	50%	75%	100%
0%					
25%					
50%					
75%					
100%					

Question 12: Please use the scale (1 to 9) to compare pairwise the reference levels in relation to the wellbeing criteria.

Wellbeing	0%	25%	50%	75%	100%
0%					
25%					
50%					
75%					
100%					

Question 13: Please use the scale (1 to 9) to compare pairwise the reference levels in relation to the economic criteria.

Economic	0%	25%	50%	75%	100%
0%					
25%					
50%					
75%					
100%					

Please feel free to add your opinion or an additional comment in the space below.

(The data of the questionnaires have been aggregated and analysed in Chapter 4.5.1).

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