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Technology Neutrality vs Technology Specificity: A critical review of the Italian and European policymaking in the energy transition

Prof. Simone Mori
SUPERVISOR

Prof. Luigi Nasta
CO-SUPERVISOR

Federico Rinaldi, 757561
CANDIDATE

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Abstract

This master thesis compares the efficiency of two different archetypal policy approaches, namely Technology Specificity and Technology Neutrality, in the context of the European energy transition of the light-duty road transport sector, specifically focusing on the impacts on the Italian energy and automotive industries. Today, the relevance of this topic is central, due to the recently adopted “regulation on CO2 emissions for new cars and vans”, which anticipates a massive revolution of the light-duty road transport sector, strongly polarizing the opinions of the stakeholders involved.

To answer the main research question, this thesis utilized a combination of existing literature and original interviews conducted with experts and key stakeholders, as qualitative inputs of the analysis, which is based on Agora’s “Technological Neutrality and Technological Openness” framework. The key findings indicate that a technology-specific policymaking approach, enforcing specific sectorial and technological sub-targets, besides the main objective of Carbon Neutrality, is required in order to account for several existing biases in the decisional space.

Keywords: Energy Transition, Decarbonization, Technology Neutrality, Fit For 55, Light-duty Road Transport, Renewable Electricity, Low Carbon Fuels.

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1. Introduction

The rapid advancement of the energy transition and the urgent need to achieve ambitious decarbonization goals have sparked a heated debate across Europe over the most effective policies and investments to facilitate the pathway towards Net Zero carbon emissions. This master thesis delves into this ongoing debate, with a particular focus on the field of light-duty transportation.

In the context of the Italian market and political landscape, the thesis aims to analyze the clash between two opposing groups of stakeholders. On one side, there are proponents advocating for full electrification of light-duty transport, a vision supported by the current European Commission. On the other side, advocates push for a more open-ended approach that incorporates alternative low-carbon energy vectors, such as biofuels and synfuels, to preserve the traditional automotive value chain, based on Internal Combustion Engines (ICE). At the heart of this thesis' reasoning lie two archetypal policy approaches, "technology-neutrality" and "technology-specificity," as defined by the study "Technology Neutrality for Sustainable Transport" (Agora Verkehrswende, 2020).

Technology-neutrality refers to an open-ended regulatory approach, focusing solely on the primary objective of reducing CO2 emissions in accordance with the 2030 and 2050 European Agenda. This approach avoids including sub-targets related to specific technologies or subsequent industrial levels. It is championed by stakeholders aiming to safeguard traditional value chains. In contrast, the technology-specificity policy approach, more in line with the current EU Commission's stance, not only includes the CO2 emission reduction target but also enforces normative constraints to promote the use of specific technologies mixes in the different highly carbon-intensive sectors, aiming at the most efficient and rapid achievement of Net-Zero carbon emissions. Advocates of this approach consider electrified mobility to be the most efficient, sustainable, and environmentally friendly option for decarbonizing light-duty road transport.

The overarching objective of this master thesis is to undertake an analysis of these two policy approaches to identify which one offers the most efficient solution for realizing the ambitious European decarbonization plan. The analysis will consider prevailing normative, technological, economic, and social conditions, and their potential future impacts on the light-duty transport industries of both Italy and Europe.

The research will begin with an extensive literature review, covering key EU legislation related to the energy transition, including the EU Green Deal, Fit For 55, REPowerEU, Renewable Energy Directive, Fuel Quality Directive, and ILUC Directive. Additionally, the review will focus on the maturity, sustainability, and current/prospective utilization of key technologies, such as Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), Low-carbon fuels (LCFs), and Hydrogen-based solutions.

Research Question

"Which policy-making approach is more efficient in enabling the European energy transition plan for transport, in relation to the normative, technological, economic and social landscape in Italy?"

To address the research question, the thesis will employ an existing framework developed by Agora in 2020, known as "Technological Neutrality and Technological Openness". This framework allows for an assessment of which type of regulation (technology-neutral vs technology-specific) is best suited for different decision spaces (technology open vs technology biased), taking into account economic indicators such as the existence of market imperfections, secondary policy objectives, and information asymmetry.

In summary, according to Agora's research model, "the potential cost-effectiveness of a technology-neutral intervention increases: (1) the greater the technology openness of the decision space is before the government intervention; (2) the less the regulation aims to address additional objectives beyond decarbonization; and (3) the less government regulators have access to information needed for cost-effective technology-specific policies."

In addition to the framework application, the thesis seeks to augment its findings through empirical data obtained from interviews conducted with representatives of the main Italian stakeholders involved in the energy transition debate. These interviews will provide valuable insights and perspectives from those at the forefront of shaping energy policies and investments. By examining how different stakeholders are affected by these policy decisions and analyzing their main arguments, the thesis seeks to shed light on the complexities of the energy transition debate.

The "discussion" chapter will present the results of the analysis, offering an informed answer to the research question, while considering the perspectives and perceptions of the involved parties. Finally, the conclusion will synthesize the main highlights of the research and outline the limitations and potential avenues for future developments.

Through this comprehensive examination of the technology neutrality versus technology specificity debate, this master thesis aims to contribute with relevant findings and implications to the ongoing energy transition discourse, signaling to policymakers and stakeholders the potential threats and opportunities of the different alternative avenues towards an efficient and sustainable decarbonization of light-duty road transport.

2. Theory

2.1 Key Legislation on the Energy Transition

This chapter addresses the legislative side of the energy transition in Europe, focusing mainly on the laws that directly impact the transport sector.

With the 2015 Paris Agreement, the world started committing towards environmental sustainability, speaking for the first time about Net Zero emission targets. Today, eight years later, Europe is at the forefront of what many call the "fourth industrial revolution", having committed massive resources and set ambitious targets for decarbonizing the energy-intensive systems.

The European sustainable energy transition path rests on some fundamental normative pillars.

In terms of objectives, the first, most important step taken after the Paris Agreement was the 2019 EU Green Deal (European Council, 2019), an ambitious bundle of legislative proposals which set two impressive goals: to achieve a CO2 emission reduction of -55% within 2030 (2030 Climate Target Plan) and to reach Carbon Neutrality – Net Zero emissions – by 2050 (European Climate Law). The key principles driving the European decarbonization are set to be:

1. Sustainability
2. Security of supply
3. Competitiveness

Notably, due to the two recent consecutive economic shocks, the pandemic and the Russian-Ukrainian war, the principle of supply security has acquired a greater weight in the evaluations of public and private stakeholders.

While the Green Deal's decarbonization goals have been approved by the member states, a lively debate still surrounds the adoption of downstream sub-targets and specific technology indications for decarbonizing the energy intensive sectors. The following paragraphs contain a comprehensive list of the most relevant European laws for the energy transition of the transport sector.

Fit For 55

The Fit For 55 (European Council, 2021) law package is a bundle of draft legislations aimed at revising the EU body of law in relation to climate, energy and transport. With a specific focus on the measures impacting the transport sector and energy products/vectors, the Fit For 55 suggests:

- A revision of the regulation on the CO2 emission standard of cars and vans, adopted by the European Council in March 2023 (with a review clause), which increases the CO2 reduction to -100% (Net Zero) by 2035.
- A revision of the Renewable Energy Directive recast (RED II), aiming at increasing the Renewable Energy share target to 40% by 2030 (vs 32%). (COM (2021) 557: RED II Revision Proposal, 2021)
- A revision of the directive on the Emission Trading Scheme (ETS), the main tool to enforce and incentivize the CO2 reduction in Europe, aiming at, among other things, introducing a separate ETS to the road transport, to incentivize fuels producers to supply more sustainable products.
- A revision of the directive on taxation of energy, aiming at correlating the fiscal imposition to the energy content and contribution towards environment protection of the energy product/vector, rather than to its volume.
- A regulation and a directive proposals aiming at boosting the uptake of Hydrogen and Low Carbon gases, by creating a regulatory framework for dedicated infrastructure, markets and integrated network planning.
- A revision of the directive on energy efficiency, aiming at reducing the EU's final energy consumption by 11.7% in 2030 (including the transport sector, in addition to buildings and industry).
- A regulation proposal aiming at ensuring the availability of recharging and refueling infrastructure for alternative energy products/vectors.
- A revision of the Effort Sharing Regulation (ESR), which sets separate emission cutting targets for the members states, according to their GDP, which has been formally adopted by the EU council in March 2023. The revision aims at increasing from -29% to -40% the member states' emission reduction targets for 2030, in the sectors currently not covered by the ETS (including transport).

Within the wide scope of the Fit For 55 package, the most relevant measure for the transport sector is certainly the review of the CO2 standard regulation (COM (2021) 556: CO2 Standards for Cars and Vans, 2021). Recently approved, this review brings several novelties in the original text of the Regulation, most importantly updating and increasing the CO2 reduction goals from newly build cars, which are due to achieve -55% emissions reduction by 2030, and -100% (net zero) by 2035. Due to the greatly ambitious nature of this proposal, associated with an emission calculation methodology which undoubtably favors the uptake of Electric Vehicles (EVs), and the phase out of the Internal Combustion Engine (ICE), it inevitably sparked great resistance among some of the main stakeholders, giving a key contribution to the birth of the hot debate that exists today around the energy transition of the transport sector. Given the many requests from the affected stakeholders to include in the review other technological options, more friendly to the refining and ICE industries, the approval of the review, although without immediate modifications, included a clause to eventually develop exceptional CO2 reduction standards for e-fuels, according to the pressing requests of Germany, one of the economies most affected by the energy transition. Not unlike Germany, Italy's ICE and refining industries have an important relative weight in the national economy, therefore, naturally, the perspective of phasing out ICE-related energy vectors/sources caused notable resistance. These opposing Italian stakeholders tend to push for technology options which are different from e-fuels, and which currently are not receiving political support in Europe, namely conventional, advanced and synthetic biofuels. However, given the opening of the commission to e-fuels, which require a different emission accounting method in order for their environmental contribution to be correctly assessed, it is still possible that, in the future, Italy's favorite technology options for decarbonization may receive a similar treatment.

REPowerEU

"REPowerEU (COM (2022) 230: REPowerEU Plan, 2022) is about rapidly reducing our dependence on Russian fossil fuels by fast forwarding the clean transition and joining forces to achieve a more resilient energy system and a true Energy Union."

The main proposal of the REPowerEU is to increase the target in the Renewable Energy Directive to 45% by 2030, 5 percentage points more than the Fit For 55 target, along with energy consumption efficiency increase, cooperation between member states in order to diversify supplies, and smart investment.

There are two kinds of coordination required: one between European measures and national investments and reforms, the other between the demand (reducing consumption and replacing fossil fuels with renewables) and the supply (creating the capacity and framework to produce renewables).

The main set of actions of this plan consists of: (1) Saving energy; (2) Diversify supplies; (3) Substitute fossil fuels and accelerate Europe's clean energy transition; (4) Smartly combine investments and reforms.

With regards to point (3) ("Substitute fossil fuels and accelerate Europe's clean energy transition"), Europe's energy transition must focus on all the main sectors of CO2 emission: power generation, industry, buildings and transport. To allow this, massive investments must be rolled out, skilled workforce secured and slow and complex permitting procedures simplified.

Focusing on the measures which affect the transport sector, a target of 10 million tons of domestic renewable hydrogen production and 10 million tons of imports by 2030 is to be set. Sub-targets for specific sectors would need to be agreed by the co-legislators. Additionally, a "Biomethane Action Plan" (SWD (2022) 230: Investment Needs, Hydrogen Accelerator And Achieving The Bio-Methane Targets, 2022) accompanies the REPowerEU document, suggesting the inclusion of industrial partnerships and financial incentives to increase the production by 2030. To stimulate energy savings and efficiency, the Commission also plans to present a "Greening of Freight Package", to increase the share of zero emission vehicles in public and corporate car fleets.

Renewable Energy Directive

The Renewable Energy Directive (Directive 2009/28/EC: Promotion of the Use of Energy from Renewable Sources, 2009) sets the target for the share of electricity to be produced with renewable sources. The target, initially set to 20%, has been updated in 2018 with the RED II Recast (DIRECTIVE 2018/2001: Promotion of the Use of Energy from Renewable Sources (Recast), 2018), increased to 32%, to be achieved by 2030. One further revision of the Directive (RED III), on which a provisional agreement has been reached only recently (Council of the EU, 2023). Within it, the renewable share of electricity target has been first increased to 40% (by 2030) within the Fit For 55 package, and further upshifted to 45% within the REPowerEU Plan.

The directive also includes rules and principles to facilitate the uptake of renewable energy sources/vectors, production and consumption rights, and biomass sustainability criteria. These aspects have also been strengthened throughout the revisions, with the aim of promoting energy efficiency and renewable-based circular economies, including specific targets for Low Carbon Fuels (i.e. Hydrogen and advanced biofuels) in the transport sector.

Finally, the RED has an additional essential function, with regards to the energy transition of the transport sector: it contains, in its annexes, the official emission calculation formula and methodology, along with the official list of emission factors for each publicly known energy source/vector.

Fuel Quality Directive & ILUC

Another important European law is the Fuel Quality Directive (FQD) (Directive 2009/30/EC: Fuel Quality Directive, 2009), which sets a GHG reduction target for fuel producers. The directive lists the sustainability criteria for renewable biofuels, referencing also the ILUC (Commission Delegated Regulation (EU) 2019/807: Indirect Land Use Change (ILUC), 2019), which limits the use of biomass-intensive fuels that compete with food and feed for the feedstock use, in terms of land occupation.

PNRR

(Piano Nazionale Di Ripresa e Resilienza (PNRR), 2021)

When it comes to the Italian regulation, decarbonizing the transport sector requires public intervention of five key levers (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022):

1. Scaling-up alternative light-duty road transport systems and managing the demand and structure of mobility;
2. Improving energy efficiency and decarbonizing end appliances (vehicles);
3. Decarbonizing fuels and energy vectors;

4. Reducing emissions associated to production of vehicles;
5. Reducing emissions associated to construction of infrastructure.

The PNRR (Piano Nazionale di Ripresa e Resilienza) aims at tackling, among other things, some of the most critical aspects of the Italian transport sectors, namely: an excessively number of vehicles per capita; a concerningly underdeveloped local public transport network; a strong heterogeneity in the territorial development of infrastructure; an excessive reliance on road transport, as compared to alternative, more sustainable means of transport (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

The measures, relevant to the transport sector, include:

- Updating, upgrading and decarbonizing local public transport;
- Reducing urban demand for polluting means of transport, by developing bike lanes, electrified micro-mobility and mobility-as-a-service;
- Developing a charging infrastructure network to facilitate the uptake of electric vehicles;
- Shifting passenger and freight transport from road and air to rail transport, expanding high-speed lines in the south of the country, upgrading cross connections and digitalizing logistics hubs.
- Initiating experimental activities for the use of low-carbon Hydrogen.

2.2 Key technologies of the energy transition

Technology evaluation criteria

The criteria that will be taken into consideration, in order to fully understand the potential contribution towards decarbonization of the alternative technologies, are: (1) GHG (Greenhouse Gas) emissions and local pollution associated with the production and use of the energy product/vector; (2) Technology maturity; (3) Economic and social costs (production costs, economies of scale, existing infrastructure, impacts on industry upstream and downstream, occupation).

1) GHG emissions and local pollution associated with the production and use of the energy product/vector

The impact of our energy-intensive activities possesses both a global and a local dimension. The global effect is determined by the emission of climate-altering greenhouse gas, in the form of carbon dioxide (CO_2) released by combustion of fuels, nowadays predominantly fossil fuels. The local effect consists of the air, water and land pollution determined by the emission of other contaminating chemical agents; limiting the observation to the transport sector, nitrogen oxides (NO_x) and fine particulate (PM_{10} and $PM_{2.5}$) are the main causes of air pollution, determining environmental and health hazards for the population of highly inhabited urban areas.

In 2019, the transport sector alone produced in Italy 25.2% of GHG emissions, and 30.7% of total CO2 emissions, 92.6% of which were entirely attributable to the road transport. Additionally, transport was also responsible for 40.3% of NOx emissions, 10.1% of PM emissions, and important quotas of other pollutants (i.e. carbon monoxide and non-methane volatile organic compounds). Specifically, due to having above-threshold emissions of NOx and PM, Italy has been under infringement procedure for violating the European directives (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

As the primary objective of the European Green Energy Transition is the reduction of global and local pollution, a crucial matter to address is the choice of emission calculation method. In this regard, some of the main arguments against the current decarbonization project, as described within the Fit For 55 package, revolve around the supposed unfairness of the TTW (Tank-To-Wheel) emission calculation method, which is deemed to be in violation of the technological neutrality principle. The alternative emission calculation methods suggested are WTW (Well-To-Wheel) and LCA-based (Life Cycle Assessment). As a general rule, there is an important trade-off to take into account: on the one hand, the requirement of having a relatively simple and easily comparable emission accounting methodology; on the other hand, the necessity to take into account all the emissions relative to the other phases of production, use and disposal of the vehicles and energy vectors/sources, which greatly complicates the analysis.

The 3 following emission calculation methods are listed in an increasingly higher complexity order, with each subsequent approach considering new aspects of emissions in addition of all those considered by the previous one (Centro Studi Fondazione Filippo Caracciolo, 2021).

Tank-To-Wheel method:

This approach to calculating emissions evaluates only those generated by the vehicle during its use, meaning, in practice, only the emissions that come out of the vehicle's exhaust. This is the reference European criterion to measure the compliance with emission standards, as well as for incentive plans definition and traffic limits setting.

Well-To-Wheel method:

In addition to the TTW emissions, the WTW approach accounts for all the emissions linked to the Well-To-Tank (WTT) segment of the energy vector/source lifecycle, including the extraction, refining & transformation, transmission & distribution and storage. Therefore, WTW = WTT + TTW. While certainly introducing complexity to the emissions calculation, by requiring consistent data collection and analysis about the WTT steps of the energy vector, this approach can unveil some emissions which can potentially completely offset the benefits/shortcomings of the energy vectors/sources resulting from the TTW approach. Some relevant examples are: the consideration of the emissions associated with the production of the electric and hydrogen energy vectors, which, although always CO2-neutral in a vacuum, in reality reflect accurately the sustainability of the energy sources with which they are produced; the increased sustainability of renewable low-carbon fuels, when considered in a circular economy perspective, as the emissions generated by their combustion are greatly offset by the emissions savings linked to the energy reuse of waste material destined to landfilling.

Life-Cycle Assessment method:

On top of the WTW's complete accounting of the energy vector/source's emissions, the LCA methodology also considers emissions linked to the entire lifecycle of the end appliance (in this case the vehicle). The LCA evaluation is also defined "cradle to grave", as it considers every step, from the extraction of raw materials to processing, manufacturing, assembling and useful life (also including maintenance) until either disposal or partial/total reuse of the materials. The main benefit is the complete consideration of the emissions associated to a specific transport technology, as the type of energy vector/source often determines the specific end appliances (for instance Internal Combustion Engine Vehicles – ICEV – versus Battery Electric Vehicles – BEV) and, in turn, raising questions over the efficiency, sustainability of production and use and ease of sourcing and disposal. The main drawback is that the LCA method requires a whole new set of hard-to-collect data, as well as a specific analysis for each different brand and model.

Notably, the Fit For 55 regulation for emissions of new cars and vans (-100% by 2035), currently based on a Tank-To-Wheel methodology, includes a provision to develop a common LCA emission accounting method by 2025.

EU position over emission calculation methods:

The CO2 emission standard regulation for cars and vans is based on a Tank-to-Wheel emission calculation methodology. The motivation behind this choice is that, since this regulation specifically targets car manufacturers, the emission-related processes in the energy vector's upstream, over which they have no influence, shouldn't be taken into account. As anticipated in the previous chapter, there is a clause in the approval of the review, in the form of a commitment to develop in a later moment a separate CO2 emission standard for e-fuel powered ICE vehicles. In fact, there is evidence that the impact of using this technology options results in net zero total emissions, being the amount of CO2 released at tailpipe level the same as the one captured from the atmosphere and used for the production of the fuel. Conversely, to the detriment of the Italian stakeholders, no similar clause has been yet provided for the Renewable advanced biofuels technology option, for which there are also valid claims of net zero impact on LCA basis.

If, on the one hand, the CO2 emission standard regulation aims at limiting the emissions from new cars, on the other hand, the Renewable Energy Directive contains the emission factors that are used to regulate the emissions from the currently circulating vehicle fleet. Compared to the CO2 emission standard regulation, the RED implements a different emission calculation method, this time considering a the emissions Well-To-

Wheel. The reason is that it is necessary to differentiate the feedstock for the production of renewable energy vectors (e.g. electricity, hydrogen, biofuels etc.).

Since 2003, the European Commission has described LCA as "the best framework for assessing the potential environmental impacts of products", identifying (COM(2003) 302: Building on Environmental Life-Cycle Thinking, 2003) the necessity to create a platform to help the development of a harmonized LCA methodology. Such platform exists ever since, called "EPLCA" (European Platform for LCA) (European Commission, 2003), and has supported several important research projects for the development of the official European LCA methodology. However, currently no official LCA-based emission calculation method exists in the EU Regulations. There are two main issues related to the LCA approach. First, there is little agreement about how to best model a LCA methodology, as many studies came out with different, often incompatible solutions. Second, the high complexity and limited data availability of this methodology creates issues in its application, making it a better tool for orienting policymaking rather than creating actual emission standards and caps (European Commission, 2020).

One thing that all the emission calculation methods listed above commonly lack from their environmental impact assessment is the local dimension of pollution. This tracking deficiency is often compensated by the inclusion of conversion factors (USEPA) to approximate the local pollution impact on air, water, soil, wildlife, etc., in terms of CO2 equivalent emissions. Nevertheless, the challenge associated with tracking the environmental impact of local pollutants represents one of the main arguments to oppose the uptake of some alternatives for the transport's decarbonization (e.g. LCFs, more details in the following paragraphs). The EU manages the limitations of local pollution from road transport with the Euro 6 regulation (COMMISSION REGULATION (EU) No 459/2012: Euro 6 , 2012), and the Euro 7 currently is being discussed. It is based on a TTW method, and sets the NOx and PM limits on car manufacturers. The targets of the Euro regulation are in line with the CO2 emissions targets, but the two regulations don't influence each other, since, in theory, they aim at achieving different objectives. However, some stakeholders have lamented the huge pressure put onto the car manufacturer to comply with the standards of both regulations, being obliged to maintain cutting edge ICE technologies, while at the same time planning their phase out by 2035, to achieve -100% CO2 emissions (RIE & Unem, 2022).

2) Technology maturity

When dealing with the different options in terms of potential technologies for decarbonizing the transport sector, it is essential to consider their state of development, as it greatly influences the feasibility of their inclusion in any decarbonization scenario. Typically, the approaches to assess the technological maturity are qualitative.

Although there is currently no official European method to assess the technological maturity, the Commission has been encouraging since 2014 the implementation of the TRL (Technology Readiness Level) tool, as part of the 2020 Horizon funding program (APRE & CDTI, 2020). The TRL model was originally created by NASA in 1990 to assess the maturity of a given technology from the basic research up to the systemic market commercialization. It is based on a 9-point scale, with each subsequent level increasing the scientific feasibility, technological feasibility, technological reliability and commercialization readiness. In reality, all the technology options considered in this thesis have either already been commercialized at systemic scale, or are potentially close to be.

Another useful proxy to understand a technology's maturity is simply to look at its cost development curve, especially in terms of TCO (total costs of ownership), as usually lower costs are determined, among other factors, by the realization of economies of scale and learning, which are possible only when the technology is fully mature and commercialized.

3) Economic and social costs

The last set of considerations regards the economic and social costs linked to the adoption of a specific technology. Whereas the previous two criteria (emissions and maturity) could be easily generalizable to any geographical context and application, the effects on the economic and social environment vary greatly according to where and how the technologies are used. Coherently with the national focus of this work, to correctly assess the economic and social costs of decarbonization-enabling technologies, a specific consideration of the Italian transport industry, in terms of its characteristic, competitiveness, occupation, added value, and related upstream and downstream industries, must be given.

One of the key points around which unfolds the discussion over the energy transition, is the matter of driving the economic growth along with a transition towards sustainable energy. Some of the technologies for decarbonizing the transport sector do, in fact, imply more deeply disruptive effects on the current industrial equilibrium, naturally causing open resistance to the strict technology subgoals included in the current decarbonization scenario. One of the main concerns justifying the resistance to this radical change is based on the assumption that us, Europeans, as first movers in the energy decarbonization, have the responsibility of demonstrating to the rest of the world that switching to clean and renewable energy is good both for the environment and for the economy. Only by maintaining our competitiveness in the international markets we will convince the other countries to follow this path to preserve our life on Earth, as our institutional strength and bargaining power are closely tied to our industrial robustness. On the contrary, sacrificing our painstakingly built industrial patrimony to pursue poorly planned environmental policies will only determine carbon leakage and welfare loss, while the global emissions will keep rising. However, no person, company or institution today can affirm with certainty which strategy will be the most efficient in achieving both the environmental and economic sustainability goals, a condition which holds true for both sides of the ongoing discussion. In truth, the European decarbonization pathway is not poorly planned, but rather a very complex set of actions pursuing multiple objectives at once and holding internal coherence based on the interdependencies among its policies. However, it also implies very restrictive measures which inevitably spark resistance and to which there are multiple viable alternative decarbonization plans.

As the change in the composition of the EU-wide fleet of new cars and vans will be the main driver for the social and economic impacts, the European Commission considers (SWD(2021) 613: CO2 Standards Impact Assessment, 2021) the following categories as primarily impacted by the CO2 emission regulation review:

- Net economic savings from societal and end-user perspectives (namely, difference of the total costs between the policy options and the baseline). The total costs include the capital costs, the fuel or electricity costs, and the operation and maintenance (O&M) costs of the vehicles. For the societal perspective, they also include the external cost of CO2 emissions.
- Costs for automotive manufacturers (namely the difference, between the policy options and the baseline, of the manufacturing costs).
- Energy system impacts: links between the CO2 standards for cars and vans and the energy system, also considering the links with the revision of the EU ETS as well as the Energy Efficiency and Renewable Energy Directives.
- Investment in alternative fuels infrastructure (recharging and refueling infrastructure).
- Macro-economic impacts, including employment.

<u>The technology options for phasing out fossil fuels and achieving the current decarbonization targets</u>

At European level, domestic transportation accounts for 21 percent of EU emissions, 60% of which comes from passenger cars, 25% from heavy-duty trucks and buses and 10% from light-duty trucks, with the remaining 5% being emitted by railway, marine, and aviation (McKinsey & CO, 2020).

Road transport in Italy today is almost entirely based on internal combustion engines (>99%), mainly fueled by gasoline, diesel, LPG (Liquified Petroleum Gas) and compressed methane (CNG, Compressed Natural Gas) (ANFIA). In terms of available alternatives to the traditional ICE, the technologies most frequently employed are:

- HEV (Hybrid Electric Vehicles), which use both an internal combustion and an electric engine, with a battery back that only recharges during the use of the vehicle (e.g. during breaking);
- PHEV (Plug-in Hybrid Electric Vehicle), variant of the regular HEV, which enables the user to recharge the battery pack directly connecting it to an electric socket;

- BEV (Battery Electric Vehicles), 100% full electric vehicles with no combustion engine, requiring to be recharged at an electric socket;
- FCEV (Fuel Cell Electric Vehicles), also full electric vehicles powered by an Hydrogen fuel cell.

There is also the possibility, for traditional ICEs, to run on alternative Low Carbon Fuels, like LNG, biofuels, synthetic fuels, recycled carbon fuels and hydrogen, with varying degree of needs for adaptation measures (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

<u>Renewable Electricity</u>

According to the European path to decarbonization, as envisioned in the Fit For 55 plan, the electricity vector will be the main decarbonization driver, by coupling the electrification of end uses to the decarbonization of power generation. This process favors the uptake of RES (Renewable Energy Sources), benefitting, within the Renewable Energy Directive, from the highest decarbonization-contribution "multipliers", which exist "in order to ensure that the positive impacts of electrified renewable energy-based transport are properly accounted for" (DIRECTIVE 2018/2001: Promotion of the Use of Energy from Renewable Sources (Recast), 2018).

Electricity, as a vector, always delivers clean, emission-free energy to end uses. However, its actual environmental sustainability depends entirely on how it is generated. In the past decade an impressive drop in the cost of RES has taken place, most notably regarding wind-power and photovoltaic, which are now essentially cost-competitive even without any public incentive (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022). In 2020, Europe exceeded its renewable energy target (COM(2010) 639: Energy 2020, 2010) of 20% (of electricity produced from RES), reaching a promising 22.1% quota, followed by a slight decrease the next year, likely due to the effects of the Covid pandemic.

Two main benefits are generally associated with the use of renewable electricity in the road transport sector:

1. *Emissions reduction*. A 100% electricity-powered BEV produces 0 emissions at tailpipe, making it one of the very few available options for car manufacturers to comply with the CO2 standard regulation's emission cap, which is calculated with a Tank-To-Wheel methodology. Coupling this with the uptake of RES in power generation (as stated in the Renewable Energy Directive), effectively allows Net Zero Emissions for transport, even from a Well-To-Wheel perspective. Another relevant upside in terms of environmental sustainability is the reduction, up to 30% (McKinsey & CO, 2020), of locally polluting emissions (NOx, SOx, combustion-related particulates (Confindustria & ANFIA, 2019)), improving the air quality of highly populated urban areas, making the electricity vector able to also comply with the Euro 6 (soon to be Euro 7) regulation. According to the Commission's impact assessment (SWD(2021) 613: CO2 Standards Impact Assessment, 2021), considerable cumulative costs of pollution, including health effects, crop losses, material and building damage as well as biodiversity loss (European

Commission, 2019), could be avoided by progressively increasing the EV penetration target in road transport.

2. *Increased energy efficiency*. “Decreasing fuel consumption is crucial to afford a long-term supply, given the resource constraints to sustainably produce all fuels” (Gorner et al., 2023). The currently circulating vehicle fleet, almost entirely based on ICEs, is highly energy intensive, with an average operating energy efficiency of around 20-25% for cars, something that represents an important obstacle for the achievement of -55% by 2030. In this regard, BEVs can greatly increase the energy efficiency of road transport, up to +300%. This implies also a further reduction of emissions: even with the current limited penetration of RES in Italy’s energy mix, the substitution of ICEVs (Internal Combustion Engine Vehicles) with BEVs can translate into a reduction of -50% emissions from road transport (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Beside these two key benefits of electrification of transport, which are mostly agreed upon, there are several other impacts and key enablers over which there is still much debate. The main uncertainties involve: *production scale up & development of public and private recharging infrastructure; public investment needs; LCA emissions; battery development and reuse; geopolitical impacts, dependencies and sourcing security; costs for users and manufacturers; international competitiveness & innovation; energy system impacts; GDP and employment impacts.*

In terms of **production scale-up issues**, research highlights that “scaling supply chains that could support the transition to 100 percent EV sales, from mining the raw materials for batteries to assembling EVs, is at least a decade-long process” (McKinsey & CO, 2020).

One of the main concerns linked to the scale-up regards the **development of public and private recharging infrastructure**. A study conducted by Confindustria and ANFIA (Confindustria & ANFIA, 2019) identifies, as one of the weaknesses of the electricity vector, its dependence on the development of public and private charging points, which may constrain the natural growth of the EV market.

The European Commission’s “CO2 emissions regulation impact assessment (SWD(2021) 613: CO2 Standards Impact Assessment, 2021)” considers the “Investment in alternative fuels infrastructure” as one of the economic dimensions most impacted by the increase of emissions target level. The definition of a common framework for the roll-out of public infrastructure constitutes a “key barrier to the market uptake and customer acceptance of zero-emission vehicles and hence an indispensable corollary to the roll-out of zero-emission vehicle fleets”. Such definition is regulated by the revision of the Alternative Fuels Infrastructure Directive (COM(2021) 559: Alternative Fuels Infrastructure Directive (AFID), 2021).

A public cost forecast (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022), estimated about 3bln€ worth of **public investment** by 2030, required to install 200’000 public charging stations, based on an hypothesis of 3.6 mln private (domestic or corporate) charging points already available. The report also highlights a critical bottleneck in the deployment of public infrastructure emerges in suburbs and historical city centers, where houses often lack private garages. The only viable solution in these contexts may be upgrading public and shared mobility.

From an environmental sustainability perspective, although there is almost no doubts that renewable electricity-powered EVs are 100% carbon neutral, both from a TWW and WTW perspective, the debate is still open when a full **LCA evaluation of emissions** is considered, including the mining and disposal steps of the vehicle and energy vector's product life cycle. A report published by the European Commission's Climate Action DG (European Commission, 2020) shows that EV powertrains have significantly lower GHG and local emissions compared to other vehicle types, through a full LCA analysis. BEVs (full-electric) emerge as the best option, although their environmental impact varies according to factors such as the use of particular materials, as well as regional and operational circumstances, namely electricity generation mixes, urban/rural/motorway road driving shares and climatic conditions. Similar conclusions are drawn by other authors (Gorner et al., 2023; Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

One specific concern emerges in all the aforementioned publications, regarding the issue of **batteries sourcing and disposal**. Battery re-use and recycling is considered a substantial opportunity to improve the environmental and economic sustainability of EVs, due to the expensive "rare earth" raw materials required to produce them (primarily Lithium, Nickel and Cobalt). These resources have significant **geopolitical implications**, as they induce significant structural changes in the sourcing chains and international dependencies (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022), with the South-Eastern Asian countries playing today an almost monopolistic role, for the greatest share of exports worldwide. The mining and disposal processes of rare earths have important consequences on both the economic (circular economies may help reducing international dependencies) and environmental dimensions (these processes still require research in order to fully assess their emissions). Finally, the challenges linked to the batteries require adequate public intervention to be dealt with. So far, the most relevant EU initiatives in this area have been the following: European Battery Alliance, a co-founded organization aimed at developing a European domestic battery value chain; European Raw Material Alliance a co-founded organization aimed at developing sustainable and resilient sourcing chains; Critical Raw Material Act (COM(2023) 160: Secure and Sustainable Supply of Critical Raw Materials, 2023), a proposal for a regulation aimed at international sourcing dependency to no more than 65% of the EU's annual consumption from a single third country.

Regarding the subject of **costs**, the Commission's impact assessment (SWD(2021) 613: CO2 Standards Impact Assessment, 2021) uses the TCO (Total Cost of Ownership), as opposed to the mere purchase cost, as a proxy to analyze the cost competitiveness of EVs, compared to traditional ICEVs. The TCO includes both the initial investment of purchasing the vehicle (CAPEX), and the cost of owning, using and maintaining it (OPEX). From this point of view, the analysis shows that higher levels of penetration of zero-emission vehicles (EVs and FCEVs) correspond to higher consumer benefits. The main explanation is that the savings in fuel expenditures during the EV's life cycle offset the higher upfront costs. Additionally, lower income segments of the population are expected to experience higher savings relative to their annual income. However, to enable the purchase by these low income groups, access to more efficient vehicles and to the second-hand market is required.

The STEMI report (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022) highlights that the competitive advantage (in terms of TCO) of electrified mobility is dependent on the availability of low-cost electricity production, as well as the optimization of batteries, the most expensive component of this mobility option. According to some studies (IEA, 2018; LeasePlan, 2021) the TCO per Km is today already competitive in BEVs with high utilization profiles, provided that electricity prices (and their price differential against fuels) and battery prices are not subject to unforeseeable future spikes. The inclusion of potential public incentives determines price parity even for the average vehicle utilization profiles in the EU. Electricity prices vary substantially among EU member states, therefore, as highlighted by McKinsey (McKinsey & CO, 2020), the transition must take into account the greater challenges faced by some countries, due to higher electricity prices and higher secondhand cars imports. Regarding the high cost of batteries, further cost reduction is likely to occur, considering the stable long-term cost reduction trend of the past years: today the price of batteries is 80% lower than 10 years ago. An interesting observation is linked to the dimension of the EVs, as the cost of batteries is greatly more incisive on the final price of lighter cars, as compared to heavier ones. (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022)

According to the Commission's impact assessment, "the costs for manufacturers increase with stricter CO2 emission targets" (which involves higher penetration of EVs). This inevitably imposes grater investments mobilization, on which depends the ability to achieve the ambitious emissions reduction targets. Interestingly, as noted by the EC, the drive towards the development of zero-emission vehicles is, in many cases, already present in the manufacturers' future plans, motivated by their spontaneous willingness to gain high market shares. A key policy enabler is to match the private investments with public infrastructure investments, in order to abate an important market-side barrier to the adoption of zero-emission vehicles.

In terms of **innovation and competitiveness**, one of the key factors that support the validity of EVs as the quickest and most effective solutions to decarbonize the transport sector is the opportunity to integrate BEVs in smart networks thanks to IT technologies (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022). This opportunity enables electrified mobility to be associated with another dominant international trend, namely the mobility-as-a-service trend, a key sector of future mobility, to which car manufacturers link a great part of their future competitiveness. According to the Commission's impact assessment (SWD(2021) 613: CO2 Standards Impact Assessment, 2021), the deployment of zero-emission vehicles, incentivized by the decarbonization targets, will have a positive impact on innovation, with stricter CO2 targets (and faster deployment of EVs) being associated to market certainty and much required long-term signals for car manufacturers to innovate. From an international perspective, innovation in zero-emission technologies strengthens the leadership of the EU automotive value chain.

As regards to the **energy system impacts**, the Commission's impact assessment maintains that "Under the baseline, demand is projected to increase in 2025. From then on, it is projected to decrease over time as vehicles meeting the CO2 targets set in the current Regulation enter the fleet". With higher penetration of zero-emission vehicles, "final energy demand decreases further and the effects of the more stringent CO2 targets for cars and vans become more outspoken from 2035 on, resulting in more drastic decline of energy demand." However, mismatch between demand and supply in the electricity market is an important threat to the full electrification scenario, which may require further technological developments and additional investments, incrementing the total cost of the electrification pathway (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Finally, although the European Commission is generally rather optimistic with regards to the impacts of the CO2 regulation on **GDP and employment** (SWD(2021) 613: CO2 Standards Impact Assessment, 2021), these topics are highly discussed with little agreement among the stakeholder, many of which are very worried about the potentially dramatic consequences for national value chains and workforce.

These paragraphs concerning the most debated aspects of mobility electrification are complemented, within this thesis project, by the interviews conducted with the main Italian stakeholders in the energy and mobility industries, reported in the Appendix.

<u>Low Carbon Fuels</u>

Under the Low Carbon Fuels (or LCFs) label falls a wide variety of combustible fuels of biogenic or synthetic origin. LCFs include, therefore, multiple products with different potentials for decarbonizing transport, being diverse in their environmental impact, stage of technological maturity and socio-economic implications. LCFs generally share the valuable quality of being easily implementable in the current energy system, as they "can be blended with petroleum-based fuels, combusted in internal combustion engines, and distributed through existing infrastructure, subject to exemptions" (IEA Bioenergy, 2023).

According to their main feedstock and technologies for production, they are categorized in the following types:

Classification based in IEA's Definitions (IEA Bioenergy, 2023)

1) Conventional biofuels – Technologically mature and commercially available, conventional biofuels are produced with sugars, starches, oil bearing crops and animal fats as main feedstocks, often raising the issue of land and food competition. Some niche conventional biofuels, such as Biogas, have been

derived by anaerobic treatment of manure and other biomass materials, greatly increasing their sustainability (bio-Methane, bio-LNG).

2) Advanced biofuels – Advanced biofuels can be produced from waste materials, stalks of wheat and corn, wood and dedicated energy crops. Many technologies are included in this type of LCFs, such as cellulosic ethanol, biomethanol, DMF, bio-DME, Fischer-Tropsch diesel, mixed alcohols and wood diesel, which range from lab-scale to commercialization stage of maturity. The Advanced biofuels refined from organic waste material (biogenic or OFMSW) are highly sustainable both from a resource-oriented and a emission-oriented perspective, due to their great contribution to circular economies.
3) Synthetic biofuels – synthetic advanced biofuels can be synthesized from gases made by thermal gasification of biomass, e.g. Fischer-Tropsch fuels (also named BtL – Biomass-to-Liquid), Synthetic Natural Gas (SNG) produced thermochemically, and DME.
4) E-fuels – Elecro-fuels are fuels based on electricity, which is required as an energy input to perform the electrolysis of Hydrogen. H2 is then blended with CO2, thanks to Carbon Capture, Utilization and/or Storage (CCUS) technologies, to produce a synthetic biofuel. While, on the one hand, their high performance in terms of carbon dioxide emissions is renowned, as well as their ability to use the existing logistic infrastructure, on the other hand, it will take a long time to build the necessary economies of scale upstream in the production phase. Therefore, although the implementation of e-fuels is going to greatly contribute to the decarbonization of light and heavy transports, it will only realistically happen in the long term, to reach the 2050 net zero objective.

Other relevant LCF technologies include: Algal biofuels, Hydrogen from biomass and Recycled Carbon Fuels (obtained from unsorted waste and plasmix, unable to be reprocessed through chemical recycling).

Four different generations (1G, 2G, 3G, 4G) of biofuels have been developed during the last 2 decades, differentiated by their feedstock and processing technology cost and sustainability level (Darda et al., 2019).

Food carbohydrates, vegetable oils, and animal fats are used in the production of first generation (1G) biofuels, including biodiesel and bioethanol. The cultivation of plants intended for the production of biofuels, which requires large amounts of soil, water, and chemical fertilizers, has raised concerns about sustainability for the environment and biodiversity over the previous ten years (2005–2015), in addition to conflicts with the production of food and feed. These led to a decrease in the production of 1G biofuel, and attention turned to other options.

By obtaining a greater decrease in GHG emissions, agricultural residues, sometimes referred to as lignocellulosic materials, can create more sustainable biofuels (2G biofuels). However, while integration with current industrial infrastructure might help to reduce costs, its commercialization necessitates favorable regulatory support, continuous technological advancement, and/or higher fossil fuel pricing. In comparison to 1G biofuels, 2G biofuels produce greater product yields, as well as higher profits. However, due to the high capital expenses and extended time frame needed for the feedstock cultivation, project investments and cost projections suggest more risk and uncertainty for 2G biofuels. It is still questioned what impact 2G biofuels have on the environment. Even if the carbon emissions are deemed acceptable, the occupation of significant amounts of land hinders the 2G biofuels' sustainably on a large production scale.

Due to the decreased direct or indirect use of land, water, and no use of pesticides compared to earlier generations of biofuels, microalgae are a viable feedstock for delivering biofuels (3G) and other bio-products in the near-to-medium term. Algae may be cultivated and grown in open water, shallow lagoons, or specific manmade ponds, called raceway ponds. The water necessary for their production may be obtained from sewage and wastewater. However, the combination of algae production and wastewater treatment is connected to high capital expenditures and high energy needs, which raises questions about the scalability of industrial production. According to Life Cycle Assessment (LCA) research, the production of biofuels from algae-biomass may either be energy-efficient with low carbon emissions, or it might be energy-demanding with high emissions like the production of fossil fuels.

4G biofuels are based on the development of metabolic engineering practices, aiming at modifying the specific properties of different types of feedstock, to enhance the desired characteristics. Although, compared to 3G algal biofuels, the economic viability is higher, 4G introduce the risk of hazardous biologic side effects that could harm the environment. 4G biofuels also refer to the portion of biofuels produced from food waste, which greatly reduces the costs and increases the sustainability and affordability of the product. However biofuels generated from organic wastes have limitations despite their low-cost feedstock, due to expensive and energy demanding production, and unsystematic waste accumulation methods.

As regards to biofuels from dedicated crops, the most consolidated national value chains are the production of bioethanol in the United States (mainly from corn) and in Brazil (from sugar cane), and the production of biodiesel in Indonesia (from palm oil), United States, Brazil and, on a smaller scale, in Europe (from alternative vegetable oils) (BP, 2021). The net energy gain of the process is debated, as well as LCA emissions abatement, due to high energy consumption in the upstream of the value chain (sowing, fertilization, irrigation, harvest, transport and production). Furthermore, the energy efficiency is very low. The energetic, economic and environmental sustainability of this type of biofuels is highly dependent on the geographical and climatic circumstances, and even in the most suitable contexts, they imply dangerous indirect effects, like the deforestation practice (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Conversely, biofuels from waste (especially waste cooking oils and waste animal fats) are very effective in abating GHG emissions and reducing impacts on food prices and land use change. Similarly, second generation biofuels derived from lignocellulosic resources (agricultural and sylvicultural waste) have a reduced environmental footprint. However, these biofuels are subject to substantially higher production costs. The listed downsides suggest, according to some studies (Ministero delle infrastrutture e della mobilità sostenibili

(Mims), 2022), a greater efficiency of electrification as a solution to abate emissions in the transport sector, therefore implying that the use of sustainable biofuels, available in limited quantities, should be prioritized in Hard-To-Abate sectors. Nevertheless, the RED includes a partial use of biofuels in light-duty transport as well, which pairs well with the considerable investments in the development of biorefineries in Italy done so far.

Synthetic hydrocarbon fuels (synfuels) necessitate, in order to achieve increased sustainability, sustainable and convenient sources of both hydrogen and carbon. To reduce costs, the production facilities of synfuels and those of decarbonized molecular hydrogen should be located nearby, in order to minimize T&D costs. The technologies for the direct collection of CO2 are still in the early maturity stages, implying high costs and high renewable energy inputs, as well as the development of high production capacity, which, at the moment, constitutes a key barrier for the uptake. The "Fischer-Tropsch" process is today the most promising path to produce liquid synfuels. Due to the significant production barriers, the solution might be valid only when the production plants are located in areas with easy access to low-cost renewable energy, and limited to sectors where other energy vectors meet difficult application challenges (HtA) (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Upsides and potential threats

According to a study conducted by Rie and Unem (RIE & Unem, 2022), LCFs are associated with several advantages, including:

- Significant reduction of CO2 emissions over their life-cycle, compared to fossil fuels, which varies in relation to the feedstock, up to net zero emissions;
- Option of being used in almost any kind of transport, essential in decarbonizing hard-to-abate sectors;
- Immediate applicability in the existing vehicle fleet, along with immediate positive environmental impact;
- Safeguard of the national value chains linked to the use of the Internal Combustion Engine (ICE), which is able to comply with the EU emission caps thanks to the LCF use.
- Promotion of the Italian refining industry and infrastructure, which, after some upgrading and updating intervention, could be used for the production of LCFs, without the need of greenfield investments.
- Ease of storage and distribution, compared to other alternative energy vectors/products.
- Mainly national value chains, with little reliance on foreign imports, addressing the energy sourcing security issue.
- Safeguard of the workforce, as the main competences can be easily repurposed.

Potential threats:

Several studies have identified potential bottlenecks and downsides associated to the production and use of biofuels. It is important to note in advance that these doubts still require much research in order to be definitively answered, as the biofuel technology is a relatively new option and rapidly evolving into different potential energy vectors.

"Food-energy-water nexus challenge" (Darda et al., 2019):

The so-called Food-Energy-Water nexus connects food, energy, water and climate to the global economy in terms of complex systems, factors between which the interaction has become critical, raising concerns over sustainable development and sourcing security. This issue regards in particular 1G and 2G biofuels, namely those that tend to compete, in terms of feedstock, with food and feed uses.

1G biofuels from food crops impact nexus resources in terms of land, food, water and fossil energy, required during cultivation and processing. Considerable amounts of soil and energy are also required for the production of 2G biofuels. From a market and industry perspective, successful Food-Energy-Water nexus projects need a transdisciplinary approach, ecological technology practices, and sustainable supply chains.

"Carbon-nitrogen nexus challenge" (Darda et al., 2019):

One important issue with biofuels is the carbon-nitrogen nexus, for which there is a trade-off between a low Carbon (CO2) and low reactive nitrogen (Nr) emissions footprint. Biofuels usually have lower Carbon footprint and higher nitrogen emissions due to intensive farming processes, while fossil fuels have a high CO2 footprint and lower Nr emissions. However, some cases such as low farming inputs switchgrass (2G) and low intensity high diversity grassland-based biofuels (2G), or waste feedstock (4G), (for example municipal solid waste-based biofuels), have low CO2 and Nr footprints, making them better options for transportation fuels.

Local emissions related to NOx and PM:

Another relevant issue is that, despite the application of the most optimistic emissions accounting methods, correctly assessing all the GHG emissions savings, in the form of CO2, LCFs will always perform worse than Electricity or Hydrogen in terms of emissions of local pollutants, especially when it comes to NOx emissions. This limitation is inextricably linked to all the combustion fuels. However, local pollutants emissions are moderated by the type of ICE, with more recent types (according to the Euro regulation) greatly reducing the PM and NOx. (Confindustria & ANFIA, 2019)

Biomass Availability:

Due to the ecosystem's limited capacity to supply bio feedstocks, biofuels are facing sustainability issues (Liu et al., 2018). However, although the scientific community agrees upon the critical nature of this issue, there is little agreement upon whether the quantity of sustainable feedstock is able to satisfy the current and future demand in Europe.

On the one hand, some researchers are concerned by the huge amounts of bio resources required for large-scale biofuels production (Darda et al., 2019). The STEMI report maintains that biofuels and synfuels will be available in limited quantities, due to limited sustainable biomass system capacity. Therefore, in order to optimize the future energy system, these vectors should be limited as a priority to the hard-to-abate sectors, for which there is currently no other better solution in terms of environmental and cost performance (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

On the other hand, there are studies (Imperial London College Consultants, 2021) which confirm the availability of all the sustainable biomass for fuels production required in Europe, both for the short, medium and long period, even after accounting for all the demand in non-energy sectors, as well as limiting the observation with the biomass which doesn't compete with food and feed, and doesn't compromise biodiversity.

Ultimately, there is no uncontestable answer by the scientific community at the moment to this problem. therefore, further research is required.

Low energy efficiency:

As previously highlighted when addressing the electricity vector, the ICE in general has considerably lower energy efficiency than the electric drivetrain. Furthermore, "alternative fuels, ethanol, MTBE and specially bio-ETBE routes show a higher energy use than traditional fossil fuels (up to a factor of 2 in the case of bio-ETBE)" (Prussi et al., 2020). Additional downsides in terms of energy efficiency are associated to gaseous energy vectors, since they require high pressure/low temperature storage solutions in order to ensure enough energy density to transport systems (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Gas flaring:

Gaseous vectors imply one more concern, which threatens their performance in terms of environmental sustainability. Gas flaring events, i.e. leaks of gas during transmission & distribution, imply potentially very high environmental footprint, which, when taken into account, risks to substantially deteriorate the sustainability profile of biogases (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Hydrogen

Hydrogen is an energy vector rather than an energy source, meaning that its production, which can happen in different ways, requires an equal or greater energy input than its yield, making the final product reflective of the CO2 emissions of its energy source. For this reason, 3 types of H2 have been identified, according to its production method, and associated environmental impact.

1. Grey hydrogen – The least environmentally friendly option, grey hydrogen is produced via Steam Methane Reforming (SMR), using the combustion of fossil fuels as the energy input, which results in major Carbon dioxide emissions, along with the release of other polluting gases. Grey H2 is the option

most widely produced today, being relatively cheap and technologically mature. However, due to its high emissions, it will unlikely contribute to the future decarbonization in any sector.

2. Blue hydrogen – Blue hydrogen is produced the same way as Grey Hydrogen, however, it also includes the use of Carbon Capture & Storage (CCS) technologies, to reduce the emissions linked to the use of fossil fuels for its production. The issue is that this option puts critical pressure on the CCS technology, from which depend both the successful capturing of CO2 emissions, and the successful storage of it, which, as of today, has not yet reached technological maturity, due to high costs and potential safety concerns.

3. Green hydrogen – By far, this is the most promising option in terms of potential contribution to the decarbonization pathway. Green hydrogen is produced by using renewable energy sources, mainly via electrolysis, which makes an exceptional opportunity to use and store the exceeding production linked to non-programmable renewable energy sources. Additionally, options to produce green H2 via thermo-chemical processed biomass and organic wastes are being developed, ensuring additional productivity, scalability and circularity in addition to the reduction of emissions (RSE & ANIE, 2023). While green hydrogen is the best means for decarbonizing certain areas (e.g. HtA), it is also, unfortunately, the most expensive and least mature option, requiring massive financial investments and policy coordination to ensure its successful implementation.

Regarding its potential applications, plans for investing in hydrogen have been included in one of the EU Parliament's resolutions (P9_TA(2021)0241: A European Strategy for Hydrogen, 2021) and confirmed in Italy within the PNRR, allocating over 3 billion euros. Hydrogen is considered very useful in dealing with two main issues of the European decarbonization path:

1) To ensure balance within a renewable electricity-driven energy system, Hydrogen can enable the matching between energy supply and demand in the real-time markets, while also providing the necessary back up to non-programmable renewable energy generation, which suffers from seasonality of production. This use is the so-called "power-to-gas", which allows the "sector coupling of electric and gas grid, acting as an energetic buffer and increasing the resilience of the electric system".

2) To decarbonize HtA sectors (i.e. Heavy industry and heavy transport), where Hydrogen has the ability of burning at extremely high temperatures and be stored with relative ease, something that electrification cannot achieve. Although, compared to fossil fuels, the fixed and variable costs of producing green hydrogen are orders of magnitude higher, its unique application in HtA sectors justifies the price premium, making the investments more financially reasonable. Additionally, because the financial feasibility of green hydrogen largely depends on the high cost of electrolyzers and

renewable electricity, the foreseeable increase in demand of both, and eventual development of economies of scale, will greatly impact its price, driving it down.

Within the private road transport, beside its use to synthesize e-fuels, Hydrogen, preferably green, can be used directly in Fuel Cell Electric Vehicles (FCEV or HFCEV). FCEVs are full-fledged Electric Vehicles, powered by an electric engine and a battery (considerably smaller than a BEV battery). The fuel cell converts H2 (fueled by charging stations) and O2 (taken from the air) into electricity, producing concurrently heat and water. Very few FCEV models are currently available on the market, partly due to the very scarce presence of public hydrogen charging stations (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

FCEVs are comparable to Battery Electric Vehicles (BEV) in terms of CO2 emissions, both from a Tank-To-Wheel, and from a Well-To-Wheel perspective (Confindustria & ANFIA, 2019). They have greater range and reduced recharging time, compared to BEV, however, the technology is in its very early development stages, meaning the costs are extremely high and massive investments are required in both production and distribution. Additionally, there are still some important technical limitations, including, but not limited to: low energy efficiency in the charge-discharge cycle; prohibitively high cost of storage, specifically for longer periods; concerns over the safety of geological storage; the “Hydrogen embrittlement” issue, which makes some steel alloys unfit for the construction of FCEVs; safety concerns linked to the non-visible flames of hydrogen combustion and odorless nature of H2 gas; low service life of fuel cells, and quick loss of performance; higher NOx emissions compared to BEV. Finally the low competitiveness of hydrogen pricewise makes its deployment in road transport dependent on incentive policies, which, given the current regulatory framework, determines that BEV are more convenient.

For these reasons, although very promising, the use of hydrogen in road transport in any significative amount will be feasible only in the long term, therefore not being counted as an option for achieving the 2030/2035 decarbonization targets for road transport. However, it is expected that Hydrogen valleys and clusters, centered on industry, will play a crucial role for renewable hydrogen. These can minimize infrastructure costs while leveraging lower production costs compared to e-fuels (Gorner et al., 2023).

2.3 Key stakeholders in the energy transition

The achievement of the European decarbonization targets implies a radical transformation of the current energy system, from the energy production, all the way to the end appliances. A revolution on such a scale naturally implies considerable resistance among all the stakeholders which see their interests endangered by the energy transition. According to the “Diffusion Of Innovations” theory (Everett Rogers, 1962), resistance to change is a natural part of the diffusion process.

While, at this point in time, every stakeholder is more or less aligned on the objective of Net Zero Carbon emissions, the true battle is fought over which technology option (and, more generally, which policy approach, between technology neutrality and technology specificity) can achieve the environmental target with the least negative socio-economic impacts. Both of the two main parties, namely the electricity and EV industry, and the low carbon fuels and traditional ICEV industry, aim at promoting the technology which, in their mind, is most successful in minimizing socio-economic costs and preserving, or even improving, the competitive positioning of the European industries in the international arena.

The assumption that the transition toward fully electrified light-duty road transport represents today the most ambitious and disruptively innovative path toward decarbonization, is an opinion that seems to be shared by both parties. Therefore, from now on, within the context of this thesis, the electrification of transport option will be regarded as the most “risky and innovative” path to Carbon Neutrality. Since this option is also currently promoted by the EU through legal obligations (COM (2021) 556: CO2 Standards for Cars and Vans, 2021), the resistors to change (or, at least, to the most disruptive form of change) will be identified in the fuels and ICE vehicles producers, promoting a more “conservative and low-risk” approach. Although the two alternative decarbonization paths considered vary substantially between themselves, both present strong opportunities, as well as challenges, for which, as of now, there is no clear definitive answer. Additionally, while the two competing sides of this debate have different objectives and requirements, strictly preferring their option over the alternative, there seems to be a third potentially occurring scenario which is the least favorable outcome for both parties: decisional instability. In fact, given the wide scope of the European decarbonization project, which in both cases requires massive long-term investments from private and public actors, a long tug-of-war decisional game, in terms of European regulation, implies detrimental effects on both parties, by reducing the investors’ confidence and threatening the early adopters who have already put in place considerable investments.

To have a closer, deep-dive look at the aforementioned debate over the best decarbonization path, this thesis conducted six interviews with subjects that were considered as the main stakeholders, the most well-informed about the ongoing debate. The interviews include opinions from representatives of: Enel and ENI (the two most important Italian utility companies), Elettricità Futura and Unem (the two most important Italian associations of energy producers), and finally Motus-e and ANFIA (the two main industry associations representing Italian vehicles producers).

Enel, Elettricità Futura and Motus-e represent the side promoting full electrification of road transport, in line with the current European trajectory (highly technology-specific); ENI, Unem and ANFIA represent the side promoting an alternative approach, driven by technology-neutral policymaking, and envisioning a more contained electrification of transport, accompanied by higher penetration of Low carbon fuels, allowing to preserve the ICE value chain. The interviews conducted for this thesis are fully reported in the appendixes.

3. Methods

To answer this thesis' Research Question, namely "which policy-making approach is more efficient in enabling the European energy transition plan for transport, in relation to the normative, technological, economic and social landscape in Italy?" the analysis will employ the framework developed by Agora in 2020, known as "Technological Neutrality and Technological Openness", utilizing, as its inputs, the qualitative observations collected in the theory chapter and thanks to the interviews.

Originally created to analyze Germany's climate policy efforts to achieve the European GHG emissions reduction targets in the transport sector, the study analyzes "how the transition to low-emission drive trains and energy sources should be addressed in regulation". A key assumption of Agora's study is that, "when it comes to the decarbonization of road transport, there's no way around state intervention". The reason is that market prices aren't fully able to convey the environmental impacts of traditional fuels use, for instance with reference to local air pollution effects.

In 2020 (year of publication of Agora's study), the positions of German stakeholders were comparable to those of Italian stakeholders in today's debate, with the central topic of the discussion being *technology neutrality*. According to the study's definitions, technology neutrality of regulation consists of two dimensions. First, "a perfectly neutral regulation intervenes directly at the level of the predefined policy objective (such as the reduction of greenhouse gas emissions), while granting as much leeway as possible on subsequent levels (e.g., in the individual sectors) and abstaining from further downstream climate regulations". Second, "it does not discriminate among individual technologies. Instead, it leaves the choice between technologies to private actors", with the assumption that these actors have a better economic and technical understanding of the alternative technology options, allowing decentralized market-based decisions without state interventions to yield a social cost optimum. The more a real-world regulatory design deviates from these prerequisites for perfect technology neutrality, the more it becomes *technology-specific*. However, as the study makes clear, the concepts of *technology neutrality* and *technology specificity* are the extremes of a "complex two-dimensional continuum". Real-life climate regulations must find an appropriate balance between both principles.

As Agora's study maintains, neither of the two aforementioned principles of policymaking should be regarded in advance as the best solutions to achieve the decarbonization of transport sector. In fact, the efficiency of either of the two paths is dependent on a large set of normative, technological, economic and social circumstances, which are properly summarized in the wider general concept of "technology openness of the decisional space".

While technology neutrality describes a particular state intervention, technology openness is instead representative of a regulatory environment. A decision space has *high technological openness before* *regulation* if "the choice of technology is undistorted apart from the distortion to be corrected for (i.e. the external costs of greenhouse gas emissions)". Instead, "if further market imperfections exist besides the external costs of greenhouse gas emissions, or if the policy decision is not only motivated by social welfare", the decision space has *low technological openness before regulation*. Technology-neutral policies achieve the decarbonization targets at minimal social costs only when the decision space is perfectly technology-open. Since, however, real-life decision spaces are typically biased, the state must introduce technology-specific regulations to correct existing biases. "Technology specificity may also be needed if the regulation pursues other goals in addition to decarbonization or if the assumption that private actors have better information than the central regulator proves false".

For a technology-specific regulation to be efficient, it is essential that regulators properly acknowledge the potential biases in the decision space, in order to design adequate corrective technology-specific instruments. Therefore, beside specifying which regulatory approach is the most efficient, given the openness of the decision space ("question of indication"), there is also the need to determine the proper form of technology specificity to address the existing biases ("question of adequacy").

Theoretical model

With the goal of comparing the efficiency of technology-specific vs technology-neutral policies, there are three main set of indicators that must be taken into account:

1) **The degree of knowledge centralization;**
2) **The presence of potential limitation of the decisional space's technology openness;**
3) **The presence of further normative objectives, beyond GHG emissions reduction.**

Each of these three categories contains a variable amount of specific indicators that together serve to answer to the broader question.

For the purpose of this thesis, Agora's research model for the definition of the decisional space's openness has been simplified by reducing the number of items of each of the 3 main indicators. The following paragraphs report the details of the analysis conducted, including the specific items utilized, associated hypotheses and a brief explanation of each item.

1) **The degree of knowledge centralization**

General hypothesis:

The higher the centrality of knowledge, the lower the probability of error of a technology-specific regulation.

Indicators:

a. Number of information carriers.

Hypothesis:

The smaller the number of information carriers, the easier it is to collect information centrally.

b. Regulator's access to information regarding current and future costs/benefits.

Hypothesis:

The higher the regulator's access to information regarding current and future costs/benefits, the easier it is to collect information centrally.

2) The presence of potential limitation of the decisional space's technology openness

General hypothesis:

In the case of low openness of the decision-making field prior to regulatory intervention, the use of technology-specific instruments has the potential to improve efficiency and increase openness.

This set of economic indicators is further divided into three additional subsets, which together help defining the general openness of the decisional space. These subsets are, respectively:

- **2a. Disturbances to the coordination of the market;**
- **2b. Potential path-dependencies;**
- **2c. Policy failures.**

2a. Disturbances to the coordination of the market

General hypothesis:

The more the coordination of the market is disturbed, the lower the technology openness of the decisional space.

Indicators:

c. Market power.

This area examines the level of horizontal integration, i.e. the intensity of competition at different stages of the value chain (at the manufacturers (a1) and in fuel supply (a2)). The higher the market concentration the greater the disruption to the coordination of the market.

c1 – intensity of the competition (car manufacturer level).

c2 – intensity of the competition (energy supplier level).

Common hypothesis (a1 and a2):

The lower the intensity of competition, the more market power can distort market coordination.

d. Users' budget restrictions (Total Costs of Ownership-TCO)

Hypothesis:

The more clearly the Total Costs of Ownership (TCO) of alternative options exceed those of the established technology, the more price biases can distort market coordination.

2b. Potential path-dependencies

General hypothesis:

The more path dependencies interfere the technology choice, the lower the technology openness of the decisional space.

Indicators:

e. Infrastructure Necessity

Hypothesis:

If existing infrastructure cannot be used by the new technologies and specific investments are needed to build the new infrastructure, path dependencies can interfere with the technology choice.

f. Learning and scale effects (application maturity and choice of technology)

Hypothesis:

The higher the price reduction margins thanks to learning and scale effects, the more current price advantages can interfere with the technology choice.

2c. Policy failures

General Hypothesis:

The more policy failures influence the viability of the competing technologies, the lower the technology openness of the decisional space.

a. Influence of politics on relative prices.

Hypothesis:

When public interventions modify the price structure of a technology, policy failures can influence the viability of said technology option.

3) The presence of further normative objectives, beyond GHG emissions reduction.

General hypothesis:

The greater the importance of further regulatory objectives, the stronger the indication for technology-specific regulation.

Indicators:

b. Contribution to the achievement of other policy objectives

h1 – Target contribution: Energy efficiency

h2 – Target contribution: Material requirements

h3 – Target contribution: Air quality

Common Hypothesis (h1, h2, h3, h4):

The higher the contribution of the technology to further goals, the stronger the case for technology-specific regulation.

4. Results

With the research methodology adequately explained in the previous chapter, it is now time to move to reviewing one by one each of the indicators in order to ultimately assess, with specific reference to the impacts on the Italian Automotive industry, which policy approach could be the most efficient in guiding the energy transition towards Net Zero Emissions of the transport sector.

As previously shown, there are three main dimensions that should be considered in order to understand the potential efficiency of a *technology neural/technology specific* regulation within the decisional space under investigation. These are, namely, (1) the degree of knowledge centralization; (2) the presence of potential limitation of the decisional space's technology openness; (3) the presence of further normative objectives, beyond GHG emissions reduction.

The degree of knowledge centralization

The centralization of knowledge is a fundamental element of this analysis, because the efficiency of a technology neutral regulation depends, among other things, on the assumption that private actors have better information than the central regulator. The specific indicators that have been selected in order to observe the degree of knowledge centralization are (1) the *number of information carriers* and (2) the *regulator's access to information regarding costs and benefits*.

In the first case, i.e. the *number of information carriers*, the underlying assumption is that "*The smaller the number of information carriers, the easier it is to collect information centrally*". The information carriers essentially correspond the observable actors in the respective area. In short, both of the main alternative technology options considered (electrified mobility and Low Carbon Fuels for ICEVs) are already fully available on the market, with an extremely high number of actors competing at both the energy vector and drivetrain production levels.

The second indicator's objective is to analyze the ability of the regulator to correctly assess private and public costs and benefit, both present and linked to the technology option's future development uncertainty. In this case, the assumption is that "*The higher the regulator's access to information regarding current and future costs/benefits, the easier it is to collect information centrally*". The most relevant proxy to understand the uncertainty of a technology's future development is its maturity. The electrified mobility option has been fully commercially available for a long time, therefore today it can undoubtably be considered mature, both with reference to the electricity energy vector and to the drivetrain technology. However, some critical issues are still in place, mostly linked to the sourcing of critical components (e.g. Lithium, Nickel, Cobalt), as well as currently limited availability of carbon-free electricity and essential infrastructure, which is subject to uncertainties due to the long-term nature of the European investment plan. These issues require either diplomatic (international outsourcing stability) or technology development efforts (reduction of raw materials requirements), implying increased uncertainty in the future costs and benefits of the technology option. As regards to the other main alternative technology option, the drive-train systems based on ICEs have been fully mature for the longest time. The multiple energy vectors that fall under the category of Low Carbon Fuels have varying degrees of technology maturity, ranging from lab-scale research to full commercialization. However, as for the specific technologies most cared by Italian stakeholders, namely advanced biofuels, the technology maturity is very high, as they are already fully commercialized. One issue regards the future availability of adequate biomass feedstock, for which, despite the confirmation given by some studies (Imperial London College Consultants, 2021), there is still little agreement within the scientific community.

Ultimately, the centralized collection of information appears to be uneasy, given the high number of actors competing in the relevant industries, and the moderate amount of uncertainty factors linked to the main alternative technology options, which, despite a generally high maturity, require deep knowledge of the future development, opportunities and risks, which can hardly be fully collected and understood by the European Commission. Such conclusion can be further strengthened by the content of the interviews collected within this thesis statement: all the participants, upon being interrogated about the dialogue between private stakeholders and public institutions, generally agreed that private stakeholders possess critical information that often struggle to be delivered to the regulator, despite praising the process for its transparency. Therefore, as the assumption that private actors have better information than the central regulator proves mostly true, the first indication leans towards technology neutrality.

<u>The presence of potential limitation of the decisional space's technology openness</u>

The decisional space's technology openness is a key factor in determining the effectiveness of either a technology-neutral or technology-specific regulation, according to the following assumption:

"*In the case of low openness of the decision-making field prior to regulatory intervention, the use of technology-specific instruments has the potential to improve efficiency and increase openness*".

This dimension is further divided into three sub category of indicators, namely "disturbances to the coordination of the market", "potential path-dependencies" and "policy failures".

In the first case, disturbances to the coordination of the market, the general assumption is that "*The more the coordination of the market is disturbed, the lower the technology openness of the decisional space*". Two indicators have been selected as the most significant, in order to observe the coordination of the market. These are, respectively, (1) *market power* and (2) *users' budget restrictions*.

With regards to the potential issues related to market power, for which "*the lower the intensity of competition, the more market power can distort market coordination*", concerns over limited competition may arise both at energy supplier and car manufacturer level. On the side of electricity, while a very high degree of competition exists within the power supply and EV manufacturing, a generalized concern regards the predominance of Chinese competitors in the electronic components manufacturing sector, which requires public intervention in order to avoid unfair competition practices, as highlighted by some of the interviewed experts. As for the fuels and ICE option, the high market power associated to the few fuel producers that compete in such industry is undeniable.

On the users' side, "*The more clearly the Total Costs of Ownership (TCO) of alternative options exceed those of the established technology, the more price biases can distort market coordination*". The TCO (total cost of ownership), which consists of both initial investment and operation expenses, is looked at as the measure of potential budget restrictions, which could influence the purchase decisions when compared to the cost of buying and owning a traditional fossil fuel combustion vehicle. For what concerns the electrified mobility option, given the low cost of electricity and the comparatively very high energy efficiency of EVs, the savings in fuel expenditures during the EV's life cycle can already offset the higher upfront costs, for high utilization profiles. Furthermore, considerable price reductions are expected to occur, given the descending price trend (in absence of dramatic international shocks) and learning curve of batteries (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022), as well as scale effects. These factors may determine, in the future, a clear competitive advantage of EVs over ICEVs, in terms of Total Cost of Ownership. However, some of the factors enabling the cost reduction of EVs are highly dependent on the existence of a well-structure public uptake planning, the stability of which is a key prerequisite to build up investors' confidence, as highlighted in the interviews. As for the utilization of LCFs in combustion vehicles, such technology does not determine any considerable cost disadvantage compared to fossil fuels-powered vehicles, on the users side, due to the ability to be run on traditional drivetrains and to use the existing infrastructure.

Given the two key assumptions linked to the indicators of market coordination disturbances, potential limitations to competition can be identified for both technology options. Moreover, users' budget restrictions can bias the free coordination of the market when it comes to EV's, which are cost-competitive only for some specific utilization profile and require political support in the form of either stable long-term uptake planning or incentives. Therefore, in this case a more technology-specific approach by the regulator is required in order to avoid perpetrating the existing biases.

Secondly, considering potential path-dependencies, the leading assumption is that *"The more path dependencies interfere the technology choice, the lower the technology openness of the decisional space".* The preferred indicators for this area are (1) *Infrastructure Necessity* and (2) *Learning and scale effects*.

The analysis of infrastructure necessity aims at discovering potential path dependencies, both in terms of usability of existing infrastructure and infrastructure investment specificity, where hard-to-share existing infrastructure and future infrastructure can bias the free choice of technology, from a market-oriented perspective. The underlying assumption is that "*If existing infrastructure cannot be used by the new technologies and specific investments are needed to build the new infrastructure, substantial path dependencies exist*". There is a clear difference between the two alternative technology options, as, on the one hand, LCFs can be readily implemented in the existing logistic and distribution infrastructure without any significant update; contrarily, full electrification of transport entails a tremendous challenge, specifically a massive overhaul and uptake of the energy distribution system, in the form of charging stations, which must be available to all the population, representing a key enabler of this technological pathway. This investment requirement is mandatory, as the existing infrastructure cannot be utilized for the purpose of recharging EVs, and private or corporate recharging can only cover a limited part of the demand. Additionally, for both technology options, there is a high degree of infrastructure investment specificity, as the distribution and storage systems are mostly incompatible with one another, even when considering alternatives beyond the main technologies chosen by this thesis (e.g. Hydrogen).

Focusing on potential learning and scale effects, the objective is to assess whether cost advantages exist for the established technology, compared to the new alternative technology options, according to the assumption that "*The higher the price reduction margins thanks to learning and scale effects, the more significant path dependencies are*". Margins of cost reduction linked to learning and scale effects may cause a misevaluation of the potential benefits and costs of a technology option, creating biases in the free choice of a decarbonization pathway. In the case of the transport electrification option there are considerable potential margins of further cost reduction for the EVs, as highlighted in the *users' budget restriction* section of the discussion. As for the main alternative technology option, while the traditional combustion drivetrain is a well-mature and established technology, with little to no potential for scale and learning effects, the LCFs may face significant cost reductions, provided political support is given for a sufficiently wide field of application, as highlighted by Mr. Del Manso in his interview.

As the electrification of mobility option require the extensive development of new infrastructure, and both technology options present, to some extent, cost reduction margins through learning and scale effects, significant path-dependencies exist and therefore require a technology-specific regulation approach, to properly account for the resulting biases.

Lastly, policy failures can contribute to limit the openness of the decisional space, leading to the following assumption: "*The more policy failures influence the viability of the competing technologies, the lower the* *technology openness of the decisional space"*. A single indicator has been elected as representative of potential policy failures, namely the *influence of politics on relative prices*.

For the purpose of analyzing this indicator, it is examined whether and which state-induced price components exist for the technology options. In the presence of price interventions by the regulator the technology openness of the decision field results restricted, as the ability of market prices to objectively reflect the externalizations is reduced. The underlying assumption is that "*When public interventions modify the price structure of a technology, policy failures can influence the viability of said technology option*". In Italy, an effort to promote the uptake of low-emission vehicles has been put in place in the form of the "Ecobonus" (Ecobonus), a fiscal incentive for sustainable mobility, based on the PNIEC guidelines (Ministero dello Sviluppo Economico et al., 2019). The Ecobonus allows Italian citizens and companies to receive a considerable fiscal price incentive for the purchase of low carbon vehicles, the amount of which varies according to the vehicle's emissions, the utilization profile, the characteristics of the applicant and whether or not an old vehicle is being scrapped. An additional cumulative price incentive can be granted by the regional government, specifically within the regions that are currently under infringement procedure due to high levels of local pollution. Further tax benefits regard the possibility for companies investing in green corporate fleets to avoid the payment of the "Ecotassa" and "Fringe benefits" expenses (Leaseplan, 2021). Another relevant type of political influence on the alternative technologies' viability regards the limitations to circulation of combustion vehicles within urban areas. In Italy, municipalities are in charge of setting the specific rules for limiting the traffic circulation in some specific urban areas ("ZTL – Zone a Traffico Limitato"), according to the "Articolo 7 del Codice della Strada" (D.Lgs. 30 Aprile 1992, n. 285). Beyond the cases in which, due to specific road conditions, access to "Ztl" areas is restricted to all types of cars, EVs are generally exempt from the prohibition set by the local regulation. Being able to drive in restricted urban areas is definitely a major upside of owning an electric car, representing a significant political influence on the comparative viability of the alternative technologies, from the user's perspective.

The different treatment given by the public regulator to the two main alternative drive-train technologies is justified according to some secondary environmental sustainability targets that will be discussed later. However, such policy-induced bias inevitably causes a significant change in the users' perceived comparative viability of either of the two main technologies, leading to a reduction of technology openness in the decisional space.

<u>The presence of further normative objectives, beyond GHG emissions reduction</u>

The last main factor for determining whether a technology-neutral or technology-specific regulation might be desirable is, as previously mentioned, the potential presence of other goals in addition to the decarbonization target. If the regulator pursues multiple environmental sustainability goals through its policies in road transport, and if the other goals (beside CO2 emissions reduction) are met to different degrees of success by the alternative technology options, the use of technology-specific regulatory instruments might be recommended.

The current European regulation does in fact pursue additional sustainability goals in parallel with its Net Zero Carbon emission plan, which heavily influence some specific policy choices regarding the technologies options which are allowed to effectively contribute to the decarbonization of road transport. The European energy transition plan, as described by the Fit For 55 legislative bundle (European Council, 2021), is based on a multitude of targets beyond the reduction of CO2 emissions, including, but not limited to, energy saving (COM/2021/558: Energy Efficiency Directive, 2021) and local pollution reduction (COMMISSION REGULATION (EU) No 459/2012: Euro 6 , 2012). Full-electric and combustion vehicles' performance vastly differ in terms of energy efficiency and local pollution (mainly in terms of NOx emissions), with the first ones having a clear edge over the second ones on both categories, even when fueled by highly sustainable advanced biofuels or synthetic e-fuels (Transport & Environment, 2021). Another important additional objective within the European Net Zero plan regards solving the sourcing security issue, as highlighted in the REPowerEU (COM (2022) 230: REPowerEU Plan, 2022) and the Critical Raw Material Act (COM(2023) 160: Secure and Sustainable Supply of Critical Raw Materials, 2023). A portion of the matter can be addressed by limiting the demand of specific materials, by favoring technologies which are less foreign import-dependent for their production. With this in mind, EVs perform distinctively worse than ICEVs, due to rare-earth materials requirements as well as established foreign market power over the electronic components production. The differential intensifies even beyond, when considering the use of Advanced Biofuels in combustion vehicles, given the possibility to take advantage of domestic waste biomass feedstock.

Therefore, given the assumptions that "*the greater the importance of further regulatory objectives, the stronger the indication for technology-specific regulation*", and "*the higher the contribution of the technology to further goals, the stronger the case for technology-specific regulation*", once again there is a strong indication that a technology-specific regulation would be the most efficient policy path.

In summary,

while the assumption that private market agents have better access to information compared to the central regulator proves true, serving as a basis for an efficient technology-neutral policymaking approach, the other two key dimensions, namely the technology-openness of the decisional space and the presence of further regulatory goals beyond decarbonization, strongly indicate the necessity of a technology-specific approach.

	Electrified mobility	**Low Carbon Fuels**
Number of information carriers	Indication of Neutrality	Indication of Neutrality
Regulator' access to info	Indication of Neutrality	Indication of Neutrality
Market power	Indication of Specificity	Indication of Specificity
Users' budget restrictions	Indication of Specificity	Indication of Neutrality
Infrastructure necessity	Indication of Specificity	Indication of Neutrality
Learning and scale effects	Indication of Specificity	Indication of Specificity
Influence of politics on relative prices	Indication of Specificity	Indication of Specificity
Other policy objectives	Indication of Specificity	Indication of Specificity

5. Discussion

Question of indication: neutrality vs specificity

According to the analysis, the European plan for decarbonizing transport is required to be highly technology-specific in order to ensure (1) fair competition, (2) the occurrence of potential cost reductions linked to learning and scale effects, (3) the correct accounting of policy-induced biases on the viability of the alternative technology options, and (4) the correct selection of technologies based on their contribution towards the achievement of additional regulatory targets.

The two categories in which the indication diverges for the two alternatives require a more attentive effort by the regulator, as the ultimate objective should be to grant a level playing field between the available options. In the case of users' budget restrictions, as a clear and spontaneously market-driven electrification of mobility trend already exists, due to foreseeable future cost-competitiveness, the regulator's intervention's only aim should be that of increasing the investors' confidence by ensuring the stability of long-term cost-reduction conditions (mainly linked to the learning curve of batteries). The same approach is valid in the case of infrastructure necessity, as the development of public recharging infrastructure is both a key enabler of the diffusion of EVs and a huge long-term investment effort, which requires decisional stability in order to be financially feasible.

However, the technology-neutrality indication given by the low degree of knowledge centralization should not be underestimated, as it may represent a critical limitation of a purely technology-specific approach. Although the European stakeholders' consultation process has been praised by some of the experts and directly involved parties for its transparency and fairness, the established lobbying practices can still bias the objective technical understanding of the alternative technology options by the regulator. Additionally, the evolutionary speed of the main alternative technologies is very high. Accurate technical information requires both a deeper dialogue today, between public and private stakeholders, as well as a continuous update and a consistently open communication channel, in which critical and disruptive innovations can be delivered and given the proper assessment and opportunity to challenge the established positions.

Question of adequacy: full electrification vs diversified technology approach

Once properly defined the efficiency of either a technology-neutral or technology-specific policymaking approach, the last step of the analysis is to deep dive into which of the many alternative technology-specific paths available is the one most fit to properly deal with the existing biases.

The two conflicting interest groups described by this thesis, namely the electricity and EV industry, and the low carbon fuels and traditional ICEV industry, promote different and mostly incompatible solutions to decarbonize the road transport sector, with the exception of being, at their core, both highly technology-specific.

The former, backed up by the currently standing European official Net Zero plan, promotes a scenario in which, by 2035, all of the newly produced cars and vans will be exclusively powered by full-electric drivetrains (either BEV or FCEV). Other sustainable energy vectors (i.e. LCFs), still included in the general decarbonization pathway, will however be limited to the decarbonization of hard-to-abate sectors, and a temporary application in the light-duty road transport, to reduce emissions from the existing circulating combustion fleet beyond 2035, up until its eventual natural turnover. Such restriction, in practice, is achieved by choosing to consider only the CO2 emissions produced by the vehicle during its use, while knowingly ignoring all the other emissions linked to the upstream of both the energy vector and the vehicle production. The key justifications for using such an emission calculation methodology are, in no particular order, (1) the aim of regulating directly the car manufacturers' behavior, coupled with their inability to influence upstream emissions; (2) the overcomplexity and hard comparability of more advanced methodologies; (3) the current absence of an officially recognized LCA methodology; (4) the evidence, although circumstantial[1], that full-electric vehicles have anyway the lowest environmental impact, even on a LCA analysis.

The economic rationale of this scenario is to focus the resource and time effort on the most promising technology, allowing an efficient public expenditure and an effective and rapid achievement of the environmental targets. Since a spontaneous, market-driven trend towards the development and commercialization of the EV platform already exists globally, supporters of this scenario claim that a well-guided complete electrification of the European road transport sector will help our economies to anticipate and lead the global trend, rather than chasing, in the future, an established foreign competitive advantage, as highlighted by the experts in the interviews. In such perspective, the economic gain of being first movers will outweigh the loss of phasing out our established industrial prowess in the ICE-related sector, provided that adequate support is given to companies and workers during the transition.

The latter group demands the revision of the chosen emission calculation methodology, in order to include highly sustainable advanced biofuels in the energy mix for light-duty transport, beyond 2035. The advanced biofuels, according to scientific evidence, can be considered carbon neutral thanks to the emission savings in the upstream, requiring a well-to-wheel or LCA approach to be properly accounted for. Such request, often labeled by its supporters as "the need for more technology-neutral decisions", in fact has nothing to do, according to the concept's actual definition, with technology neutrality. Very simple changes, namely the creation of specific exceptions for the LCF's emissions accounting, would achieve what's being demanded by

[1] See chapter 2.2 – Key technologies of the Energy transition (renewable electricity).

these stakeholders, as has already been done with the e-fuels, following Germany's request for it. Despite the widespread concern over the unavailability of sufficient feedstock to cover all the energy uses which today depend on fossil fuels, thorough research (Imperial London College Consultants, 2021) has been conducted to demonstrate the opposite, highlighting the existence of enough sustainable, non-food&feed competing biomass.

Supporters of this scenario still recognize the upsides of electrified mobility, therefore imagine a high penetration of both technologies in the future energy mix of the European road transport sector. From such perspective, the economic rationale is to achieve better stability and reduce the risk factors through the diversification of the future technologies. At the same time, preserving the option of domestically producing internal combustion engines will allow to safeguard the national ICE components value chain, which has a substantial relative weight in the Italian economy, and otherwise will be doomed to a complete phaseout, with potential massive repercussions in the absence of a sufficiently well-planned industrial and occupational transition.

Sufficient consideration should also be given to the potential of the alternative technologies to create circular economies. Advanced biofuels are, by definition, a product of circular economies, as the waste created by other human activities, which would be otherwise likely end up in landfills, is used as a feedstock for producing valuable energy. However such potential, of which European institutions are well-aware, isn't necessarily linked to its application in light-duty road transport, and will not be wasted in case the full electrification project goes through. On the other hand, an effort to create circular economies for the re-use of batteries and other critical components of EVs is fundamental to reduce the environmental impact linked to the disposal, and to reduce the production costs.

Ultimately, given that both solutions possess a robust economic rationale and require a comparable level of public planning and intervention as a key enabler for their success, the true comparison comes down to a few factors. The most notable key difference regards the very last indicator of Agora's analysis framework, namely the contribution of individual technologies towards the achievement of additional targets beyond the reduction of CO2 emissions. In this field, the different performance of the two main technologies in discussion becomes very clear.

On the one hand, the two goals of reducing the energy intensity of our society (efficiency target) and improving the quality of air by reducing emissions of local pollutants (air quality target) find their best solution in the first scenario, namely the total conversion to full electric drivetrains. In fact, BEVs are 300% more energy efficient than ICEVs on average and don't produce emissions of NOx at all, while emitting fine particulate only from the deterioration of tires and brakes, not from the power unit. Conversely, internal combustion engines are comparatively inefficient, with the production of LCFs being even more energy-intensive than traditional fossil fuels. In addition, while the Euro 6 engine already massively reduces the emissions of local pollutants, a non-negligible share of local pollution is still produced, and the reduction of emissions is highly dependent on individual behaviors regarding the correct maintenance of the vehicle.

On the other hand, the target of increasing the economy's stability through the reduction of the European dependence on critical raw materials is better met by the LCFs scenario. Indeed, reducing the penetration of BEVs allows to import fewer rare and expensive natural resources which Europe lacks, and over which concerning foreign established monopolies exist. However, it must be noted that such challenges could be partially overcome even in the first scenario, by developing domestic value chains for the refinement of rare-earth raw material and production of electronic components, as well as diversifying international trade partners and ensuring, via diplomatic efforts, stable and reliable relations with them. Additionally, as noted by one of the experts interviewed in this thesis, an effort of remapping the domestic natural resources could potentially help discover new mineral deposits for us to mine directly.

One final observation regards the infrastructural costs, which constitute a key distinction between the two competing technologies. As extensively explained earlier in the analysis and in the theory chapters, while the application of LCFs requires virtually no update of the logistic and distributional infrastructure, the transition towards electrified mobility requires massive resource and time investments in order to create an adequate availability of public charging stations. Such requirement is a key enabler of an extensive use of EVs and a highly challenging process from a urbanistic point of view, both for historical towns and isolated rural areas. However, in the comparison of the two suggested scenarios, either solutions rely on the penetration of EVs (only partial in the alternative LCF scenario), therefore none of the two options allow to avoid the high infrastructural costs of the transition.

Key Implications

The analysis conducted so far highlights some interesting implications for policymakers and stakeholders involved in the energy transition of the road transport sector.

Firstly, the main objective of this master thesis was to apply the interpretative framework created by Agora (Agora Verkehrswende, 2020) in order to understand which normative, technological, economic and social conditions can justify the use of a technology-neutral or technology-specific policymaking approach in leading the transition toward Carbon Neutrality in the light-duty road transport sector. After a qualitative study of the specific conditions of Italy's Automotive and Energy Generation industries, a technology-specific approach appears to be required due to several distortion of the decisional space, and the most efficient in order to successfully achieve the important secondary environmental targets set by the European Union. However, the limited availability of key technical information to the central regulator, compared to the private actors operating within the analyzed industries, represents a significant threat for the success of a purely technology-specific approach, requiring the creation of sufficient opportunities for exchanging crucial knowledge between private and public stakeholders.

Secondly, the analysis also highlights that both of the two main alternative scenarios for decarbonizing the light-duty road transport sector require, in fact, a substantial level of public intervention, indicating that the "technology neutrality" claim might be, at the very least, misleading. The economic rationale behind the demand for including the LCFs option in the future energy mix of light-duty road transport is robust, but still greatly benefits from a public effort to coordinate the energy transition between sectors, safeguarding the free market competition, efficiently allocating resources for the costly investments required, allowing the realization of potential learning and scale effects, managing the inevitable industrial and occupational shifts, and concurrently aiming at the best outcomes in terms of energy efficiency, air quality and sourcing security.

Thirdly, as for the two alternative transition pathways, the analysis' aim was mainly to isolate the true distinction between them, without the presumption of establishing which of the two transition recipes is the best. Provided the realization of some essential enablers, both projects appear to be potentially capable of achieving Carbon Neutrality, or miserably fail in case said key enabling conditions aren't met. In terms of outcomes, what truly distinguishes the two alternative pathways is the ability of their supported technologies to achieve secondary environmental and economic targets beyond the simple reduction of CO2 emissions in the light-duty road transport sector. However, as different objectives are better achieved by different technology options, an objective evaluation should start from clearly ordering, by priority and urgency, the three aforementioned secondary targets of the energy transition, a task which requires further analysis.

Fourthly, from a purely economic point of view, the two alternative pathways for the decarbonization of light-duty road transport are guided by opposite rationales. On the one hand, the full electrification scenario values, above all, the potential of creating new income through the development of domestic value chains for the refining, production, assembling, disposal, recycling and reusing of EV-connected products, while embracing the responsibility of centrally managing the consequent industrial and occupational transition, a key aspect to avoid collateral damage. On the other hand, the alternative scenario, supported by stakeholders of the refining and ICE industries, is driven by a more conservative approach, which aims at achieving the Net Zero as safely as possible, avoiding the risks linked to a complete industrial and occupational transition by preserving the existence of the ICE industry, lifting such enormous responsibility off of the European institutions' shoulders. The analysis carried out in this master thesis work lacks the instruments to objectively conclude whether it is more desirable to pursue a more risky, but also potentially more rewarding, transition pathway, or to moderate the revolutionary targets, in exchange for a potentially more resilient and cautious light-duty road transport future technology mix. However, while the answer to such interrogative is difficult, the relevant implication highlighted by this thesis work is the fact that the European Union, aware of the challenges linked to its approach, still decides to pursue the riskier, more revolutionary path, backed up by many stakeholders who are convinced that the future benefits will outweigh the potential losses.

Lastly, the research highlighted that, while the two main groups of stakeholders disagree on many key aspects of how to carry out the decarbonization of the light-duty road transport sector, they agree that the perspective of decisional instability represents, for both parties, the worst-case scenario. In fact, without the assurance that the European institutions will stay true to a clearly defined plan for decarbonizing the carbon intensive sectors in the upcoming years, there is no financial basis for expecting a sufficient return on investments for the long-term commitments required by private stakeholders. Unfortunately, such critical concern collides with another issue, linked to the Net Zero Carbon plan, that emerged during the interviews conducted for this master thesis, namely the fact that the timeframe required to enable an objective evaluation of the outcomes of today's decisions over the future technology and energy mix of light-duty road transport is, in truth, much longer than the ambitious deadlines set by the EU. For this reason, many stakeholders from both parties believe that the European Union has been too hasty in communicating its goals to the rest of the world, a problem that has been aggravated by the two major international shocks (the Covid-19 pandemic and the Russian invasion of Ukraine) which followed the announcement of the 2030 and 2050 CO2 emissions targets as part of the EU Green Deal (European Council, 2019), drastically changing the stability of our domestic economies and the perceived polarization of the international arena. The contradiction between the two issues must be carefully evaluated by the policymakers, keeping into consideration both the need for adjusting and fine-tuning the Net-Zero plan according to new technological and economic findings, and the necessity of remaining coherent to the decisions which already shaped the long-term investments. The upcoming review windows and the European parliamentary elections of June 2024 will be crucial milestones in determining the success of the future Energy Transition.

6. Conclusion

With the objective of analyzing the efficiency and sustainability of the main alternative solutions suggested by Italian stakeholders to pursue Carbon Neutrality in the light-duty road transport sector, this thesis has gone through an extensive observation of the legislation, technological landscape and key stakeholders' positions linked to the European decarbonization plan. The stage of collecting theoretical information through the literature review and interviews with key stakeholders in this master thesis, has provided the inputs for answering the main Research Question, "Which policy-making approach is more efficient to enable the European energy transition plan for transport, in relation to the normative, technological, economic, and social landscape in Italy?".

Agora's "Technological Neutrality and Technological Openness" framework (Agora Verkehrswende, 2020), allowed to translate qualitative and empirical data into an answer to whether a "Technology-neutral" or "Technology-specific" regulatory approach would be more desirable, as well as to isolate and highlight the most critical aspects of and key differences between the two main alternative decarbonization scenarios analyzed by this thesis. According to the results of the analysis, in relation to the normative, technological, economic and social characteristics of the decision-making space, a technology-specific approach comes out as the best and most efficient regulatory pathway, in order to avoid perpetrating the existing biases in the European light-duty road transport sector during the process of achieving Carbon Neutrality. The efficiency of a purely technology-specific approach is, however, partially questioned by the limited availability of accurate and up-to-date information by the central regulator over technological and economic matters of the light-duty road transport industry, entailing the necessity of deepening such central knowledge in future revision opportunities of the European road to Net-Zero emissions plan.

Thanks to the key contributions of the interviewees, as well as a thorough literature review, the analysis conducted within this master thesis has also highlighted other relevant implications for public and private stakeholders, specifically regarding the comparison between the "full electrification of transport" scenario, and the "diversified technologies" alternative scenario, advocated by stakeholders of the fuel refining in ICE industries. A key similarity between the two scenarios is that neither of those requires a technology-neutral regulatory approach, but rather different choices in the decision-making process, having both robust scientific evidence for being considered theoretically able to achieve Carbon Neutrality. As for the differences between the two alternative pathways for decarbonizing light-duty road transport, it all comes down to two key factors: (1) the two technology mixes proposed vary in their ability to achieve secondary sustainability targets, with full electrification being more suited to reduce overall energy consumption and local pollution, and LCFs achieving better sourcing security by reducing the reliance on foreign impots of rare and expensive raw materials; (2) the two solutions differ in terms of ambitions and risk factors, as full electrification entails greater economic and financial risks, as well as greater potential gain, while the LCF scenario is naturally more conservative.

Finally, an additional observation regards the potential existence of dangerous contradictory relation between the concern of ensuring decisional stability, as a key element to create investors' confidence, and the need to allow future review opportunities of the European energy transition plan, to allow recent and future international economic shocks and technological breakthroughs to enter the decision-making equation.

As a conclusive reasoning of this master thesis, given the increasing urgency of achieving the primary objective of reducing the carbon intensity of our economies, to safeguard life on this planet, the final decisions over the economic and secondary environmental objectives, and therefore, ultimately, over the preferred approach to decarbonize light-duty road transport, should be based on the goal of increasing, as much as possible, the probability of successfully achieving the already very ambitious primary decarbonization target.

Limitations & further developments

In writing this master thesis, there have inevitably been some research limitations, which, for the purpose of maintaining a high degree of transparency, are worth highlighting, with the goal of contextually suggesting some future developments to overcome the obstacles and expand the field of knowledge.

Firstly, due to time constraints, the foundational research model applied in this master thesis (Agora Verkehrswende, 2020) has been simplified, reducing the total number of indicators of each field of observation. For this reason, as a recommendation to future research aiming at expanding the contents of this thesis, a more faithful application of Agora's original research model would certainly lead to more robust conclusions.

Secondly, the research model is based, at its core, on qualitative observations of the normative, technological, economic and social characteristics of the research field, without a purely quantitative reasoning. A deeper understanding of the topic could originate, in future research, from the inclusion of quantitative indicators and elaborations, possibly even combining a business model to forecast and evaluate the competing scenarios' efficiency.

Thirdly, the focus of this master thesis is narrowed down to the analysis of the energy transition in the light-duty road transport sector. Conversely, the European "road to Net-Zero Carbon emissions" plan includes provisions for each of the main sectors contributing to GHG emissions (i.e. power generation, industry, transport, constructions and agriculture). Future research could benefit from a broader perspective on the European energy transition, potentially revealing further systemic threats, opportunities and path-dependencies which may depend on the choice of either decarbonization pathway.

Fourthly, while the contributions of experts and key stakeholders of the light-duty road transport and power generation sectors have been of paramount importance to this master thesis, a relatively small number of viewpoints have been collected. Future studies on this field should consider expanding the amount and variety of interviews to be conducted, possibly including policymakers, consumers and operators in other industries (e.g. hydrogen).

Fifthly, since the ongoing hot debate between the two groups of stakeholders analyzed by this master thesis is, at its core, highly polarized, some researcher's biases, sprung during the literature review, as well as during the many conversations which stimulated this master thesis, may have unintentionally influenced the analysis, despite the absence of any direct or indirect conflicting interest, and the attempt to keep an objective perspective.

Finally, this field of knowledge would certainly benefit from further research on the following topics, on which there isn't clear agreement by the scientific community, yet: a common, official definition of a LCA emission accounting methodology; the forecasted availability/unavailability of sufficient biomass for producing LCFs; the LCFs' limited application's effect on their development, uptake and application in sectors other than "Hard-to-Abate", due to the lack of economies of scale.

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Appendix – Interviews

- First interview: ENEL

1. Name and job position of the interviewee:

Michele Nesa – Head of European innovation, E-mobility and digital policies, Enel Group.

2. Company of the interviewee:

Enel is a utility company, which operates in several countries, namely Italy, Spain, Slovakia, Romania as the main European locations, as well as South and North America, as the biggest player in renewable energy. Enel also operates in the electricity distribution and electrified mobility and recharging infrastructure (Enel X way), both in the public and private sectors.

3. Company's and interviewee's opinion on the ongoing debate over policy and technology:

Regarding the technology neutrality discussion around the European policies for decarbonizing mobility, Mr. Nesa reminds us that the European institutions initially chose to dissect the decarbonization plan into two separate legislations, one addressing the fuel side (RED), the other addressing the improvement of the engines (CO2 standard). The Renewable Energy Directive promotes the development of alternative sustainable fuels, including biofuels, e-fuels, renewable electricity and hydrogen, meant to substitute fossil fuels in order to abate emissions. The CO2 standard, specifically based on a tailpipe emission evaluation methodology (Tank-To-Wheel), aims at guiding the supply of vehicles characterized by greater energy efficiency and lower CO2 emissions. This combined approach aims at concurrently abate emissions, both from new cars, and from the traditional ICE-based fleet which will keep circulating way beyond the 2035 deadline. While in the short term, due to the partial penetration of zero-emission vehicles, sustainable biofuels and e-fuels will play a primary role in the abatement of emissions, in the long term LCFs (low carbon fuels) will substantially decrease and be substituted by electricity, due the tailpipe metric chosen for the CO2 standard regulation. In Mr. Nesa's opinion, alternative emissions metrics as, for instance, LCA or the inclusion of a specific exception for LCFs in the CO2 standard could be considered, although, as evidenced by research, the electrified light mobility solution appears to be most efficient and appetible by car manufacturers, which are already moving toward it with targets often even more ambitious that the ones set by Europe. To change the emission calculation methodology could entail some benefits, but would also imply the need to readapt and update the whole legislative package to avoid overlapping. In addition, two considerations should be made: on the one hand, the LCA approach still lacks a common scientifical definition, with the proposals analyzed by the Commission so far not showing any relevant environmental benefit while implying greater costs; on the other hand, the renegotiation of the current regulatory framework would cause major delays, with the risk of not meeting the current decarbonization deadlines. Finally, Enel sees that, even when applying the entire LCA evaluation, taking into account the upstream and downstream of the competing technologies, research shows that the EV remains the best solution to decarbonize light-duty transport.

Due to the recent shocks, namely the pandemic and the Ukrainian war, Enel is aware that some specific considerations are now much more important than they were a few years ago, namely the issue of the European dependance on foreign imports for the supply of some critical components. This problem may be reflected in the approach of the next European legislation, which may or may not deviate from the current energy transition pathway. However, today's massive investments of car manufacturers toward the electrification trend may signal that the markets, both European and foreign, could be against a drastic change in the decarbonization objectives. At any rates, given these clearly dominant trends in the markets, the complete electrification will be achieved regardless, in the long term. Regarding the currently set deadlines, there might be a political drive to change and postpone them, also considering that the CO2 standard regulation already includes some windows for reviewing its contents. Such actions could be taken also on the basis of the actual development of the infrastructure and strategic industries. Beyond the considerations about deadlines, Enel firmly belies that there is no obstacle to the complete electrification of light mobility in 2050. This assumption is also backed up by the car manufacturers' stance, given their shared commitment in the electrification trend, as demonstrated by the investments already in place. On this topic, the industry highlights the need to pay attention to the effort required to follow through on the electrification of the fleets, which may be made far more difficult by some additional targets, such as the ones set in the EURO 7 regulation. Therefore, while car manufacturers seem to support the reduction of global (CO2) and local (NOx and PM) emissions, through the shift to electrified mobility, they require to be able to focus their investments on the EVs, also in order to safeguard international competitiveness. In this perspective, Mr. Nesa believes the industry's opposition to some provisions included in the Euro 7 dossier to be understandable.

4. Interviewee's perception about the importance and impact of secondary policy objectives within the decarbonization project:

Regarding the influence of secondary objectives (i.e. air quality, efficiency, sourcing security) on the current European policies for the transport sector's decarbonization, Mr. Nesa personally believes that the urban areas' high local pollution justifies a regulatory intervention, acknowledging that transport is only one of the many factors concurring to the problem. Geopolitical considerations over resources and raw materials' sourcing are also essential, and must be taken into account by the policymaker. The recent shock caused by the interruption of Russian gas supplies highlights that the issue is not limited to the electricity sector, and must be addressed in all areas through the development of European value chains, which becomes even more important during the transition toward renewable energy. The issue related to raw materials sourcing must be properly addressed by the European institutions, by planning a stable and resilient supply network through diplomacy, as well as developing a circular economy for the recycling and reuse of resources, through European gigafactories. The development of the European value chain also serves another fundamental purpose, which is to avoid the loss of jobs linked to the industrial transition. This issue is particularly relevant in Italy, given the great relative weight of the ICE components manufacturing sector within our economy; that said, Italy should avoid the mistake of reasoning in a vacuum, since most of the ICE components are essentially exported to German producers, many which are already clearly oriented towards the electrification. This issue requires an accurate plan for rethinking our production and reskilling our workforce, in order to meet the needs of our customers. Once again, the development of national gigafactories for the production of batteries represents a huge investment opportunity, and a means to retain our international competitiveness.

5. Interviewee's perception about the dialogue between private stakeholders and public institutions:

Focusing on the amount and detail of information available to the EC, regarding the different technologies options available to decarbonize, Mr. Nesa describes the European policymaking process as cumbersome and overly bureaucratic. Preceding the proposal and discussion of the policies, there has been a long preparatory phase in which all the stakeholders have been consulted (namely industry associations and lobbies of the energy sector, car manufacturers and components producers, as well as NGOs), and given an opportunity to provide inputs and information. However, given the contradictory nature of information coming from direct competitors, it is the Commission's duty to take a final decision, which can hardly be satisfactory for each party. The opportunity to provide technical inputs is fully available, however, clearly, a political compromise is necessary: the main issues and discontents derive from this process. However the democratic process grants that the initial proposal is then analyzed and reviewed in subsequent phases by the Parliament and Council, until an agreement has been reached.

6. Interviewee's perceptions about the dangers of the energy transition in terms of limited market coordination issues (consumers' budget constraints and potential market power):

Regarding potential issues related to limited competition and monopolies that could emerge from the electrification of the transport sector, Mr. Nesa highlights the predominance of Chinese competitors in the electronic components manufacturing sector, due to their peculiar internal market development and great drive toward international competition. It is of paramount importance to preserve the competitiveness of European cars and components manufacturers, by granting the necessary public support and preventing non-competitive practices and behaviors of foreign players that operate in our domestic markets. The manufacturing of batteries is central to this issue, being batteries the most valuable link of the chain, therefore, as previously mentioned, a European industry must be developed and made into a competitive voice in the international market. To allow this, a great coordination is required among industrial players, research centers and governments. A similar competition concern should regard the American players, given the recent measures aimed at building a domestic battery industry within the USA borders. Europe needs to facilitate European manufacturers to operate at home, allowing a steady access to critical raw materials for the production of EVs and preserve employment, through reskilling of producers and services providers. These key risks must be managed carefully and on time.

Given the current price inaccessibility of EVs to large segments of the population, Mr. Nesa believes that there is room for reducing production costs and final prices, through scale and learning effects. Data forecasts show expectations for a substantial cost reduction of batteries, a trend interrupted last year due to the supply chains disruption caused by the war. New technologies reducing or avoiding the need of critical raw materials are being developed, with a great margin for improvement. The batteries learning curve is also another factor causing further cost reduction of batteries, and in turn, EVs. In the perspective of EVs uptake, non-premium products are essential and will be launched eventually, to grant greater access by more segments of the population. In all segments, EVs are prospected to achieve price parity with ICEVs within the next 3-4 years. In the low cost product lines, a greater attention should be given to the competition with Chinese companies, given their business model.

Interviewee's concluding thoughts:

In conclusion, Mr. Nesa argues that the debate is very useful to stimulate constructive criticism and improvement in policymaking. However extremizations of the debate are detrimental, and the perspectives should remain open and wide-sighted, considering both national and international issues and opportunities. The CO2 standard is still open to revisions, therefore the debate is still determinant in influencing the future policy trajectories. However, beside specific policies and deadlines, a general masterplan is required, as it is an accurate planning of all the variables affected by the energy transition, which require some specific and definitive enablers in order to succeed.

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- Second interview: ENI

1. Name and job position of the interviewee:

Renato De Filippo, Head of Regulatory Positioning and Associations – Refining, Fuels, Mobility, ENI.

2. Company of the interviewee:

Eni is a well-rounded energy company that operates in many different businesses. It is a top player in the production and refining of oils and other fossil fuels, constantly chasing innovation and improvement of its business model, to remain in line with the European regulation and with the demand, through ambitious investments towards increasing the sustainability of its products and processes.

3. Company's and interviewee's opinion on the ongoing debate over policy and technology:

With regards to the EU's 2030 and 2050 decarbonization goals, Eni's strategy pursues multiple technology options:

The production and refining of advanced biofuels, sustainably sourcing the feedstock from both European circular economy activities, and imports from Africa, having banned the use of palm oil. In this field, Eni competes with many players, notably Neste Oil, Total and Repsol, from which it differentiates itself by having fully converted two refining plants (Gela and Venezia, soon also Livorno), which grants greater efficiency and quality compared to its competitor, producing biofuels in traditional plants.

Through its subsidiary company called Eni Plenitude, Eni is the second largest operator in the Italian electricity market, moving towards clean and renewable electricity production and also being the second largest operator for the installation of charging stations for electric vehicles.

Other important decarbonization levers in Eni's strategy are the development of CCS (carbon capture & storage) plants in the Norwegian North Sea, the uptake of Hydrogen economies in UK's industrial districts, where it operates as T&S, carbon offset eco-forest projects, and finally upstream emission management measures (e.g. flaring, production processes decarbonization).

With respect to the ongoing debate over the decarbonization targets and sub targets set by the European Commission in the Fit For 55 package, Eni's position is clear: the European Commission's idealistic approach to the decarbonization is dangerous and comparatively inefficient. Such negative view of the EU's energy transition policymaking is mainly ascribable to the use of a TTW methodology for the emission calculation and standard setting, which inevitably determines a preferential treatment for the full electric option over the others. In ENI's view, rather than favoring either of the multiple alternative technologies for decarbonization, the regulator should pursue a "holistic approach", or, coherently with this thesis' chosen nomenclature, a technology-neutral approach. For Eni, this means to grant equal opportunities for all the GHG-neutral technologies to be considered by private and public actors without politics-driven biases, something that is only possible assuming a LCA-based emission calculation methodology.

Despite Eni's neutrality requirement, the company still acknowledges that different technologies are better suited for different purposes, pinpointing the heavy-duty transport sector as the one that will most benefit from the use of non-electric, carbon-neutral energy vectors, given the technical limitation of renewable electricity applications. The electric car is a viable option in the light-duty transport decarbonization, however, further research should be conducted to fully understand its environmental sustainability, as the production of batteries may lead to a higher impact than predicted. More specifically, Eni promotes the inclusion of advanced sustainable biofuels, one of its main innovative products, as an official CO2 neutral energy vector for the decarbonization of transport, as well as for other high-emissions sectors. After all, Eni argues, sustainable advanced biofuels have a similar functioning to e-fuels, which do emit GHG emissions at tailpipe, but have a negative CO2 impact in the upstream, achieving overall carbon neutrality if evaluated on a LCA basis. Therefore, if the Commission has already opened up to the possibility of an exceptional derogation for the e-fuels, why shouldn't it do the same for advanced biofuels? On this topic, the recent agreement on e-fuels represents a spark of hope for Eni, to finally reach a compromise with the Commission, able to satisfy all the parties involved. Therefore, in the short-term, it is one of Eni's priority to insist on this opening towards CO2-neutral fuels.

In Eni's view the downsides of the current policy approach of the European Commission are also, symmetrically, the upsides of a technology neutral approach:

- Heavy burden that the consumes will have to bear, when forced to invest into costlier technologies. As regards to the electricity market, a careful observation of the costs evolution for the taxpayers is required, considering the foreseeable consumption peak.
- Massive public and private investment will be required due to the high infrastructural costs of updating the network, to match it with the demand for EV charging points and overall higher consumption.
- An occupational shock and a change of skillsets required in the new system will occur in any case, but the current EU's energy transition path is not designed to minimize the damage. Eni already started to convert its refining plants in order to retain and preserve the workforce assets on which it has invested so much. In the context of ICE components, many operators of the northern Italian industry district have no way to reconvert their activity, leading to the risk of collapse of the entire value chain.
- Last, but not least, there is the geopolitical aspect. Eni is surprised that, after having experienced the worse consequences of depending for a 40% share of energy consumption on the import of Russian

gas, Europe is comfortably planning to bind itself to China for the import of rare earth materials, essential component of the electric car.

Interviewee's concluding thoughts:

As a final note, although Eni doesn't support the overall approach of the EC to the energy transition, it finds its dialogue with European institution to be pleasantly transparent, as, even without having full knowledge of every detail, the interaction is generally direct and clear. However, as long as the approach will be TTW rather than LCA, there won't be the necessary quality of information.

- Third interview: Elettricità Futura (information and positions are updated to 15 May 2023)

1. Name and job position of the interviewee:

Alessio Cipullo – Head of Technical Affairs at Elettricità Futura.

2. Company of the interviewee:

Elettricità Futura: the main sector association (part of Confindustria) of the Electricity value chain in Italy, representing over 70% of the electricity market. Mr. Cipullo leads the team for policies, regulation, European affairs and sectoral studies conducted both internally and in collaboration with other partners.

3. Company's and interviewee's opinion on the ongoing debate over policy and technology:

As regards to the "technology neutrality vs specificity" theme, Mr. Cipullo believes that it is necessary to use objective parameters as the interpretation key for this debate. With a focus on electricity generation, the main driver for the energy transition is certainly, on the one hand, the environmental protection concern, as a global trend, but also, importantly, on the other hand, the subject of costs. Today, despite the recent increase in the prices of raw materials, LCOE (Levelized costs of electricity), and technologies like wind turbines and solar panels, these energy options remain cost-effective, by having achieved a steady, substantial long-term price drop, guiding the market towards a spontaneous preference for them. Looking at the Automotive sector, global trends and technology developments are an important indicator. In terms of sales and general future orientations of car manufacturers, there is agreement about electrification being the main trend. Many car manufacturers are spontaneously planning to uptake the EV platform, as electricity is both able to comply with environmental sustainability standards (including air quality) and its technologies are evolving towards cost-effectiveness. As Mr. Cipullo argues, wherever electrification is feasible, it is convenient to pursue it, also considering that the decarbonization process of electricity generation already entails a more sustainable mobility, provided a high penetration of EVs.

Given these premises, Elettricità Futura's 2030 Plan for the electricity sector (Elettricità Futura, 2023) foresees a significant increase in Italy's electricity demand, from ~315 to ~360 TWh (with a part of the increase due to the uptake of electrified mobility), coupled with an uptake of renewable electricity, going from 35% to 84% of the total electricity generation mix. Another element that encourages this trend is the greater energy efficiency of EVs compared to all the other technology alternatives. Therefore, beyond the debate around the defense of specific interests, from a technical point of view there is a clear and objective justification for pursuing the uptake of electrified mobility. The technical evaluation must, from Mr. Cipullo's point of view, always prevail. In this context it is of paramount importance to understand the automotive value chain, and to adequately plan its reconversion, possibly expanding it thanks to the inclusion of new processes linked to the system's electrification. Elettricità Futura has recently participated to an observation and forecasting study on the evolution of the automotive value chain, together with Motus-E and CAMI. The report (Motus-E, 2022) highlights the opportunity of employment net gain, provided that the value chain follows a specific, electricity-driven evolutionary path.

As regards to the alternative scenarios for the decarbonization of mobility, which generally demand technology neutrality and plan to preserve the ICE through the uptake of alternative low-carbon energy vectors, Elettricità Futura believes that these technologies will be useful in a transitory period, to help decarbonize hard-to-abate sectors. Biofuels are especially useful where other technologies are still behind in terms of technical readiness, as in the case of hydrogen and e-fuels. One key question regards the available volumes: are these technologies effectively able to cover the energy demand? To give an objective evaluation of their feasibility it is worth looking once again at the global trends. Many big players in the aviation manufacturing are leaning towards the research and development of a hydrogen-based aviation, which requires a different platform from the current one, incompatible with the current blend of Jet fuel and biofuels. In any case, the electrification of end uses is an ongoing trend in Italy, and it must be strengthened to maintain its competitive advantage, as Confindustria Energia pointed out in the report on energy infrastructures (Confindustria Energia, 2022), which examines the infrastructural developments needed to enable the decarbonization.

4. Interviewee's perception about the importance and impact of secondary policy objectives within the decarbonization project:

As regards to the influence of other policy objectives (i.e. raw materials, energy efficiency and air quality) on the decarbonization pathway, Mr. Cipullo believes that these are very important. To set further objectives in terms of specific targets means to trace a clear path, providing also a basis for the update of the PNIEC (Ministero dello Sviluppo Economico et al., 2019), the national energy and climate plan. Elettricità Futura believes these clear indications to be necessary to set and coherently follow a direction. The greater effort to decarbonize is possible as the electricity sector has been clearly set on this path for a long time, and could help the entire system to meet the aggregate target, by performing more easily a greater change in a shorter time.

5. Interviewee's perception about the dialogue between private stakeholders and public institutions:

In mr. Cipullo's opinion, it is important that the market cooperates with the regulator by providing a constant exchange of relevant information. The subjects who have a direct access to the market knowledge must be able to influence the regulatory direction, as the investors are naturally incentivized to have an objective evaluation of the technology alternatives' potential, in order to obtain a financial return. At the same time, regulators must facilitate investments without the risk of jeopardizing their success. As an example, the Critical Raw Materials Act (COM(2023) 160: Secure and Sustainable Supply of Critical Raw Materials, 2023) is an important first step to enable the development of a European battery value chain. Due to limited direct access to rare earths raw materials in Europe, a circular economy must be built for producing, recycling and reusing batteries, which will support the internal demand.

6. Interviewee's perceptions about the dangers of the energy transition in terms of limited market coordination issues (consumers' budget constraints and potential market power):

Regarding problems for market coordination, there is no concern when it comes to competition limitations on the supply-side. Several actors in Italy compete in the electric mobility market. Interoperability of infrastructure must be granted, as an important requisite for a fair competition. A key enabler for the electrification of transport regards the recharging infrastructure. While Italy has a relatively good situation in urban areas, compared to other European countries, we're still very much behind on the recharging infrastructure of highways, for which, as lamented by many charging stations operators, there are access barriers due to limited cooperation by the highway service areas operators. This is a critical issue which requires much effort to overcome, as the development of electric infrastructure and the development of the market are parallel and depend on each other's success. When it comes to private purchase decisions, the subject of investment cost difference between alternative technologies is highly discussed. The current trend leads to believe in a progressive reduction of EVs purchase costs, given the strong global competition, as well as the impressive general effort to research and develop alternative technologies from the currently mainstream ones (e.g. Lithium), attempting to reduce the Lithium percentage or using entirely different materials, cheaper and easier to source. An important evidence of this trend is the impressive global magnitude of the innovation: the energy storage and automotive innovation areas are some of the most active in terms of new patents, signaling their strong appeal and promising potential future development. The market is therefore definitely going towards this direction, progressively driving down the prices, even net of the most recent rise of raw materials and energy prices. Clearly, scale and learning economies will further facilitate this process.

Interviewee's concluding thoughts:

In conclusion, electrification is not rational only from an environmental perspective. The 2030 plan highlights an impressive potential for new investments, up to 320 bln€ in the 2022-2030 period, which, according to Elettricità Futura's future development outlook, implies the creation of 540 thousand new jobs in 2030 in the electricity sector and its supply chain, in addition to the 120 thousand today. The opportunity is therefore also in terms of economic growth, with positive spillovers on many different sectors linked to electrification, including renewables development, electricity generation and electrified end-uses, with great relative weight of the automotive industry.

"Abbiamo tutti gli strumenti e le basi per poter fare questa rivoluzione: è fattibile. È ovvio che per realizzare questi obbiettivi ci vuole anche un cambio di passo. Nel 2022 abbiamo istallato il triplo delle rinnovabili rispetto agli anni precedenti, ma siamo ancora lontani da quello che ci serve. C'è molto da fare, ma le basi ci sono. Bisogna spingere forte, tutti assieme, in quella direzione."

"We have all the tools and the basis to be able to make this revolution: it is feasible. It is obvious that to achieve these goals we also need a change of pace. In 2022 we installed three times more renewables than in previous years, but we are still far from what we need. There is much to be done, but the foundations are there. We have to push hard, all together, in that direction."

- Fourth interview: Unem

1. Name and job position of the interviewee:

Franco Del Manso, Rapporti internazionali, ambientali e tecnici – Consulente, UNEM.

2. Company of the interviewee:

Unem is a sector association which primarily represents Italian fuel producers, operating in the oil industry downstream market. Additionally, Unem has a broader interest in all forms of energy production for mobility, including biofuels, renewable gases and electrified transport. Finally, Unem manages and represents the majority of the energy logistics in Italy, covering over 80% of the market share.

3. Company's and interviewee's opinion on the ongoing debate over policy and technology:

In Mr. Del Manso's view, the Fit For 55 Package tightened up a previous regulation which was already problematic, since it had set a CO2 emissions cap for light-duty vehicles according to an incomplete and environmentally misleading calculation method: a Tank-To-Wheel method. This methodology, by measuring emissions exclusively with a tailpipe approach, ignores the additional emissions that have been generated by the energy vectors in the upstream. This issue of the TTW methodology allows to mistakenly define as "carbon neutral" the EVs, which, although lacking the emissions linked to combustion, depend, for their use, on an energy vector which has likely already emitted a considerable amount of CO2, as, taking the two extreme cases, no distinction is given between the electricity produced with renewable sources and the one produced with the combustion of coal. The same goes for the Hydrogen vector. The only way to truly decarbonize our mobility and help the environment, in Mr. Del Manso's opinion, is to have the technology neutrality as the main requisite: while it is essential to have a clear final target, every viable technology option should be allowed to contribute in its achievement. Unem, together with the industry it represents, is currently developing technologies that are able to make the ICE carbon neutral. Why, Unem asks, shouldn't this scientifically proved, carbon neutral technology option have the opportunity to decarbonize transport?

Regarding the critical matter of sustainable feedstock availability for biofuels production, Mr. Del Manso confirms that Unem has put significant effort in researching this issue, by commissioning a study (Imperial London College Consultants, 2021) to the London Imperial College, to find an answer for three main questions: (1) is there the necessary biomass quantity to satisfy the current and future demand?; (2) Is there enough biomass which doesn't compete with food and feed uses?; (3) does this biomass comply with the sustainability requisite of not compromising biodiversity at European and global level? Each of these three questions received a positive answer, since, based on the cited study, between now and 2030, there is an available sustainable biomass equal to ~60-90 mtons which could be used for the production of biofuels, vis-à-vis a current biomass demand equal to ~30 mtons, projected to grow to about ~70-80 mtons in 2030, in case of a regulatory approval. Additionally, when considering a long-term, 2050-oriented perspective, an equally positive answer is given to the sustainable biomass availability question. In fact, the liquid fuel demand is expected to decrease to approximately half of today's values, due to the inevitable penetration of electrified mobility, increased efficiency of ICEs and the uptake of public transport and mobility-as-a-service practices. The liquid fuels amount ultimately needed in 2050, based on Unem's assessment, will be roughly 170 mtons, while the supply capacity of carbon neutral fuels is expected to be over 160 mtons, partially derived from sustainable waste, residue and biomass not competing with food and feed (e.g. garbage, byproducts, scrap materials, degraded soils crops, etc.) and the remaining part is expected to be synfuels.

Mr. Del Manso states that Unem's approach to the decarbonization of mobility does not aim at directly antagonizing the competitors (e.g. electricity industry), unlike them, who, in Del Manso's view, fiercly aggress the transport market (new frontier to them), by demanding the legal ban of alternative solutions. Unem is aware of the utility of electrified mobility, especially in relation to some specific circumstances, such as the elimination of local pollution (with the exception of fine particulate) from road transport in crowded urban areas. Therefore Unem fully supports the development of electrified mobility, as demonstrated by its 2030 and 2050 scenario, where there is still a significant penetrations of EVs. In short, in Mr. Del Manso's view, every competing decarbonization technology can and should coexist, reciprocally aiding each other in the grand scheme of the Net Zero Emissions plan, according to the principle of Technology Neutrality.

Another key issue, connected to the previous one, regards the Hard-To-Abate sectors, in which, due to technical limitations, electricity is unfit to serve as the future energy vector, whereas Low Carbon Fuels are undoubtably seen (even by the EC) as the best alternative to decarbonize. Given this required application of LCFs, Mr. Del Manso highlights that the ban of ICEs in cars and vans overly restricts the field of applicability of LCFs, making it hard to justify investments due to the lack of scale and learning economies perspectives. On the other hand, to realize electric engines is a very simple task. Therefore, a need for developing economies of scale cannot justify, in Mr. Del Manso's view, the concentration of all the efforts to decarbonize automotive exclusively on the EVs technology. The same holds true for the generation of electricity, as even a projection of total electrification of road transport entails a marginal impact on total electricity demand, therefore not requiring further economies of scale to justify its uptake.

4. Interviewee’s perception about the importance and impact of secondary policy objectives within the decarbonization project:

Mr. Del Manso recognizes the undeniable importance of secondary policy goals (i.e. energy efficiency, raw materials sourcing and air quality) on the decarbonization pathway. However, while the EVs are significantly more efficient than ICEVs, they require a battery, which has an important environmental footprint, a costly recharging infrastructure to be realized from scratch, also very environmentally impactful, and a supply of 100% renewable energy, which is yet to be put in place. When it comes to air quality, Euro 6 engines emit near-zero traditional pollutants, therefore the turnover of the circulating fleet will already almost entirely abate local pollution.

5. Interviewee’s perception about the dialogue between private stakeholders and public institutions:

As regards to the availability of all the relevant information during the European policymaking process, Mr. Del Manso emphasizes the different power of lobbying groups to leverage and influence the European regulator. Namely, in the last years, the electricity lobby has acquired a significantly greater power to sway the political decisions of the Commission in the context of mobility, as compared to fuels lobbies. However, during the subsequent phases of deliberation, the relative weight of specific countries and the political affiliations make the difference in the approval or rejection of regulatory law proposals. Despite the influence of the lobbies, Mr. Del Manso still believes that all the relevant information about technology alternatives for the decarbonization of transport have been successfully delivered to the EU institutions. The current Commission’s position is based, Mr. Del Manso believes, on ideology, often inconsistent, as in the case of the approval of the e-fuels option, driven by the requests of Germany, while having rejected the sustainable biofuels, both of which have been scientifically proven to be carbon neutral. The same can be said, according to Mr. Del Manso, for the Internal Combustion Engine, for which the Commission could simply use a basic emissions credit system to avoid its phaseout, while ensuring a net zero usage even with a manufacturer-focused, TTW evaluation methodology.

6. Interviewee’s perceptions about the dangers of the energy transition in terms of limited market coordination issues (consumers’ budget constraints and potential market power):

From Mr. Del Manso’s point of view, the EU legislation bounds the automotive industry to converting to full electric, a technology which is still neither completely mature, nor fully available to large segments of the EU population, by dictating the specific technologies to be deployed in the effort to achieve CO2 reduction targets. Unem’s objective is to instead empower everyone to contribute to the decarbonization of road transport, by introducing a proposal to amend the regulation for the purpose of promoting the uptake of carbon neutral fuels.

These products will be accessible to everyone without distinction, being 100% compatible with the currently available powertrains, allowing to immediately initiate a significant decarbonization of the circulating vehicle fleet, something that electrified mobility will be able to achieve only in the distant future. The EU legislation, in Del Manso's view, forces the uptake of a very expensive technology, which isn't successful in reducing the emissions is the short term, and which doesn't allow, yet, to carry out all the necessary function for mobility (the electricity vector is undeniably useful in short urban trips, but presents limitations for long trips and heavy transport).

Another key issue for the full conversion of the system to electrified mobility regards, from Unem's point of view, the availability of rare-earth raw materials and components for the EVs, which, as things currently stand, almost entirely depend on contracts with the Asian monopolists. The plans to realize gigafactories in Europe for the construction of batteries do not solve the problem of lacking domestic availability of raw materials, and the construction process, currently predominantly outsourced from Asian manufacturers, will never see European producers successfully hold against their international competitors. This geopolitical issue has the potential to cause in the future similar consequences to the recently experienced energy crisis. Therefore, in Mr. Del Manso's view, the only effective way to ensure supply security and avoid foreign market power, is the diversification of technologies and energy sources.

Interviewee's concluding thoughts:

In conclusion, Unem urges that such important decisions, which greatly impact on industry and society, should be taken on the basis of well-proven scientific evidence, rather than on ideology.

"L'imposizione di una mobilità solo elettrica, di fatto distrugge tutta una filiera che è un'eccellenza mondiale, quella della componentistica dei motori a combustione interna, mentre relega i costruttori attuali a dei semplici assemblatori, che non possono più sviluppare la loro capacità di ricerca e sviluppo. Decisioni di questo tipo devono considerare tutti gli effetti che esse comportano, non solo ambientali, ma anche sociali, economici e di concreta realizzabilità."

- Fifth interview: Motus-e

1. Name and job position of the interviewee:

Francesco Naso - Secretary general at Motus-E

2. Company of the interviewee:

Motus-E is an industry association representing over 65 electric mobility companies in Italy. Associates are divided into four main clusters: (1) EV producers (e.g. Volkswagen, Renault, Tesla, Smart, Iveco, Scania etc.); (2) Charging point operators and recharging service providers (e.g. Enel X Way, Recharge Plenitude, A2A E-moving, Free To X, Ionity etc.); (3) recharging infrastructure constructors & EV components manufacturers (e.g. Siemens, ABB E-mobility, Bonfiglioli, STMicroelectronics etc.); (4) services – insurance companies, consultants, rental companies, vehicles and batteries end-of-life companies.

3. Company's and interviewee's opinion on the ongoing debate over policy and technology:

With regards to Motus-E's position on the technology neutrality debate, the company believes that an unfocused resource and time effort, spread over a wide range of different solutions, does not allow an efficient public expenditure, given the limited time available to achieve the environmental targets. Positions cleared, Mr. Naso states that the regulator is still pursuing the technology neutrality principle, as the zero emissions (tailpipe) requirement, in a vacuum, does not entail an indication for a specific technology. In this sense, the ICE phaseout by 2035 is technology neutral, being the only technologies able to successfully meet the challenge, at the moment, only full electrification and hydrogen. In any case, the 2035 deadline is a signal to the automotive industry of an already ongoing trend, necessary to guide investments, as much as to reduce the uncertainty for the investors. As a proof, in reaction to Germany's and Italy's demand for the inclusion of e-fuels and biofuels, which second-guesses the phaseout decision, ACEA itself (the European Automobile Manufacturer's Association) lamented this decisional instability, declaring the need to have a clear and set objective. Motus-E is willing to get into the technology neutrality discussion, only to the extent that it wants to highlight the need to anticipate and lead the global dominating trend of shifting towards electrified mobility, rather than ending up chasing an established foreign competitive advantage in the future. There is often no clear causal relationship between the regulator's intervention and the spontaneous industrial innovation, being often simultaneous and reciprocally strengthening. The main mistake concerning the technology neutrality principle, in Mr. Naso's view, is often to think of it as the ultimate objective; it is not. Rather, the main objective is the decarbonization, while the technology neutrality is one of the multiple alternative path to pursue the final objective, not being necessarily the correct and most efficient one.

Regarding the great economic impact of the transition of mobility on the ICE industry, Mr. Naso believes that the best countermeasure to negative impacts on industry is to anticipate the trend, in line with what France, Spain, Germany, Poland, Hungary and Slovakia, among others, are already doing. The technology trend is now clear to the majority, the main reasons being cost efficiency, which is expected to steadily increase in the future, and electricity's suitability with another mainstream trend, namely mobility-as-a-service. Innovation is key from the national economy and industry point of view, and requires attraction of investments within borders, the only realistic solution to retain competitiveness in the international arena. Italy has chosen to be late-adopter for the past years, slowly deteriorating its market position in the automotive industry, from tier 1 producers to predominantly tier 2 and 3 components suppliers, implying lower innovation opportunities. Additionally, the Italian capitalistic model is mostly family-driven, therefore riskier options are generally disregarded, to the detriment of innovation. Investments attraction and R&D are therefore fundamental to make an opportunity out of a threat, as there are still great margins for improving the EV-related technologies. The innovation frontiers not only regard disruptive innovation to completely change core components, but also minor innovations to increase the cost-effectiveness, efficiency and reliability of the existing technologies. Chinese companies currently dominate the innovation frontiers, but it doesn't have to be this way forever. To enter the market competitively requires great effort and accurate planning to play around China's and US's protectionist policies.

Concerning the Commission's choice to use a tailpipe (TTW) emissions calculation method for determining the CO2 footprint of cars and vans, in the CO2 standard regulation, Mr. Naso points out that the emissions of EVs are lower than their counterparts, even on a LCA perspective. It is also worth noting, in Mr. Naso's view, how impressively the EV's environmental footprint has been reduced during the last five years, based on the technical improvements of batteries. On the other hand, a LCA methodology, although feasible, would be rather inefficient in this specific application, as the regulation aims at tackling the environmental impact of car manufacturers, which have no control over the production of fuels. Other laws already effectively address this issue, namely the RED III, by regulating the uptake of renewable fuels, which will be required to power road mobility for many more years after 2035, along with other types of (heavy) transportation.

4. Interviewee's perception about the importance and impact of secondary policy objectives within the decarbonization project:

One important premise, which Mr. Naso stresses out, is that every human activity linked to the production of goods or services has an environmental impact. The push to adopt a wider approach to emissions calculation (with WTW or LCA perspectives), misses out a key aspect of the evaluation, the one linked to public health.

For the longest time, our society has accepted to breathe dangerous pollutants such as NOx, PM10, PM2.5, and so on. Biofuels and E-Fuels do not solve this issue, therefore, in this perspective, Motus-e finds that a tailpipe evaluation of emissions makes perfect sense. The Euro 6 standard, with specific reference to the "d" variance, is, according to Motus-e, a valuable solution to address local pollution. However, Motus-e agrees that the Euro 7 standard is unreasonable in view of the upcoming transition towards electrified mobility, as it requires investments which will not have time to be repaid and will subtract resources from the main objective. However, for as valuable as Euro 6 engines are, their NOx and PM impact is not neutral and depends greatly on the vehicle's proper maintenance by the users. Conversely, EVs have zero tailpipe emissions regardless of the users' behavior, and the engine generally requires little to no maintenance.

An additional concern, in Mr. Naso's opinion, is to use our energy in the most efficient way possible, as we, Europeans, have painstakingly learned in 2022, with the least energy wasted during its transformation into electricity or heat. To "electrify everything", which has been one of ONU's mandates, means exactly to aim towards a fully electrified world, a scenario in which there will be half the energy requirement of today's fossil fuel-driven system. Even if combustible fuels will still be part of our future energy mix, they need to be used in the most efficient way, which, in Mr. Naso's opinion, it's not with ICE light-duty vehicles.

To the concerns linked to sourcing of rare-earth materials, key components of the EVs, Motus-e answers that, first of all, we never had any concern over the sourcing of other raw materials, such as steel, and yet 85% of the steel used in the EU comes from China. The self-criticism over sourcing security is rational considering the two recent shocks, e.g. the pandemic and the Ukrainian war, however it should be generalized to all the critical materials. The EU's Critical Raw Material act is already a significant reaction, by prohibiting excessive interdependence over individual critical raw materials (65%). Beside this, Mr. Naso clarifies that batteries do not contain rare earths, which are specific elements with important ferro-magnetic properties only required in certain types electric engines (permanent magnet motor), while alternative solutions don't need them. When it comes to the batteries, in Mr. Naso's view, it is necessary, on the one hand, to secure diplomatic relations with stable countries for the sourcing of raw materials (Lithium, Nickel, Cobalt etc.), something that, based on our current international partnerships, isn't much of a concern (with the exception of Nickel). On the other hand, due to public concerns, being Europe a highly populated area, mining has been mostly abandoned, along with an accurate mapping of the resources available within borders, which vastly differ from 50 years ago, based on today's critical industrial needs (Italy's last resource mapping dates back to 1972). Some innovative mining techniques are also able to greatly increase the environmental sustainability as compared to the ones currently implied in main exporting countries. Finally, refining is also a key opportunity to develop a national value chain; in fact China mainly thrives on refining of imported raw materials, as Copper, Aluminum, Nickel and Lithium are mostly outsourced. To gain access to a competitive market position, European countries could direct some of their investments into the development of a national refining industry of critical raw materials. On the other hand, a key uncertainty among the stakeholders regards the potential availability of sustainable feedstock for biofuels production, to realistically cover the system's needs, as well as an affordable price in the case of e-fuels. These doubts, in mr. Naso's view, have not yet been given a definitive answer.

5. Interviewee's perception about the dialogue between private stakeholders and public institutions:

Regarding the level of detail of the information possessed by the EU institutions, about the alternative technology options for the decarbonization of mobility, Mr. Naso believes that the public regulator has access to accurate technical information. However, many private operators possess more detailed information, being interested in trying to inform the public regulator, with the purpose of providing the tools to properly evaluate the destination and magnitude of public and private investments. However, despite the presence of well-informed actors in Italy, Mr. Naso believes that the most important question is whether there is enough skilled workforce able to cover tomorrow's industrial needs. To face potential shortages, our country needs to have training programs for the whole human resources chain of an industrial system which is going towards a radical transformation. Our country's interest should be to facilitate and encourage industrial doctorates within borders and to attract foreign skilled personnel through fiscal incentives, as well as to attract foreign private investments.

6. Interviewee's perceptions about the dangers of the energy transition in terms of limited market coordination issues (consumers' budget constraints and potential market power):

Motus-e acknowledges the risk of consolidation of dominant market positions (for instance CATL), therefore thinks that a regulatory intervention is required and desirable to avoid foreign monopolies and competition barriers in Europe. Regarding budget restrictions on the users side, Mr. Naso thinks that the costs will progressively decrease and used vehicles will start to be available allowing larger segments of the population to access electrified mobility. At the same time, mobility-as-a-service will decrease the need for families to own a car, providing an alternative, attractive solution for those who will not be able to afford an EV.

Interviewee's concluding thoughts:

As a concluding note, Mr. Naso believes that there is a concerning amount of misinformation in the public debate, causing confusion in the buyers, which are led to act more conservatively. The result threatens to be that the car, regardless of its power system, being a durable and costly good, will not be bought at all, due to the great informational uncertainty that comes out of media and public institutions. Electrical mobility is a technology option, with its pros and cons; as such, it should cease to be seen as an absolute good or evil, and start to be evaluated objectively and neutrally as an industrial trend we should better understand and anticipate, rather than chase.

- Sixth interview: Anfia

1. Name and job position of the interviewee:

Luca De Vita, Institutional relations and technical regulation, ANFIA (Associazione Nazionale Filiera Industria Automobilitstica).

2. Company's and interviewee's opinion on the ongoing debate over policy and technology:

Regarding the technology neutrality principle, ANFIA believes that it should be promoted as a value, which allows to achieve the 2030/2035 environmental targets using all the available resources. While some of the technology options have the potential to be more cost effective and easily deployable, it is inefficient to make an ex-ante decision, as it could entail deeper negative long-term consequences on the industry, denying the possibility of protecting both the environment and the economy. Italy should be even more interested in defending the technology neutrality, considering the great importance of its national ICE industry, which shouldn't be forgotten and sacrificed just to chase the fastest option to achieve the environmental target.

Regarding the choice of a TTW emission calculation method in the CO2 emission standard regulation, Mr. De Vita maintains that the most easily measurable indicator was preferred by the regulator, allowing an apparently unquestionable tracking of the emissions linked to the use of the end appliance. This reasoning, backed up by the objective inability to precisely account for the upstream and downstream emissions, is justifiable if the objective is to limit the emissions produced locally in predetermined areas (e.g. urban areas). However, being CO2 a molecule which is stored in the atmosphere, regardless of its specific point of origin, the TTW evaluation is open to make huge mistakes on the total amount of global emissions, with potentially notable biases on the true environmental impact of specific technology options. While easily measurable, the TTW method, in Mr. De Vita's point of view, is unsuccessful in fully considering all the elements of the "equation", therefore giving an incomplete answer to which technology is best suited to reduce the CO2 emissions. An approach which exclusively focuses on tailpipe emissions is blind towards the true environmental impact, on a global scale.

Focusing on the characteristics the LCF (low carbon fuels) technology, Mr. De Vita highlights one of the main upsides of renewable biofuels (non-food&feed competing), namely their contribution to circular economies, with greatly positive spillovers on environmental protection, as, for instance, efficient use of resources. Within the circular economy perimeter, renewable biofuels compensate their tailpipe emissions, with a substantial emission savings in the upstream of the fuel production. However, while a tank-to-wheel evaluation shows higher emissions overall, the main benefits are visible only with a LCA or WTW approach. On the one hand, Mr. De Vita fully supports the advanced biofuels project, also considering their relatively inexpensive production and ease of implementation; on the other hand, while acknowledging similar upsides when it comes to e-fuels, in terms of environmental sustainability and safeguarding of the ICE industry, Mr. De Vita is concerned about the access barrier of such technology, due to incredibly high production costs. Moreover, there is uncertainty whether, in time, the production costs of e-fuels could be abated by scale or learning effects. Therefore, in Mr. De Vita's opinion, the inclusion of the exception for e-fuels in the CO2 regulation act isn't very helpful in safeguarding the ICE industry, due to their non-competitive prices, being instead mostly a political sweetener.

Another important issue, highlighted by Mr. De Vita, is that the Commission's decision over the decarbonization path has been made prior to the Ukrainian war and Russian gas shock, when the perspective of importing batteries and raw material from China and other countries was considered to be virtuous, in line with the positive regard of international interdependence. Nowadays, given the progressive stiffening of international relations, this choice, based on hasty analyses, is based on a misevaluation of the importance of depending on another country's exports. Ultimately, from Mr. De Vita's point of view, the core issue is that the world is currently changing at a pace that is far higher than the ability of member states and European institutions to analyze reality. While the next European Commission and Parliament will be elected during the ongoing crisis, the ones currently in charge have based their decisions on parameters which don't reflect today's situation. In Mr. De Vita's opinion, eventually the ongoing development of automated drive systems would have spontaneously promoted the electricity vector in the automotive sector, being the energy vector best fitting with the autonomous drive and mobility-as-a-service requirements.

3. Interviewee's perception about the importance and impact of secondary policy objectives within the decarbonization project:

Although many car manufacturer have already accepted and invested in the electrification trend, now demanding political stability in order to justify said investment, there shouldn't be, according to ANFIA, such restrictive requirements on the technology options for 2035. The fundamental reasoning behind this line of argument is that what is considered the most efficient technology option today, could not be a sufficient answer to the problem in 12 years from now. Additionally, to contingently set a target on ICE local emissions with the Euro 7 regulation is even more dangerous, as the incoherence of European policies, asking the achievement of incompatible goals to car manufacturers, puts a serious harm on the feasibility of the emission reduction project. The impression given by the Euro 7 discussion, in Mr. De Luca's view, is that even the European Commission is unsure about the successful achievement of the 2035 emission targets, leaving a sense of uncertainty in the automotive industry. The main objection by the automotive industry, as Mr. De Luca points out, is that the required investment to comply with the Euro 7 standards will determine a price spike of traditional ICE vehicles, which today are the most affordable and widely purchased option, further eroding the ability of low-income segments of the population to afford autonomous mobility.

4. Interviewee's perception about the dialogue between private stakeholders and public institutions:

To the question about the amount and detail of information available to the EC to correctly evaluate the technology options, Mr. De Luca answers that the information is incomplete, due to the short time that the Commission has given itself to formulate a plan. The question is whether it is better to decide quickly or to be more patient in collecting all the elements for an accurate evaluation. Mr. De Luca is not in the position to answer this question, as he believes that the time frame to understand the consequences of such decision is too wide to grasp for anyone today. Due to the bad environmental reputation that the automotive sector has built up in time with the European institutions, Mr. De Vita thinks that the industrial side of the matter has not been adequately analyzed, specifically regarding the normal R&D time requirements of the industry. This lack of consideration determines, from the automotive sector's perspective, a sense of being unable to interact with the European policymaking in any of its phases, as the decisions seem to be made without full acknowledgement of the state of art of the subject. Mr. De Vita highlights two aspects as the main causes of this approximative evaluation, namely the great public opinion's resonance of every environmental issue, and a sort of "original sin" which stains the automotive sector, which, in time, lacked an autonomous drive to innovate towards environmental sustainability (the greatest example being the Diesel gate). However, if that's what Mr. De Vita believes to be the root cause of the quick stigmatization of the automotive sector by the EC, he states that a greatly ambitious policy like the energy transition, should rather be based on objective scientifical proof than on gut feelings.

5. Interviewee's perceptions about the dangers of the energy transition in terms of limited market coordination issues (consumers' budget constraints and potential market power):

In terms of potential competition limitations in the new upcoming automotive industry, Mr. De Vita emphasizes how traditional fossil fuel industries have always been characterized by oligopolies, with tremendous power to determine fuel prices based on total control of market quantities. In contrast, the ICE components and traditional ICEV industries have very high levels of competition, allowing the customers to choose among many different viable alternatives. These industries risk to be intentionally destroyed and replaced by other sectors starting from scratch, with the realistic possibility that the energy transition will be unsuccessful.

Interviewee’s concluding thoughts:

Mr. De Vita believes that today it is too premature to determine whether it’s better to focus all of our efforts on the solution that currently has the highest potential, or to try to preserve our established competitive industries while transitioning at a slower pace, while pursuing the technology neutrality principle. However his instincts lean towards the second option. At any rate, the true turning point will be in 2026, which is the time window to review the regulation, considering also that, at that time, a new legislature will be in place of the current one. To support technology neutrality, in Mr. De Vita’s view, is essential in order to question the current majority’s position, which may not be the same tomorrow due to our limited ability to compute and understand all the long-term consequences of this revolution. The key point is to allow the envisioning of alternative solutions able to achieve the same objective, while avoiding the fossilization on current leading trends.

Appendix - Summary

1. Introduction

The rapid advancement of the energy transition and the urgent need to achieve ambitious decarbonization goals have sparked a heated debate across Europe on the most effective policies and investments to facilitate the pathway towards Net Zero carbon emissions. This master thesis delves into this ongoing debate, with a particular focus on the field of light-duty transportation.

In the context of the Italian market and political landscape, the thesis aims to analyze the clash between two opposing groups of stakeholders. On one side, there are proponents advocating for full electrification of light-duty transport, a vision supported by the current European Commission. On the other side, advocates push for a more open-ended approach that incorporates alternative low-carbon energy vectors, such as biofuels and synfuels, to preserve the traditional automotive value chain, based on Internal Combustion Engines (ICE). At the heart of this thesis' reasoning lie two archetypal policy approaches, "technology-neutrality" and "technology-specificity," as defined by the study "Technology Neutrality for Sustainable Transport" (Agora Verkehrswende, 2020).

Technology-neutrality refers to an open-ended regulatory approach, focusing solely on the primary objective of reducing CO2 emissions in accordance with the 2030 and 2050 European Agenda. This approach avoids including sub-targets related to specific technologies or subsequent industrial levels. It is championed by stakeholders aiming to safeguard traditional value chains.

In contrast, the technology-specificity policy approach, more in line with the current EU Commission's stance, not only includes the CO2 emission reduction target but also enforces specific normative constraints to promote the use of specific technologies mixes in the different highly carbon-intensive sectors, aiming at the most efficient and rapid achievement of Net-Zero carbon emissions. Advocates of this approach consider electrified mobility to be the most efficient, sustainable, and environmentally friendly option for decarbonizing light-duty road transport.

The overarching objective of this master thesis is to undertake an objective analysis of these two policy approaches to identify which one offers the most efficient solution for realizing the ambitious European decarbonization plan. The analysis will consider prevailing normative, technological, economic, and social conditions, and their potential future impacts on the light-duty transport industries of both Italy and Europe.

Research Question

"Which policy-making approach is more efficient in enabling the European energy transition plan for transport, in relation to the normative, technological, economic and social landscape in Italy?"

To address the research question, the thesis will employ an existing framework developed by Agora in 2020, known as "Technological Neutrality and Technological Openness”. This framework allows for an assessment of which type of regulation (technology-neutral vs technology-specific) is best suited for different decision spaces (technology open vs technology biased), taking into account economic indicators such as the existence of market imperfections, secondary policy objectives, and information asymmetry.

In addition to the framework application, the thesis seeks to augment its findings through empirical data obtained from interviews conducted with representatives of the main Italian stakeholders involved in the energy transition debate. These interviews will provide valuable insights and perspectives from those at the forefront of shaping energy policies and investments. By examining how different stakeholders are affected by these policy decisions and analyzing their main arguments, the thesis seeks to shed light on the complexities of the energy transition debate.

Through this comprehensive examination of the technology neutrality versus technology specificity debate, this master thesis aims to contribute with relevant findings and implications to the ongoing energy transition discourse, signaling to policymakers and stakeholders the potential threats and opportunities of the different alternative avenues towards an efficient and sustainable decarbonization of light-duty road transport.

2. Theory

2.1 Key Legislation on the Energy Transition

The European sustainable energy transition path rests on some fundamental normative pillars.

In terms of objectives, the first, most important step taken after the Paris Agreement was the 2019 EU Green Deal (European Council, 2019), an ambitious bundle of legislative proposals which set two impressive goals: to achieve a CO_2 emission reduction of -55% within 2030 (2030 Climate Target Plan) and to reach Carbon Neutrality – Net Zero emissions – by 2050 (European Climate Law). The key principles driving the European decarbonization are set to be:

4. Sustainability
5. Security of supply
6. Competitiveness

Fit For 55

The Fit For 55 (European Council, 2021) law package is a bundle of draft legislations aimed at revising the EU body of law in relation to climate, energy and transport. With a specific focus on the two measures that most impact the transport sector and energy products/vectors, the Fit For 55 suggests:

- A revision of the regulation on the CO2 emission standard of cars and vans, adopted by the European Council in March 2023 (with a review clause), which increases the CO2 reduction to -100% (Net Zero) by 2035.
- A revision of the Renewable Energy Directive recast (RED II), aiming at increasing the Renewable Energy share target to 40% by 2030 (vs 32%). (COM (2021) 557: RED II Revision Proposal, 2021)

Recently approved, this review of the CO2 standard regulation (COM (2021) 556: CO2 Standards for Cars and Vans, 2021) updates and increases the CO2 reduction goals from newly build cars, which are due to achieve -55% emissions reduction by 2030, and -100% (net zero) by 2035. Due to the greatly ambitious nature of this proposal, associated with an emission calculation methodology which undoubtably favors the uptake of EVs (Electric Vehicles), and the phase out of the ICE (Internal Combustion Engine), it inevitably sparked great resistance among some of the main stakeholders, giving a key contribution to the birth of the hot debate that exists today around the energy transition of the transport sector. Given the many requests from the affected stakeholders to include in the review other technological options, more friendly to the refining and ICE industries, the approval of the review, although without immediate modifications, included a clause to eventually develop exceptional CO2 reduction standards for e-fuels, according to the pressing requests of Germany, one of the economies most affected by the energy transition. Given the opening of the commission to e-fuels, which require a different emission accounting method in order for their environmental contribution to be correctly assessed, it is still possible that, in the future, Italy's favorite technology options for decarbonization may receive a similar treatment.

The Renewable Energy Directive (Directive 2009/28/EC: Promotion of the Use of Energy from Renewable Sources, 2009) sets the target for the share of electricity to be produced with renewable sources. The target, initially set to 20%, has been increased to 40% (by 2030) within the Fit For 55 package, ad further upshifted to 45% within the REPowerEU Plan. The directive also includes rules and principles to facilitate the uptake of renewable energy sources/vectors, production and consumption rights, and biomass sustainability criteria. Finally, the RED has an additional essential function, regarding the energy transition of the transport sector: it contains, in its annexes, the official emission calculation formula and methodology, along with the official list of emission factors for each publicly known energy source/vector.

Fuel Quality Directive & ILUC

Another important European law is the Fuel Quality Directive (FQD) (Directive 2009/30/EC: Fuel Quality Directive, 2009), which sets a GHG reduction target for fuel producers. The directive lists the sustainability criteria for renewable biofuels, referencing also the ILUC (Commission Delegated Regulation (EU) 2019/807: Indirect Land Use Change (ILUC), 2019), which limits the use of biomass-intensive fuels that compete with food and feed for the feedstock use, in terms of land occupation.

2.2 Key technologies of the energy transition

The criteria that will be taken into consideration, in order to fully understand the potential contribution towards decarbonization of the alternative technologies, are:

1. GHG (Greenhouse Gas) emissions and local pollution associated with the production and use of the energy product/vector;
2. Technology maturity;
3. Economic and social costs (production costs, economies of scale, existing infrastructure, impacts on industry upstream and downstream, occupation);

As the primary objective of the European Green Energy Transition is the reduction of global and local pollution, a crucial matter to address is the choice of emission calculation method. In this regard, some of the main arguments against the current decarbonization project revolve around the supposed unfairness of the TTW (Tank-To-Wheel) emission calculation method, which is deemed to be in violation of the technological neutrality principle. The alternative emission calculation methods suggested are WTW (Well-To-Wheel) and LCA-based (Life Cycle Assessment). As a general rule, there is an important trade-off to take into account: on the one hand, the requirement of having a relatively simple and easily comparable emission accounting methodology; on the other hand, the necessity to take into account all the emissions relative to the other phases of production, use and disposal of the vehicles and energy vectors/sources, which greatly complicates the analysis. Notably, the Fit For 55 regulation for emissions of new cars and vans (-100% by 2035), currently based on a Tank-To-Wheel methodology, includes a provision to develop a common LCA emission accounting method by 2025.

The technology options for phasing out fossil fuels and achieving the current decarbonization targets

In terms of available alternatives to the traditional ICE, the technologies most frequently employed are:

- HEV (Hybrid Electric Vehicles), which use both an internal combustion and an electric engine, with a battery back that only recharges during the use of the vehicle (e.g. during breaking);

- PHEV (Plug-in Hybrid Electric Vehicle), variant of the regular HEV, which enables the user to recharge the battery pack directly connecting it to an electric socket;
- BEV (Battery Electric Vehicles), 100% full electric vehicles with no combustion engine, requiring to be recharged at an electric socket;
- FCEV (Fuel Cell Electric Vehicles), also full electric vehicles powered by an Hydrogen fuel cell.

There is also the possibility, for traditional ICEs, to run on alternative Low Carbon Fuels, like LNG, biofuels, synthetic fuels, recycled carbon fuels and hydrogen, with varying degree of needs for adaptation measures (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

In terms of available alternatives to fossil fuels, the main technologies considered are:

- Renewable electricity;
- Low Carbon Fuels (LCFs);
- Hydrogen.

<u>Renewable Electricity</u>

According to the European path to decarbonization, as envisioned in the Fit For 55 plan, the electricity vector will be the main decarbonization driver, by coupling the electrification of end uses to the decarbonization of power generation. This process favors the uptake of RES (Renewable Energy Sources), benefitting, within the Renewable Energy Directive, from the highest decarbonization-contribution "multipliers", which exist "in order to ensure that the positive impacts of electrified renewable energy-based transport are properly accounted for" (DIRECTIVE 2018/2001: Promotion of the Use of Energy from Renewable Sources (Recast), 2018).

Electricity, as a vector, always delivers clean, emission-free energy to end uses. However, its actual environmental sustainability depends entirely on how it is generated. In the past decade an impressive drop in the cost of RES has taken place, most notably regarding wind-power and photovoltaic, which are now essentially cost-competitive even without any public incentive (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022). In 2020, Europe exceeded its renewable energy target (COM(2010) 639: Energy 2020, 2010) of 20% (of electricity produced from RES), reaching a promising 22.1% quota, followed by a slight decrease the next year, likely due to the effects of the Covid pandemic.

Two main benefits are generally associated with the use of renewable electricity in the road transport sector:

3. *Emissions reduction*;
4. *Increased energy efficiency*.

Beside these two key benefits of electrification of transport, which are mostly agreed upon, there are several other impacts and key enablers over which there is still much debate. The main uncertainties involve:

production scale up & development of public and private recharging infrastructure; public investment needs; LCA emissions; battery development and reuse; geopolitical impacts, dependencies and sourcing security; costs for users and manufacturers; international competitiveness & innovation; energy system impacts; GDP and employment impacts.

Low Carbon Fuels

Under the "Low Carbon Fuels (or LCFs)" label falls a wide variety of combustible fuels of biogenic or synthetic origin. LCFs include, therefore, multiple products with different potentials for decarbonizing transport, being diverse in their environmental impact, stage of technological maturity and socio-economic implications. LCFs generally share the valuable quality of being easily implementable in the current energy system, as they "can be blended with petroleum-based fuels, combusted in internal combustion engines, and distributed through existing infrastructure, subject to exemptions" (IEA Bioenergy, 2023).

According to their main feedstock and technologies for production, they are categorized in the following types:

5) Conventional biofuels;
6) Advanced biofuels;
7) Synthetic biofuels;
8) E-fuels.

Upsides:

According to the study conducted by Rie and Unem (RIE & Unem, 2022), LCFs are associated with several advantages, including: (1) significant reduction of CO2 emissions over their life-cycle, compared to fossil fuels, which varies in relation to the feedstock, up to net zero emissions (e-fuels); (2) option of being used in almost any kind of transport, essential in decarbonizing hard-to-abate sectors; (3) immediate applicability in the existing vehicle fleet, along with immediate positive environmental impact; (4) safeguard of the national value chains linked to the use of the Internal Combustion Engine (ICE), which is able to comply with the EU emission caps thanks to the LCF use; (5) promotion of the Italian refining industry and infrastructure, which, after some upgrading and updating intervention, could be used for the production of LCFs, without the need of greenfield investments; (6) ease of storage and distribution, compared to other alternative energy vectors/products; (7) mainly national value chains, with little reliance on foreign imports, addressing the energy sourcing security issue; (8) safeguard of the workforce, as the main competences can be easily repurposed.

Downsides:

1. The so-called Food-Energy-Water nexus connects food, energy, water and climate to the global economy in terms of complex systems, factors between which the interaction has become critical, raising concerns over sustainable development and sourcing security. This issue regards in particular 1G and 2G biofuels, namely those that tend to compete, in terms of feedstock, with food and feed uses.

2. One important issue with biofuels is the carbon-nitrogen nexus, for which there is a trade-off between a low Carbon (CO_2) and low reactive nitrogen (Nr) emissions footprint. Biofuels usually have lower Carbon footprint and higher nitrogen emissions due to intensive farming processes, while fossil fuels have a high CO_2 footprint and lower Nr emissions. However, some types of LCFs have low CO_2 and Nr footprints, making them better options for transportation fuels.

3. Another relevant issue is that LCFs will always perform worse than Electricity or Hydrogen in terms of emissions of local pollutants, especially when it comes to NO_x emissions. This limitation is inextricably linked to all the combustion fuels. However, local pollutants emission is mediated by the type of ICE, with more recent types (according to the Euro regulation) greatly reducing the PM and NO_x. (Confindustria & ANFIA, 2019)

4. Due to the ecosystem's limited capacity to supply bio feedstocks, biofuels are facing sustainability issues (Liu et al., 2018). However, although the scientific community agrees upon the critical nature of this issue, there is little agreement upon whether the quantity of sustainable feedstock is able to satisfy the current and future demand in Europe. However, there are studies (Imperial London College Consultants, 2021) which confirm the availability of all the sustainable biomass for fuels production required in Europe, both for the short, medium and long period, even after accounting for all the demand in non-energy sectors, as well as limiting the observation with the biomass which doesn't compete with food and feed, and doesn't compromise biodiversity.

5. The ICE in general has considerably lower energy efficiency than the electric drivetrain. Furthermore, "alternative fuels, ethanol, MTBE and specially bio-ETBE routes show a higher energy use than traditional fossil fuels (up to a factor of 2 in the case of bio-ETBE)" (Prussi et al., 2020). Additional downsides in terms of energy efficiency are associated to gaseous energy vectors, since they require high pressure/low temperature storage solutions in order to ensure enough energy density to transport systems (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

6. Gaseous vectors imply one more concern, which threatens their performance in terms of environmental sustainability. Gas flaring events, i.e. leaks of gas during transmission & distribution, imply potentially very high environmental footprint, which, when taken into account, risks to substantially worsen the sustainability profile of biogases (Ministero delle infrastrutture e della mobilità sostenibili (Mims), 2022).

Hydrogen

Hydrogen is an energy vector rather than an energy source, meaning that its production, which can happen in different ways, requires an equal or greater energy input than its yield, making the final product reflective of the CO2 emissions of its energy source.

Hydrogen is considered very useful in dealing with two main issues of the European decarbonization path: to ensure balance within a renewable electricity-driven energy system, and to decarbonize Hard-to-Abate sectors. However, the technology is in its very early development stages, meaning the costs are extremely high and massive investments are required in both production and distribution. Additionally, there are still some important technical limitations. For these reasons, although very promising, the use of hydrogen in road transport in any significative amount will be feasible only in the long term, being therefore not counted as an option for achieving the 2030/2035 decarbonization targets for road transport.

2.3 Key stakeholders in the energy transition

While, at this point in time, every stakeholder is more or less aligned on the objective of Net Zero Carbon emissions, the true battle is fought over which technology option (and, more generally, which policy approach, between technology neutrality and technology specificity) can achieve the environmental target with the least negative socio-economic impacts. Both of the two main parties, namely the electricity and EV industry, and the low carbon fuels and traditional ICEV industry, aim at promoting the technology which, in their mind, is most successful in minimizing socio-economic costs and preserving, or even improving, the competitive positioning of the European industries in the international arena.

To have a closer, deep-dive look at the aforementioned debate over the best decarbonization path, this thesis conducted six interviews with subjects that were considered as the main stakeholders, the most well-informed about the ongoing debate. The interviews include opinions from representatives of: Enel and ENI (the two most important Italian utility companies), Elettricità Futura and Unem (the two most important Italian associations of energy producers), and finally Motus-e and ANFIA (the two main industry associations representing Italian vehicles producers).

3. Methods

To answer this thesis' Research Question, namely "which policy-making approach is more efficient in enabling the European energy transition plan for transport, in relation to the normative, technological, economic and social landscape in Italy?" the analysis will employ the framework developed by Agora in 2020, known as "Technological Neutrality and Technological Openness", utilizing, as its inputs, the qualitative observations collected in the theory chapter and thanks to the interviews.

According to the study's definitions, technology neutrality of regulation consists of two dimensions. First, "a perfectly neutral regulation intervenes directly at the level of the predefined policy objective (such as the reduction of greenhouse gas emissions), while granting as much leeway as possible on subsequent levels (e.g., in the individual sectors) and abstaining from further downstream climate regulations". Second, "it does not discriminate among individual technologies. Instead, it leaves the choice between technologies to private actors", with the assumption that these actors have a better economic and technical understanding of the alternative technology options, allowing decentralized market-based decisions without state interventions to yield a social cost optimum. The more a real-world regulatory design deviates from these prerequisites for perfect technology neutrality, the more it becomes *technology-specific*.

As Agora's study maintains, neither of the two aforementioned principles of policymaking should be regarded in advance as the best solutions to achieve the decarbonization of transport sector. In fact, the efficiency of either of the two paths is dependent on a large set of normative, technological, economic and social circumstances, which are properly summarized in the wider general concept of "technology openness of the decisional space". A decision space has *high technological openness before regulation* if "the choice of technology is undistorted apart from the distortion to be corrected for (i.e. the external costs of greenhouse gas emissions)". Instead, "if further market imperfections exist besides the external costs of greenhouse gas emissions, or if the policy decision is not only motivated by social welfare", the decision space has *low technological openness before regulation*. Technology-neutral policies achieve the decarbonization targets at minimal social costs only when the decision space is perfectly technology-open. Since, however, real-life decision spaces are typically biased, the state must introduce technology-specific regulations to correct existing biases. "Technology specificity may also be needed if the regulation pursues other goals in addition to decarbonization or if the assumption that private actors have better information than the central regulator proves false".

For a technology-specific regulation to be efficient, it is essential that regulators properly acknowledge the potential biases in the decision space, in order to design adequate corrective technology-specific instruments. Therefore, beside specifying which regulatory approach is the most efficient, given the openness of the decision space ("question of indication"), there is also the need to determine the proper form of technology specificity to address the existing biases ("question of adequacy").

With the goal of comparing the efficiency of technology-specific vs technology-neutral policies, there are three main set of indicators that must be taken into account:

4) The degree of knowledge centralization;
5) The presence of potential limitation of the decisional space's technology openness;
6) The presence of further normative objectives, beyond GHG emissions reduction.

Each of these three categories contains a variable amount of specific indicators that together serve to answer to the broader question. For the purpose of this thesis, Agora's research model for the definition of the decisional space's openness has been simplified by reducing the number of items of each of the 3 main indicators

4. Results

While the assumption that private market agents have better access to information compared to the central regulator proves true, serving as a basis for an efficient technology-neutral policymaking approach, the other two key dimensions, namely the technology-openness of the decisional space and the presence of further regulatory goals beyond decarbonization, strongly indicate the necessity of a technology-specific approach.

	Electrified mobility	**Low Carbon Fuels**
Number of information carriers	Indication of Neutrality	Indication of Neutrality
Regulator' access to info	Indication of Neutrality	Indication of Neutrality
Market power	Indication of Specificity	Indication of Specificity
Users' budget restrictions	Indication of Specificity	Indication of Neutrality
Infrastructure necessity	Indication of Specificity	Indication of Neutrality
Learning and scale effects	Indication of Specificity	Indication of Specificity
Influence of politics on relative prices	Indication of Specificity	Indication of Specificity
Other policy objectives	Indication of Specificity	Indication of Specificity

5. Discussion

The analysis conducted so far highlights some interesting implications for policymakers and stakeholders involved in the energy transition of the road transport sector.

Firstly, the main objective of this master thesis was to apply the interpretative framework created by Agora (Agora Verkehrswende, 2020) in order to understand which normative, technological, economic and social conditions can justify the use of a technology-neutral or technology-specific policymaking approach in leading the transition toward Carbon Neutrality in the light-duty road transport sector. After a qualitative study of the specific conditions of Italy's Automotive and Energy Generation industries, a technology-specific approach appears to be required due to several distortion of the decisional space, and the most efficient in order to successfully achieve the important secondary environmental targets set by the European Union. However, the limited availability of key technical information to the central regulator, compared to the private actors operating within the analyzed industries, represents a significant threat for the success of a purely technology-specific approach, requiring the creation of sufficient opportunities for exchanging crucial knowledge between private and public stakeholders.

Secondly, the analysis also highlights that both of the two main alternative scenarios for decarbonizing the light-duty road transport sector require, in fact, a substantial level of public intervention, indicating that the "technology neutrality" claim might be, at the very least, misleading. The economic rationale behind the demand for including the LCFs option in the future energy mix of light-duty road transport is robust, but still greatly benefits from a public effort to coordinate the energy transition between sectors, safeguarding the free market competition, efficiently allocating resources for the costly investments required, allowing the realization of potential learning and scale effects, managing the inevitable industrial and occupational shifts, and concurrently aiming at the best outcomes in terms of energy efficiency, air quality and sourcing security.

Thirdly, as for the two alternative transition pathways, the analysis' aim was mainly to isolate the true distinction between them, without the presumption of establishing which of the two transition recipes is the best. Provided the realization of some essential enablers, both projects appear to be potentially capable of achieving Carbon Neutrality, or miserably fail in case said key enabling conditions aren't met. In terms of outcomes, what truly distinguishes the two alternative pathways is the ability of their supported technologies to achieve secondary environmental and economic targets beyond the simple reduction of CO_2 emissions in the light-duty road transport sector. However, as different objectives are better achieved by different technology options, an objective evaluation should start from clearly ordering, by priority and urgency, the three aforementioned secondary targets of the energy transition, a task which requires further analysis.

Fourthly, from a purely economic point of view, the two alternative pathways for the decarbonization of light-duty road transport are guided by opposite rationales. On the one hand, the full electrification scenario values, above all, the potential of creating new income through the development of domestic value chains for the refining, production, assembling, disposal, recycling and reusing of EV-connected products, while embracing the responsibility of centrally managing the consequent industrial and occupational transition, a key aspect to avoid collateral damage. On the other hand, the alternative scenario, supported by stakeholders of the refining and ICE industries, is driven by a more conservative approach, which aims at achieving the Net Zero as safely as possible, avoiding the risks linked to a complete industrial and occupational transition by preserving the existence of the ICE industry, lifting such enormous responsibility off of the European institutions' shoulders. The analysis carried out in this master thesis work lacks the instruments to objectively conclude whether it is more desirable to pursue a more risky, but also potentially more rewarding, transition pathway, or to moderate the revolutionary targets, in exchange for a potentially more resilient and cautious light-duty road transport future technology mix. However, while the answer to such interrogative is difficult, the relevant implication highlighted by this thesis work is the fact that the European Union, aware of the challenges linked to its approach, still decides to pursue the riskier, more revolutionary path, backed up by many stakeholders who are convinced that the future benefits will outweigh the potential losses.

Lastly, the research highlighted that, while the two main groups of stakeholders disagree on many key aspects of how to carry out the decarbonization of the light-duty road transport sector, they agree that the perspective of decisional instability represents, for both parties, the worst-case scenario. In fact, without the assurance that the European institutions will stay true to a clearly defined plan for decarbonizing the carbon intensive sectors in the upcoming years, there is no financial basis for expecting a sufficient return on investments for the long-term commitments required by private stakeholders. Unfortunately, such critical concern collides with another issue, linked to the Net Zero Carbon plan, that emerged during the interviews conducted for this master thesis, namely the fact that the timeframe required to enable an objective evaluation of the outcomes of today's decisions over the future technology and energy mix of light-duty road transport is, in truth, much longer than the ambitious deadlines set by the EU. For this reason, many stakeholders from both parties believe that the European Union has been too hasty in communicating its goals to the rest of the world, a problem that has been aggravated by the two major international shocks (the Covid-19 pandemic and the Russian invasion of Ukraine) which followed the announcement of the 2030 and 2050 CO2 emissions targets as part of the EU Green Deal (European Council, 2019), drastically changing the stability of our domestic economies and the perceived polarization of the international arena. The contradiction between the two issues must be carefully evaluated by the policymakers, keeping into consideration both the need for adjusting and fine-tuning the Net-Zero plan according to new technological and economic findings, and the necessity of remaining coherent to the decisions which already shaped the long-term investments. The upcoming review windows and the European parliamentary elections of June 2024 will be crucial milestones in determining the success of the future Energy Transition.

6. Conclusion

With the objective of analyzing the efficiency and sustainability of the main alternative solutions suggested by Italian stakeholders to pursue Carbon Neutrality in the light-duty road transport sector, this thesis has gone through an extensive observation of the legislation, technological landscape and key stakeholders' positions linked to the European decarbonization plan. The stage of collecting theoretical information through the literature review and interviews with key stakeholders in this master thesis, has provided the inputs for answering the main Research Question, "Which policy-making approach is more efficient to enable the European energy transition plan for transport, in relation to the normative, technological, economic, and social landscape in Italy?".

Agora's "Technological Neutrality and Technological Openness" framework (Agora Verkehrswende, 2020), allowed to translate qualitative and empirical data into an answer to whether a "Technology-neutral" or "Technology-specific" regulatory approach would be more desirable, as well as to isolate and highlight the most critical aspects of and key differences between the two main alternative decarbonization scenarios analyzed by this thesis. According to the results of the analysis, in relation to the normative, technological, economic and social characteristics of the decision-making space, a technology-specific approach comes out as the best and most efficient regulatory pathway, in order to avoid perpetrating the existing biases in the European light-duty road transport sector during the process of achieving Carbon Neutrality. The efficiency of a purely technology-specific approach is, however, partially questioned by the limited availability of accurate and up-to-date information by the central regulator over technological and economic matters of the light-duty road transport industry, entailing the necessity of deepening such central knowledge in future revision opportunities of the European road to Net-Zero emissions plan.

Thanks to the key contributions of the interviewees, as well as a thorough literature review, the analysis conducted within this master thesis has also highlighted other relevant implications for public and private stakeholders, specifically regarding the comparison between the "full electrification of transport" scenario, and the "diversified technologies" alternative scenario, advocated by stakeholders of the fuel refining in ICE industries. A key similarity between the two scenarios is that neither of those requires a technology-neutral regulatory approach, but rather different choices in the decision-making process, having both robust scientific evidence for being considered theoretically able to achieve Carbon Neutrality. As for the differences between the two alternative pathways for decarbonizing light-duty road transport, it all comes down to two key factors: (1) the two technology mixes proposed vary in their ability to achieve secondary sustainability targets, with full electrification being more suited to reduce overall energy consumption and local pollution, and LCFs achieving better sourcing security by reducing the reliance on foreign impots of rare and expensive raw materials; (2) the two solutions differ in terms of ambitions and risk factors, as full electrification entails greater economic and financial risks, as well as greater potential gain, while the LCF scenario is naturally more conservative.

Finally, an additional observation regards the potential existence of dangerous contradictory relation between the concern of ensuring decisional stability, as a key element to create investors' confidence, and the need to allow future review opportunities of the European energy transition plan, to allow recent and future international economic shocks and technological breakthroughs to enter the decision-making equation.

As a conclusive reasoning of this master thesis, given the increasing urgency of achieving the primary objective of reducing the carbon intensity of our economies, to safeguard life on this planet, the final decisions over the economic and secondary environmental objectives, and therefore, ultimately, over the preferred approach to decarbonize light-duty road transport, should be based on the goal of increasing, as much as possible, the probability of successfully achieving the already very ambitious primary decarbonization target.