Estimating European Transport Investment Needs for Completing 2030 Climate Targets

Antoine Bizien

Master Thesis

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Institute for Climate Economics

Estimating European Transport Investment Needs for completing 2030 Climate Targets

By

Antoine Bizien

Student Number : 5854318

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Graduation committee

First Supervisor & Chair:	Dr. J.A. Annema, TU Delft
Second Supervisor:	Prof. W. Veeneman, TU Delft
External Supervisor:	Clara Calipel, I4CE

Summary

On the road towards net-zero CO_2 emissions, the European Union aims to reduce its emissions by 55% in 2030 compared to 1990 levels, requiring profound changes in the economy and society. The "Fit for 55" policy package supports this transition by notably setting targets for renewable energy production, transport electrification, and building renovation. Implementing the policies will require massive investments in the European economy. Knowing the level of investment to be made is key to understanding the macroeconomic impact of the transition, creating investment policies and prioritizing sectors.

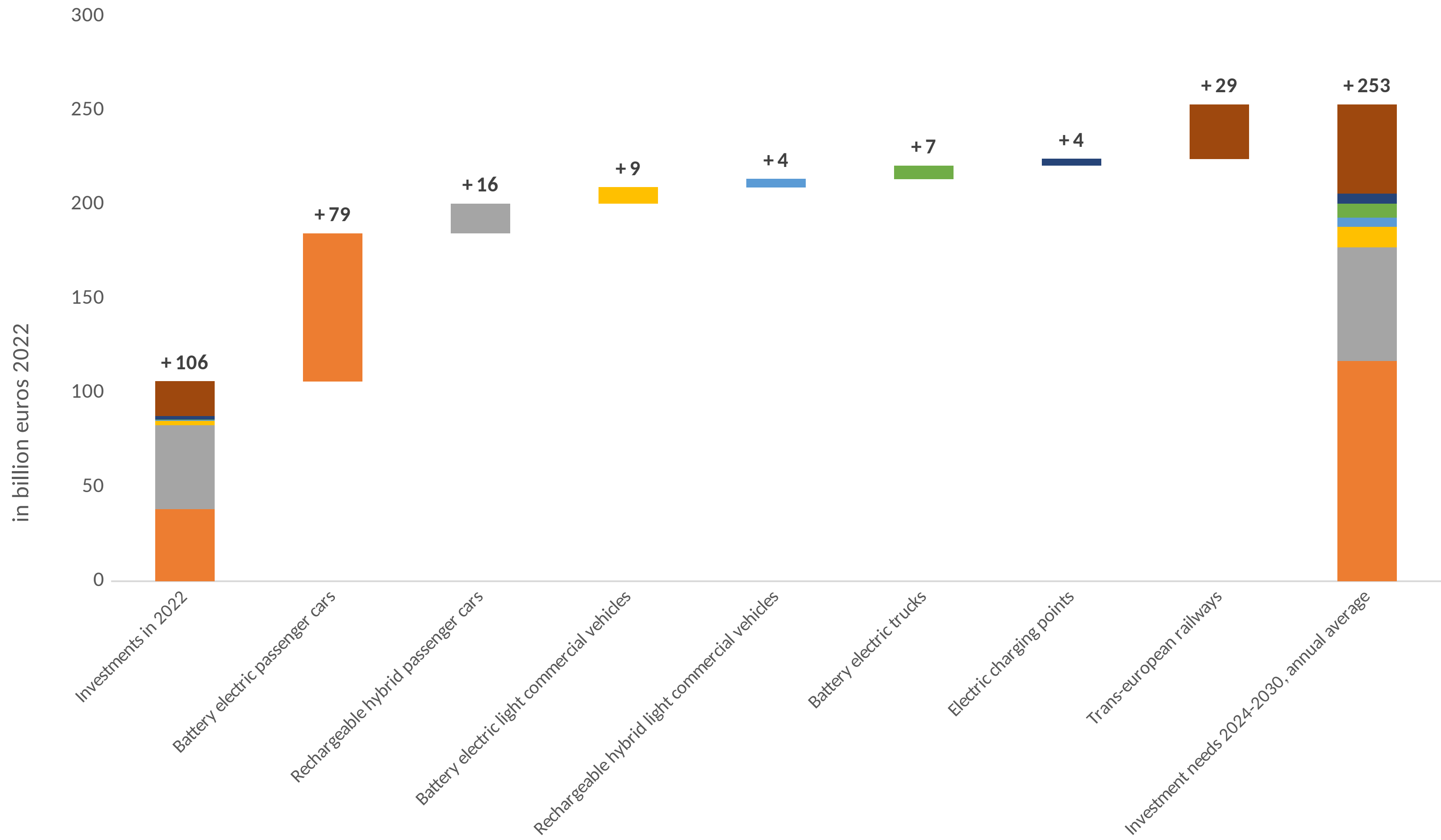
However, in the transport sector, accounting for around 30% of the total EU CO_2 emissions, no independent assessment of the investment needs has been found. **In this master thesis, the level of gross investments required for meeting 2030 transport policies at the European scale is estimated and compared to the historical level**. The approach followed provides granular details between passenger cars, commercial vehicles, charging points, and trans-European railways. The European Policies were first translated into deployment scenarios. Taking into account technological improvements, investments were finally estimated.

The results show that between 2024 and 2030, **making EU targets in the transport sector requires 253 billion euros of investments per year, or** 1.6% of the EU GDP (Figure 1). When compared to the current level, 42% of the yearly investment needs are already met. It leaves an investment gap—defined as the extra investment necessary compared to the current level - of 147 billion euros, or 0.9% of the EU GDP. Investment needs between now and 2030 are primarily driven by the electrification of vehicles, which accounts for 78% of the total deficit. Essential support to this technological shift, additional investments in charging points only represent 2% of the total deficit. Trans-European Railways, with a deficit of 29 billion euros, has the second-highest need for additional investments (20%). These figures ignore investment needs in key transport systems for reducing CO_2 emissions not covered by European regulation, such as urban public transport.

From a policy perspective, the Regulation setting CO_2 standards (2023)—to generalize electric vehicles—was found not to be sufficient for achieving climate objectives. Results also show that **recent investment trends in railways and rechargeable hybrids are stagnating, in contradiction with the necessary increase in investments**. For all sectors, filling the investment gap is key to meeting climate objectives. A political discussion is required to define the right balance between private and public investment. If public money was to be invested, I recommend targeting infrastructure as an enabler of private investment. However, challenges in the implementation of policies remain. Notably, the social impacts on Europeans of electrification and carbon prices are still uncertain, and the effectiveness of the modal shift toward rail is not guaranteed with this policy package.

For the scientific community, this thesis helps to understand the macroeconomic effects of the transition. **This thesis is also a use case for using the investment gap as an indicator for monitoring policies. Through the** proxy of investment, the implementation of the European transport policy is tracked. It provides a reliable indicator measuring both price evolution and technology deployment that stands out for its uniqueness and selectivity. Fitting the language of policymakers, it is easily communicable, as proven by the press coverage of the report I co-authored at the Institute for Climate Economics. On the other hand, this indicator doesn't inform about the triggers of the investment, may oversimplify the environmental benefits of the technologies considered, and should be treated with caution when not compared to fossil investment.

Figure 1 – Investment gap of the European Economy for meeting the 2030 climate target in the transport sector, decomposed by technology



Source: Author. This figure presents the gross investments necessary for implementing European transport climate policies in the European economy. It compares the 2022 level to the average annual investment required between 2024 and 2030. In 2022, 106 billion euros were invested, while 253 billion euros are required annually between 2024 and 2030. For each technology, the investment gap compares the investment required with 2022 investments. For example, compared to 2022, an extra 79 billion euros are needed for battery-electric passenger cars.

Acknowledgments

The final chapter of my education lies in front of you. Eight years after receiving my high school diploma, this thesis concludes my Master's in Engineering and Policy Analysis. I joined it with the idea that scientific analysis can benefit policymakers for facing the challenge and threat of the climate crisis. This Master's Thesis is my attempt to see if I was right.

I conducted it with the Institute for Climate Economics - I4CE. The warm welcome and the rich discussions I had there have made these months a fulfilling period for me. I learned how to look for impact by playing with the political context and navigating through the actor space. I would like to thank my supervisor, Clara Calipel, for her mentoring and trusting me with this project.

Managing the rhythm and objectives of a think-tank with academic standards was a challenge I struggled with. My supervisors, Dr. Jan Anne Annema and Prof. Wijnand Veeneman were there to help me make the switch. I would like to thank them for their patience and continuous support in the writing process. Their constructive criticisms have challenged me to examine this work under new lenses.

If this thesis wasn't a straight line, it echoes my academic journey between France and the Netherlands. At every step, I could always count on the support of my loving parents and family. I cannot summarize with a sentence all what I received that made me who I am. *Merci pour tout !*

My decision to come to the Netherlands was impulsive. Thanks to the people I met here, I can also say that it was a good one. With my friends, I enjoyed a light-hearted, varied, and overall fun time. I am looking forward to seeing how our friendships will continue. Leaving the Netherlands for this thesis has left me with a bittersweet taste. Thankfully the flavor of eating ice cream with you, Nina, helped me overcome it.

With learning and memories, I feel more than ready to experience future adventures.

Antoine Bizien,

May 2024

Front page picture : David Bartus

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1. Introduction

1.1. Background

In 2015, all countries pledged in the Paris Agreement (Paris Agreement to the United Nations Framework Convention on Climate Change., 2015) to limit global warming to "well below 2, preferably to 1.5 degrees Celsius", compared to pre-industrial levels. To keep emissions below 1.5°C, global emissions should be net-zero in 2050 and have reduced by 45% in 2030 compared to 2010 (IPCC, 2022, p. 12). However, since then, global emissions have continued to increase: from 35.7 GTCO2eq in 2015 to 37.5 GtCO2eq in 2023 (Friedlingstein et al., 2023).

The route to net zero still exists. According to the International Energy Agency (IEA) between now and 2030, it requires a mix of behavioural changes and the uptake of technologies aiming at reducing fossil-fuel consumption (IEA, 2023, p. 69). For example, electric vehicles, wind power, and hydrogen are key. For the 2030 target emission reduction, the IEA estimates that more than 80% of the emissions reductions are feasible with technologies that are already mature.

However, the latest data show that states are not doing enough to develop these solutions. The UN in its latest assessment of policy plans provided by States, shows that they remain insufficient to limit global temperature rise to 1.5°C (UNFCC, 2023). Moreover, studies have shown that the targets set in these plans will most likely not be met. In 2019, Den Elzel et al. (2019) showed that only 6 out of the 20 countries of the G20 are expected to meet their unconditional target. At the time, The European Union wasn't expected to meet its target. Since then, the European Commission proposed the Green Deal in 2019 to make the EU climate-neutral by 2050 and reduce emissions of 55% in 2030 compared to 1990 (European Commission, 2019b).

To reach the target the European Commission has proposed a policy package, called Fit for 55 (EU Commission, 2021). However, European regulations have a long history of falling short (Haverland & Romeijn, 2007; Weibust & Meadowcroft, 2014, Chapter 10). Monitoring the progress of policies is necessary for ensuring the effectiveness of the law (Tosun, 2012) and intends to ensure that policies are accomplishing their expected goals (Howlett et al., 2009, p. 185).

1.2. Policy gap in the monitoring of EU climate policies

Building on the results from literature review, I defined a framework for analyzing the different methods for monitoring climate policies based on their research objective (see 2.1.2). This framework has been used for mapping the different instruments for monitoring the climate progress of the European Union presented in Table 1.1. Annex 1. gives a detailed overview about the monitoring made by the European Commission. For each research question, an associated policy gap is identified.

Table 1.1: Monitoring Solution from the European Union for Climate Mitigation Progress and the policy gap identified

Order	Question	Existing solution for the European policy	Policy gap identified

A	How are CO2 emissions evolving?	The European Environment Agency is tracking historical emissions (European Environmental Agency, 2023)	None
B	Is the official target sufficient for meeting climate objective?	The European Union aims for being net-zero in 2050 with an intermediate target of -55% in 2030 (Regulation (EU) 2021/1119, n.d.)	None - Aligned with the IPCC recommendation.
C	Are the expected emissions reduction associated with policies sufficient for meeting the official target?	The European Commission provides every 5 years a study on the expected emission reduction based on the National plans. It analyses expected national CO2 emissions reduction with the policies implemented and concludes about the progress in meeting the target.	The review of Member States plan is only done every five years. Compared to the 2030 target, the time period is short. The latest review shows that "emissions by 2030 reduce under existing and planned measures by 45 % and 50 % respectively below 1990 levels" (European Commission, 2023a, p. 9).
D	Is the official target credible from a political perspective?	The target of -55% is legally binding. The EU Institutions and the Member States are bound to take the necessary measures at EU and national level to meet the target (Regulation (EU) 2021/1119, n.d.).	Not discussed here. See for example, (Peeters & Athanasiadou, 2020) discussing Effort Sharing Regulation obligations for Member States.
E	Are the policies implemented on time?	The monitoring of the progress in the implementation of policies, is mainly done by Member States submitting national energy and climate plans. These plans are reviewed every five years (see C.). Members States should also communicate on their progress for specific texts. The Commission monitors the progress of the EU as a whole, in particular as part of the annual State of the Energy Union report every two years (European Commission, n.d.).	Schonefeld (2021) shows that the reporting on specific texts from Member States, lacks different element such as a: a common framework, and European scale overview, and and a monitoring not only focusing on effects. This observation is shared by the European Commission that states that 'More detailed monitoring is needed to assess progress on enabling factors that drive emissions in the different sectors to better highlight areas where progress is lacking or more action is needed" (European Commission, 2023a)
F	Are the required	The impact assessment of the	Not discussed here – For the

	technologies ready for deployment?	Climate Law includes part about technology assumptions.	2030 target, the IEA estimates that more than 80% of the emissions reductions are feasible with technologies that are already mature (IEA, 2023, P.69

From this overview, policy gap E will be addressed. It seemed the most interesting to tackle. Indeed, the policy package proposed by the European Commission is sufficient for meeting the 2030 target, but there is a current implementation gap in the policies (European Commission, 2023a, p. 9).

1.3. Research gaps address by the Master Thesis

From a policy perspective, it is of interest to monitor the implementation of the EU policy package. I decided to use the investment gap as an indicator for monitoring progress of climate policies. The investment gap (also called investment deficit or financing gap) "is defined as the difference between current flows and average needs to meet the long-term goals of the Paris Agreement." (Shukla et al., 2022, sec. FAQ 15.3). Estimating investments required for meeting the objective of the Fit for 55 is necessary to define such indicator. The second part of the literature review test the existence of a research gap on the investment needs for meeting transport regulation. The scope to transport as this subject seemed ignored by the different studies.

The literature review showed that multiple research gaps existed about the monitoring of climate policies and on measuring the investment required for meeting the European policies on Transport (see 2.1.3 and 2.2.3. for details).

The main research gap this Master Thesis will address is to provide an independent and transparent assessment of investment needs for meeting European policies on transport (**Research gap 6)**. The bottom-up approach chosen, providing a granular breakdown of the investment needs (partly addressing **Research gap 7**). This Master Thesis will also provide an use-case of using the investment gap as an indicator for monitoring the implementation of climate policies contributing to the scientific debate **(Research gap 4).**

<u>Definition:</u>

The IPCC defines investment as: "Investment, in an economic sense, is the purchase of (or CAPEX for) a physical asset (notably infrastructure or equipment) or intangible asset (e.g., patents, IT solutions) not consumed immediately but used over time." (IPCC, Working group III, Chapter 15)

This thesis limits itself to purchase of physical good . It corresponds to the **gross fixed capital formation in durable goods** of official statistics (European Union Statistical Office, 2010) in the economy. Simply put, it measures the total spending on buying goods that will help reduce emissions, measuring the **total acquisition cost**. It's important to note that the investments are measured at the **European economy scale**. All actors, public or private, are considered.

Section III-2 gives details for this definition and discusses the reasons and implications of this choice.

1.4. Research scope

This research aims to measure the investment required for meeting European Transport policies objectives. For the European Union, reducing transport emissions is key to meeting the target of -55% in 2030. Transport is responsible for around 30% of Europe's emissions (European Environmental Agency, 2023b), making it one of the most polluting sectors. Moreover, it's the only sector in the European Union that has increasing CO2 emissions. In 2021, it had increased by 25% compared to 1990. (European Environmental Agency, 2023a).

For meeting the 2030 target, the favoured scenario proposed (European Commission, 2020a, p. 52) shows that transport should reduce its emissions by 16,3% in 2030 compared to 2015. Missing the target for transport would lead to too many emissions in 2030. But it would also threaten the longer-term transition due to carbon lock-in effects (Seto et al., 2016). Cars have indeed a lifetime as long as 35 years in Europe (Held et al., 2021) and infrastructures are made to last decades (Guivarch & Hallegatte, 2011).

For transport, the policy package could be summarised as follows:

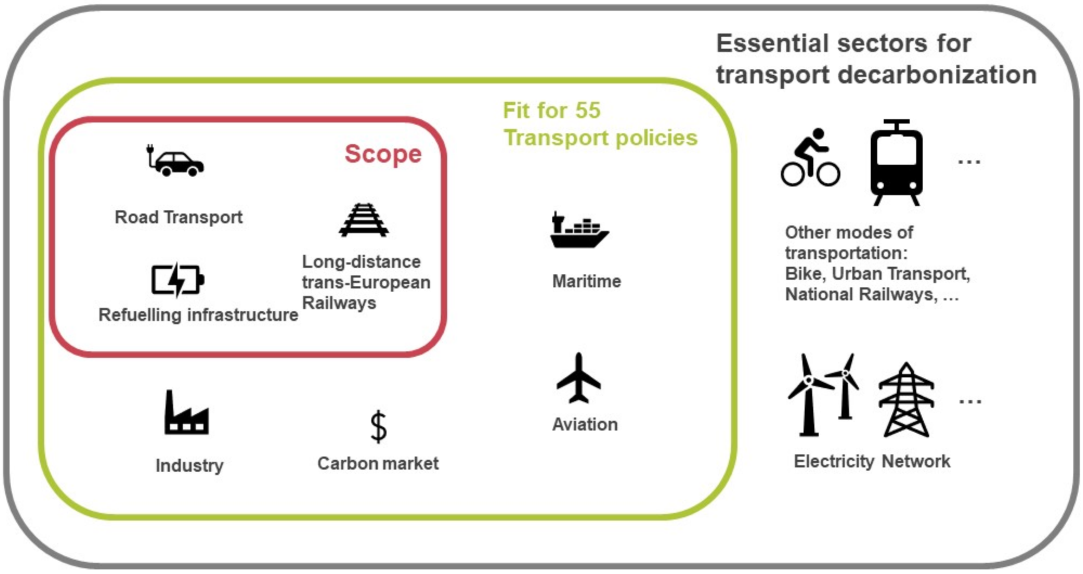
1. Transport emissions are caped. The European Union has implemented an emission trading scheme including notably aviation, maritime and road transport (the European Parliament and of the Council, 2023a , (2023/959)). Total emissions are limited and "right-to-emit" are bought. With this system, one can guarantee that the total emissions won't be above the ceiling. The second objective is to give a price to carbon, to incentivize decarbonisation.

2. To accompany the decarbonisation, the European Union is implementing standards. For maritime (the European Parliament and of the Council, 2023d , 2023/1805) and aviation (the European Parliament and of the Council, 2023e , 2023/2405), the CO2 density of fuel used is limited. Road transport, sets maximal standards of emissions for the new vehicles sold (European Commission, 2023c; the European Parliament and of the Council, 2023b , 2023/851)
3. Finally, it favours modal shifts by developing infrastructure. Infrastructures objectives for supporting the deployment of alternative fuel are set (the European Parliament and of the Council, 2023c, 2023/1804) Rail has historically been created as a patchwork of different countries' networks. It makes travel slow and uneasy for the citizens and raises issues of compatibility at the border between different countries. The European Union has tried to alleviate the issue by (i) encouraging transborder connections (ii) setting standards (iii) developing long-distance fast trains (European Commission, 2021e).

Analysing CO2 emission per sector, land transport originates 3 times more CO2 emissions than aviation and maritime transport, accounting for 76% of C02 emissions of transports in 2021 (European Environmental Agency, 2023). Intersecting with the European regulation agreed, I decided to focus on the electrification of new vehicles, the deployment of public charging point infrastructure and the deployment of long-distance railways infrastructure. Figure 1.1 details, using a bull-eye diagram, the scope used.

Maritime and aviation transport being covered by the European regulation are thus excluded from the scope of this study. Also most of the national and local transport is not covered by European law. Bikes, urban transport, or national railways are then not covered by European Regulation. More details on the regulation covered are presented in Methodology.

Figure 1.1 - Bull-eye diagram for the perimeter of study.



Source: Author. This diagram presents the different sectors essential for decarbonization, the one covered by European texts and the one included covered by this study.

1.5. Research questions and research approach.

This master thesis will answer the main following research question, addressing the research gaps identified.

What are the investments required in the European Union economy for meeting the "Fit for 55" regulations for road and rail transport and how do they compare with current levels ?

In addition three sub-research question have been defined:

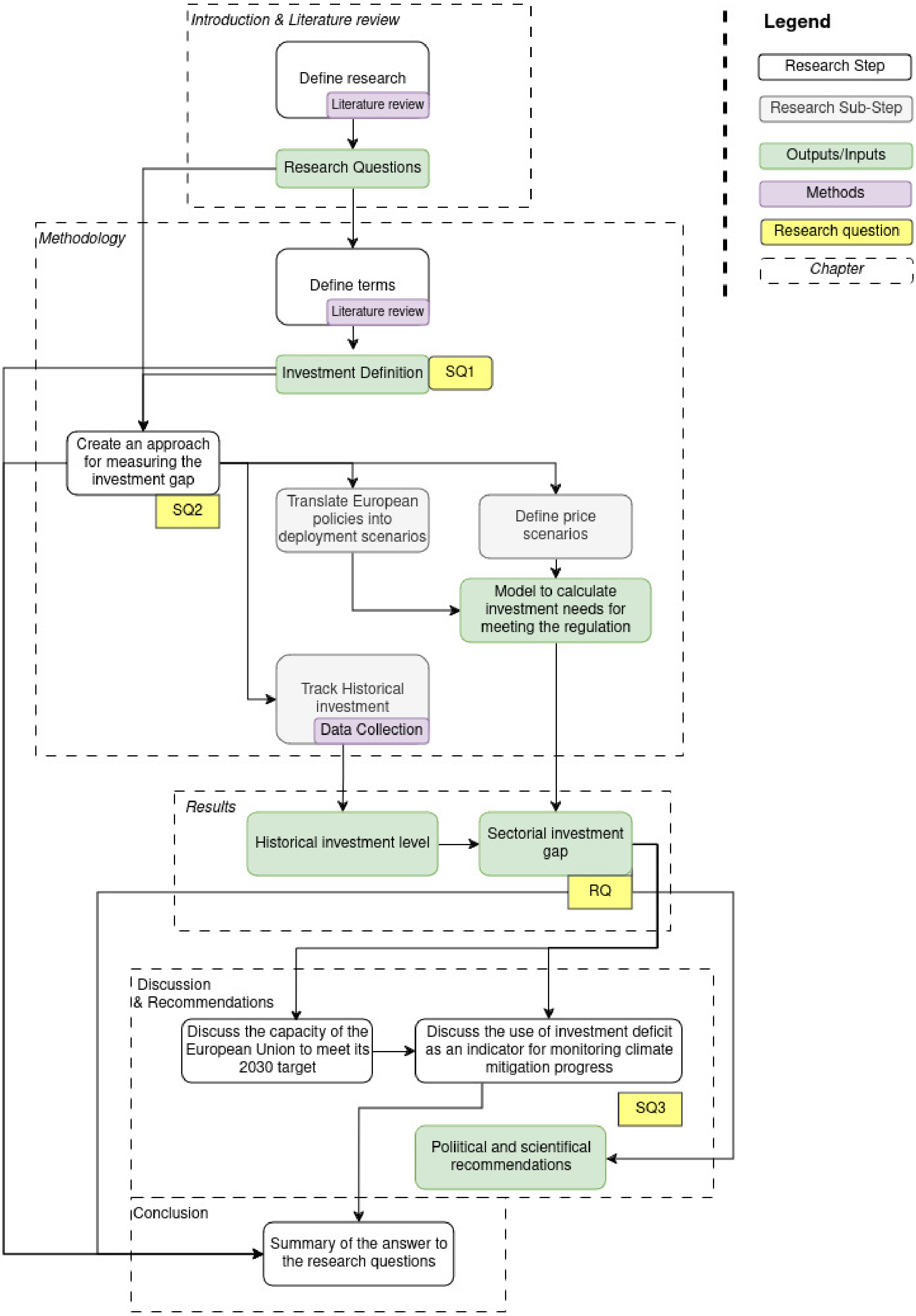
SQ1: What different definition of investment can be used ?

SQ2: How to estimate investment needs for meeting the European regulation ?

SQ3: Can the investment deficit be used to monitor implementation of the policies ?

The research approach followed to answer the different research question is presented on Figure 1.2.

Figure 1.2 - Research flow diagram and corresponding legend.



Source: Author. The flow represents the research trough the different steps using the outputs and inputs. For some steps the research method is precised. Answers to the research questions are given through the Thesis and summarized in the Conclusion. Note that "SQX" stands for "Sub-Question X"and "RQ" for the main research question,

1.6. Scientific and societal relevance

This master thesis encompasses the objectives of the *Engineering and Policy Analysis* program, which it concludes. The success of European transport mitigation policies, requiring coordinated action at a continental scale to tackle global warming is a Grand Challenge. The content of the study includes a model of the transport system investment needs. By providing detailed insights into the investment needed to meet the European regulation, this study will allow for better decision-making. During the master thesis, contact with policy-makers, institutions, or NGOs has been planned and organized to communicate findings.

This political outreach has been possible by conducting the project inside a think-tank in the Europe team of the Institute for Climate Economics – I4CE. It "i*s a non-profit research organization that provides independent policy analysis on climate change mitigation and adaptation" (I4CE, 2022)*. Paris-based, it promotes climate policies that are effective, efficient, and socially fair, with a focus on economic aspects (I4CE, 2022). This Master's Thesis was part of a wider project to estimate the investment needs for meeting the 2030 target of the European Union on Energy, Transport, and Buildings. It led to the publication of a report (Calipel et al., 2024). The press coverage following the presentation of the report proves the great interest from civil society on this topic. Annex 7 summarizes the press coverage.

Besides filling the research gaps identified above, this thesis aims to contribute to the ongoing debate about the transition. In 2024, more than 400 million people in the European Union, will go to vote for the next European Parliament. This election will start a five-year new period for the European Union, with a new Commission that will be chosen during the summer. A political debate is needed to propose means to invest in climate. Some members of the European Parliament have already raised this question of investment as a key challenge for the climate transition (Contexte, 2023).

Finally, the scientific community could benefit from this approach in several ways: other researchers could use the approach proposed to measure progress in the implementation of other policies looking at investment, the methods proposed to estimate investment needs for mitigation policies, or use the inputs for their research (for example in studies that want to study the macro-economic effect of the transition).

1.7. Thesis structure

The rest of this thesis is divided into five chapters. In Chapter 2, the literature review and the research gaps identified are presented. The methodology chosen is explained in Chapter 3. The results of the study are presented in Chapter 4. The results are discussed in Chapter 5, and policy and scientific recommendations are presented. Finally, the master thesis is concluded in Chapter 5.

2. Literature review

This chapter sets the backbone of the master thesis.

This literature review has two main objectives. It aims to understand the state-of-the-art methods for monitoring the progress in transport mitigation policies. The different methods are presented with their associated purpose. The second objective of the literature review is to confirm the existence of a knowledge gap in the measurement of European Transport Investment's needs for meeting 2030 climate targets.

I present the methods, results separated between the themes, and the research gaps identified in the literature review.

2.1. Methodology of the literature review

The first step of the literature review involves collecting scientific sources. A research strategy combining different methods was followed. The following subsections detail the various steps.

Firstly, the initial research strategy aimed to achieve a comprehensive understanding through systematic search. However, not enough results from scientific sources were collected. In the second part, the extension of the results dataset is explained by conducting backward snowballing from the sources found. Additionally, the process of supplementing sources by consulting an expert on investment in climate policies from I4CE and integrating official sources is detailed. Finally, the research approach chosen is discussed.

Due to a limited number of studies, the scope on the monitoring has been extended to all mitigation policies not specific to transport. As Sustainable Development Goals (SDGs) include goals linked with climate mitigation (Koundouri et al., 2021), papers on this specific topic have also been included in the literature review.

Figure 2.1 summarizes the research method and Annex 6 lists all papers found, the topic of the papers, and if it was included finally.

2.1.1. Systematic search

The first step of the literature review was to conduct systematic research. Table 1.1 summarises the query terms used.

The first set of queries is for better understanding how the progress of mitigation policies could be measured and how they could be monitored. As explained above the query terms are not limited to transport, but include all mitigation policies and SDGs. Combined queries with words specifying the object “Climate Objectives”, “mitigation progress”, and “Climate Policy” and the methods wanted “Measuring progress”, “Monitoring” and “Indicators” have been used. Results were filtered for after 2015, the year of the Paris Agreement. Each search was limited to the first 15 pages of results on Google Scholar. The selection process was made either based on the title or based on the abstract, checking if the selection criteria were met.

The second set of queries is to review all scientific sources on the investment needs for meeting European transport regulation. It was made on Scopus to have an exhaustive limited search. On the contrary to Google Scholar, Scopus provides a limited number of results, only the one matching exactly the query. Table 2.2 presents the query used. It combines a technological focus limiting the number of results on transport, a topic focus with only results explicitly about Investment and the green deal, and the geographical scope of The European Union. To account for studies with a slightly different geographical scope, both Europe and the EU have been included and different synonyms for the green deal. The systematic search resulted in 150 results. After reviewing the articles based on the selection criteria, 7 papers measuring the investment needs of transport for meeting climate targets in the European Union were found.

Table 2.1 - Summary of query terms used for the systematic search.

Search Engine	Query	Selection criteria	Number of papers included
Google Scholar	Measuring Progress Climate Objectives Monitoring Climate Mitigation Progress Indicators Climate policy	After 2015 Explicitly on Mitigation Explicitly linked with policies About methods for measuring progress in mitigation policies	12
Scopus	TITLE-ABS-KEY (transport*) AND TITLE-ABS-KEY (europe* OR EU) AND TITLE-ABS-KEY (investments) AND (TITLE-ABS-KEY (green AND deal) OR TITLE-ABS-KEY (net-zero) OR TITLE-ABS-KEY (decarbon*))	Measurement of transport investment needs for transport at the European Union scale for meeting climate targets.	7

*This table describes the queries used for the systematic search of the literature review describing the search engine, query terms, selection criteria and number of paper found. The * indicates that a different ending is possible.*

2.2.2. Backward snowballing

The systematic research yielded limited results, with only 19 papers eligible for inclusion, insufficient for obtaining a comprehensive overview of the state-of-the-art. To supplement these sources, a backward snowballing method was employed, starting from the initial set of articles selected. Due to time constraints, focus was directed towards the IPCC Working Group III Report (Shukla et al., 2022). This report summarizes the state-of-the-art solutions for mitigating climate change.

In the report, the search was targeted through specific keywords presented in Table 2.2. As all the papers included in the IPCC report are already about mitigation, the keywords can be only about the methods for policy monitoring or about investment. The paragraph around the results found were then reviewed to find interesting sources. Using this method, 12 papers were read and 9 were included in the literature review based on the same selection criteria as for the systematic search. The Chapter 15 about Investment and Finance was also read, looking for investment needs assessment but no extra sources was found. In addition, one article was added by snowballing from another source. I decided to stop the snowballing from other sources because of time constraints and because some results were found multiple times.

Table 2.2 – Description of the snowballing search method

Source for snowballing	Keywords for searching in the document	Selection Criteria	Number of papers included
(Shukla et al., n.d.-a)	Monitoring, Measuring progress, Tracking Progress, Evaluating progress	Explicitely on Mitigation Explicitely linked with policies About methods for measuring progress in mitigation policies	9
(Olazabal et al., 2019)	None	-	1

This table presents the sources, the keywords if used, the selection criteria and the number of results of the snowballing.

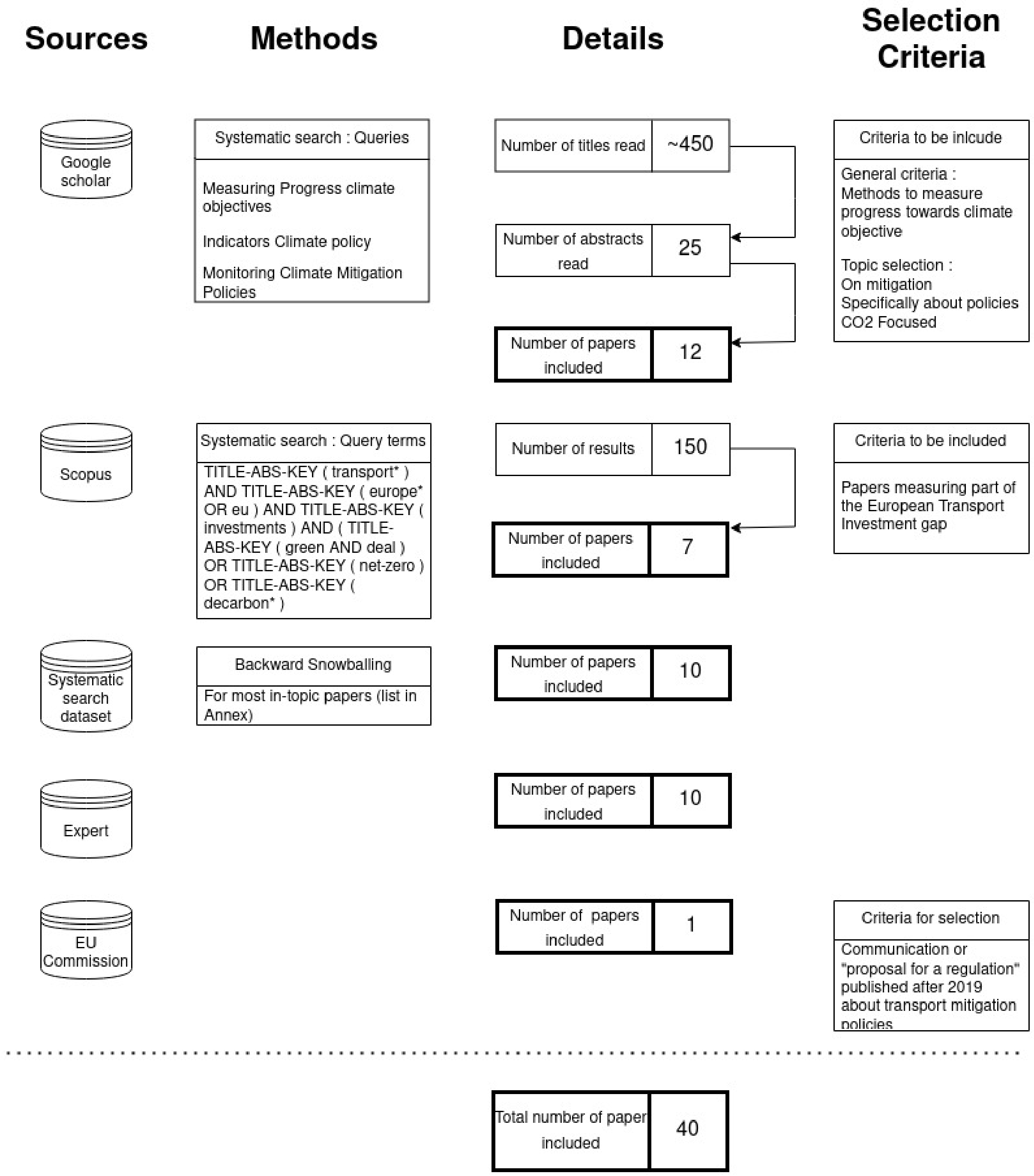
2.2.3. Additional methods

Finally, to complement the sources, I have asked an expert and European Commission documents were reviewed.

Hadrien Hainaut from I4CE indicated sources complementing the systematic search and the snowballing. The sources he indicated were about investments as a way to track policy progress and papers about European Green Deal monitoring. Mr. Hainaut has been measuring French climate investment and investment needs for more than 10 years and was thus a relevant person to ask. 10 papers have been added to the dataset.

I also completed the research by looking at the Staff Working Documents from the EU Commission since 2019 about the completion of the 2030 target. All the results from the Staff Working Documents are from the same model called PRIMES. They are counted as one paper but it includes several different documents.

Figure 2.1 - A schematic summary of the first literature review research strategy.



Source: Author. This figure presents for each step, the sources used, the methods for extracting papers from the source, the selection criteria for sorting the results and finally the number of paper found.

2.1.4. Discussion about the research strategy for the literature review

The initial research strategy using systematic search provided limited results. For the first set of queries, the query terms used were too broad, as the results below are mixing distinct studies and methods. Using a more specific research term, as in the third query with the word "Indicator" could have helped to narrow down the scope. The search engine used for the systematic search has a mixed figure. On the one hand, the use of Google Scholar helped to have a rapid overview of what were the different sub-subjects in the literature. On the other hand, it resulted in a loss of time in sorting the varied results.

To overcome the difficulties, Scopus was used for the second set of queries. Even with targeted search 150 sources were found. Moreover, Scopus provided with numerous papers that were out of scope, explaining the low number of papers finally included. Finally, none or the search engine was fully satisfying.

In the systematic search method on Google Scholar, the results were limited to the first 15 pages of results, so approximately 150 results per query. This threshold was arbitrarily set. To see if this threshold was coherent , the result page where the papers was found was checked. From the 3 queries, 2 papers after page 12 on the research on Google Scholar were included in the 12 papers reviewed. Stopping at page 15 is then not justified with ex-post analysis.

Snowballing from the IPCC report turned out to be the most efficient way to gain a precise overview of the monitoring method. However, the results found are mainly the most influential papers or on a global scale, as only one exemplification of the monitoring at a national scale was found with this method.

Finally, asking the expert helped to refine the results. However, the results were precise of the literature review and already focused on the scope of the thesis.

2.2 Results

This section presents the results of the literature review based on the two themes identified: Monitoring climate policies progress and measurement of the EU transport investment needs for meeting regulation.

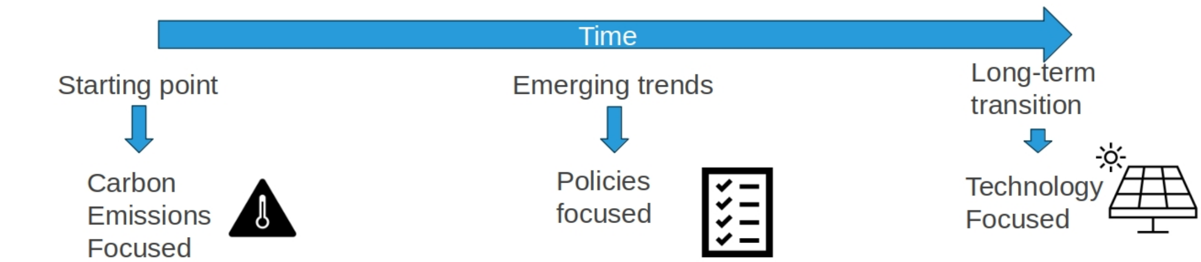
2.2.1. Monitoring climate policies progress

The first objective of the literature review is to understand the broader context of monitoring mitigation policies to observe how investment tracking integrates into it. A typology of methods has been created based on the time horizon and associated goals. Lastly, the research gaps found are concluded along with the choices made for this thesis.

The literature review provided varied results. The spectrum is large from using the number of laws on a topic as an indicator of progress to measuring emissions figures using satellite data (Friedlingstein et al., 2023). They differ also on the timescale and the purpose they are assessed. For example, one may want to track historical progress, evaluate short-term figures or indicate future reduction pathways (Peters et al., 2017). The explanation for the choice of the method to support the purpose of the study is generally lacking.

The typology presented below classiffy the different methods and purposes of studies. The paper from (Peters et al., 2017) should be highlighted. It’s the only finding that proposes a comparative analysis of methods to measure the progress of mitigation policies, justifying different use cases. The decomposition proposed below expands this framework, by adding use cases and defining multiple methods for each specific objective. The typology is based around general research question and time horizon. Figure 2.2 summarizes the results.

Figure 2.2 - Framework for mapping the different methods for monitoring progress towards climate objective.



Question	Methods
How are CO2 emissions evolving ?	Measuring historical progress through carbon emissions.

Question	Methods
B. Is the official target sufficient for meeting climate objective?	Reviewing announcements to estimate mitigation effort progress.
B. Are the expected emissions reduction associated with policies sufficient for meeting the official target?	Modelling the effect of policies to forecast future emissions.
D. Is the official target credible from a political perspective?	Estimating the likelihood of progress through political context.
E. Are the policies implemented on time?	Assessing progress through an indicator

Question	Methods
F. Are the required technologies ready for deployment?	Evaluating technological developments to analyze long-term pathway

Source: Author. This figure presents the different methods found for monitoring climate mitigation progress and their use cases. They are separated based on their time horizon and the focus object.

A <u>How are CO2 emissions evolving? Measuring historical progress through carbon emissions.</u>

A first set of papers found aimed at tracking and measuring historical carbon emissions. In this case, they are measuring the alignment of historical carbon emissions with different scenarios to deduct a future carbon budget.

The Global Carbon Budget by Friedlingstein et al. (2023) scrutinize total human emissions, comparing them against the established emission ceiling. The methodology is based on multiple models to simulate the climate system. This granular approach, encompassing notably atmospheric CO2 concentration, emissions from fossil fuel use and land-use changes, as well as absorption by the ocean and biosphere, establishes a carbon budget imbalance. Monitoring historical emissions can also be done at the level of companies. Schiemann et al. (2019) study how CO2 reporting could become instrumental in both policy tracking and incentivizing corporate actors.

Studies on carbon budget and emissions have been helpful in setting a policy space for global warming, notably during the Conference of the Parties negotiations. At a national or international scale, they require however complex physical modelling.

B <u>Is the official target sufficient for meeting climate objective? Reviewing announcements to estimate mitigation effort progress.</u>

Most of the studies found looked at emerging trends to see if they are aligned with climate objective.

To gauge future trends, the first approach is to look at States official plans. From the literature reviewed, the main idea is to measure progress towards climate objective from the review of the announcement comparing it to the reduction needed. The Nationally Determined Contributions (NDCs) outlined in the Paris Agreement (Paris Agreement to the United Nations Framework Convention on Climate Change., 2015), serve as a foundation for country-level policy tracking.

Rogelj et al. (2016a) review and sum up all the announcements of NDC to determined global total emissions reduction of the plans. Höhne et al. (2020) evaluate global progress by scrutinizing net-zero emission goals and decisions to halt fossil fuel exploration. Den Elzel et al. (2019) compare the target of National Determined Contributions to the Paris Agreement to independent studies on the actual projected emissions. At the local level, Salvia et al. (2021) reveal that cities covering 25% of the European population must intensify efforts for the EU to meet its climate reduction target, after having reviewed more than 825 city level plans.

Reviewing plans by states or inside a member State has two main advantages. Its simplicity, being mainly accounting and literature study, it doesn't require a large model. And results are easily communicable and understandable. They are however dependent on the results provided by official sources.

C Are the expected emissions reduction associated with policies sufficient for meeting the official target? Modelling the effect of policies to forecast future emissions.

To go beyond the information provided in the National Determined Contribution plans some researchers try to forecast the exact emissions reduction associated with the policies. The effect of policies is modeled by large model mixing socioeconomic characteristics, energy and CO2 effects.

The World Energy Outlook (IEA, 2022) reviews implemented policies and announced policies of States all over the World. They then provide an estimate of the emissions reduction from these policies based on an model linking economy-energy-climate effects. Roelfsema et al. (2020) estimated the associated emission reduction at the global scale implementing the policies of the different countries.

Such methods provide independent analysis of states' emissions announcements and help to understand the dynamic of emissions reduction. They require great modeling capacity .

D Is the official target credible from a political perspective? Estimating the likelihood of progress through political context.

Another way to monitor the progress of climate mitigation policies is to estimate if the plan will be met. Some researchers are using "credibility" of the political announcement as a way to estimate if mitigation policies are making progress.

The credibility of these plans can be evaluated by estimating the likelihood of progress based on the political context. Numerous aspects can be used as a proxy to evaluate the credibility. Averchenkova&Bassi (2016) employ indicators of the political and historical context to assess the feasibility of policymakers keeping their promises, while Schaffrin et al. (2015) derive an index of national policy output based on the frequency of law and the importance of their content. Shivakumar et al. (2018) look at specific indicators of the policy content to track the progress of policy development for a specific technology – smart energy solutions - at the EU scale. Michaelowa (2018) scrutinizes specific indicators of the content of 108 transnational announcements, Sridhar et al. (2021) emphasize the importance of institutions as indicators for ensuring a successful transition.

These studies are interesting to give a broader understanding of what is a successful climate transition. The political and policy context is then a key determinant in the success of the implementation of policies.

E Are the policies implemented on time? Assessing progress through an indicator.

Other studies have tried to determine if the objectives of the policies or National Determined Contributions were going to be met. To determine if progress aligns with goals, indicators become instrumental to follow the progress of the policies on a range of determined points. Vogt-Schilb & Hallegatte (2017) emphasize the importance of clear targets and indicators for tracking climate policy progress.

Similarly to the complexity of climate mitigation objectives, Sustainable Development Goals comprise 17 goals and 169 targets. Having a single index, summarizing all indicators, is appealing, but hard in practice (Hák et al., 2016). Diaz-Sarachaga et al. (2018) review the SDG index to show that 60% of the SDG indicators are being disregarded in this index because of missing information. Relying solely on aggregated indices may introduce sensitivity issues to indicator weighting, as cautioned by Miola& Schiltz (2019).

Having an indicator set or dashboard, could avoid the issue of weighting different objects. As shown by Gunnardosttir et al. (2020), multiple choices can be made for the set. 57 indicator sets were found that monitor progress towards sustainable energy development. Most of them lacked transparency or had links between indicators. Rüdinger (2018) proposes integrating indicators into dashboards. ECNO (2023) has applied this method to follow the European transition.

Indicators themselves, are still subject to discussion. Sartor (2016) discusses the selection of indicators for monitoring the European climate transition. Gunnardosttir et al. (2020) discuss the quality of a good indicator while Salvan et al. (2022) suggest criteria for tracking the implementation of EU Green Deal policies on agriculture, emphasizing relevance, comprehensiveness, interpretability, data quality, efficiency, and avoiding overlap. For Europe, investment in UK building sectors has been used to understand the alignment of the sector with climate targets (Dobrinevski & Jachnik, 2021) or for manufacturing industries in Norway (Dobrinevski & Jachnik, 2020). At a national scale by Hainaut& Cochran (2018) proposes to track climate investment in the French economy to test the alignment with Paris Agreement and Jachnik et al. (2019) argue that this work is necessary for determining adequate financial instrument at a technology deployment level.

In conclusion, indicator seems the main tool and method to track progress in the implementation of policies. The choice of the indicator and the way to present results concentrate most of the difficulties. To overcome these difficulties, dashboards and indexes are commonly used. Investments have been used as an index for some studies.

F Are the required technologies ready for deployment? Evaluating technological developments to analyse long-term pathways.

Finally, evaluating technological developments becomes crucial for analyzing long-term pathways. Peters et al. (2017) emphasize tracking the development and deployment of alternative technologies helps to monitor if the enablers of future emissions reduction are ready. The methods proposed follow a bottom-up approach, decomposing by technology deployment and prices, highlighting the importance of price declines, and deployment for technological progress. Huisingh et al. (2015) propose examining progress from the perspective of individual technologies or policies, with criteria such as cost and perspectives for monitoring. Technologies with small units are identified as more efficient for accelerating the transition, as suggested by Wilson et al. (2020).

This prospective analysis is essential to have plans based on credible technology for the transition. The IEA proposes technology roadmaps for tracking the progress of key technologies (IEA, 2023a)

2.2.2. Investment needs for European transport policies

From the first theme of the literature review, this Master's Thesis focuses on tracking the progress in the implementation of European regulations (section E. Are the policies implemented on time?) as it seems the most interesting from a policy perspective (see Introduction). I chose to focus on investment as an indicator for tracking policy progress. More precisely, the level of the investment deficit, define as the difference between current flows and average needs to meet the long-term goals of the Paris Agreement. " IPCC (FAQ 15.3), will be assessed.

The second aim of the literature review is to check the existence of a knowledge gap in measuring the investment deficit for meeting European Regulations. The main difficulty in calculating the investment deficit is to estimate the investment needs induced by the regulation. The results presented here are limited to the scope of the studies. The different methods used in the literature reviewed are discussed in the Methodology section.

From academic sources, some studies have estimated the investment required for sub-parts of the transport system. Ganter et al. (2024) have estimated the investment needs for deploying hydrogen infrastructures, according to the Fit for 55 objectives. Tsiropoulos et al.(2022) test scenarios for deploying charging points according to the main scenario of the Fit for 55 Impact Assessment and measure investment needs.

Some studies calculate the investment required with a general transition of the transport system. García-Olivares et al. (2020) measures the investment required for the transport system to meet a 100% renewable target in 2050 at the same "transport conditions" as in 2016. Charalampidis et al. (2019) looks at the macro-economic impacts of manufacturing mainly electric vehicles, and calculates the investment required for the industry and infrastructure shift. Tamba et al. (2022) looks at the impact of road electrification on the employment market. Van der Zwann et al. (2013) investigate the different technology deployment pathways for transport in the 21st century, using investment as a metric to compare the pathways.

About the European policies for decarbonizing transport, Klaaßen & Steffen (2023) do a meta-analysis on the different investment costs for meeting the European objectives for infrastructures including transport infrastructures. For the institutional level, there is a patchwork of estimates of the investment needs from the European Commission. The European Commission estimates a transport climate investment need at around 489 billion euros ('2015) per year between 2021-2030 (European Commission, 2021c, p. 69) The International Energy Agency, provides also an estimate of the investment needs but at the European scale (not just the European Union) and to reach net-zero CO2 emissions by 2050, disregarding 2030. They do not provide details about their methodology or do not disclose the investment needs by sector.

2.3. Research gaps

Different research gaps can be highlighted from the literature reviewed. From the first theme, the following research gaps are the most salient.

Research gap 1: There is a lack of unified framework for monitoring climate mitigation policies. All the papers included in this literature review were about monitoring climate mitigation progress but the terms used have various definition and use case. The work from Peters et al. (2017) was the only one offering such framework but the framework proposed did not included all the papers found. This typology to categorize methods based on research questions and time horizons is a step towards addressing this gap, but further refinement and validation of such a framework would be beneficial.

Research gap 2: There is limited comparative analysis of the different methods at different time horizon. The studies focus on one specific aspect of the transition. However, as shown in the paper of Iyer et al. (Iyer et al., 2017a) shows that a country can be in line with mid-century goals but that would imply unrealistic technological deployment. More research providing a comprehensive overview at different time horizon is necessary.

Research gap 3: The credibility assessment of plan is lacking of a comparative analysis to understand the benefits of the different methods. While some studies assess the credibility of policy announcements, there's a gap in understanding how to effectively evaluate the likelihood of policy implementation and success. The field is currently a patchwork of different methods which look at different part of the policy space without global view.

Research gap 4: For assessing progress through an indicator, the literature reviewed highlight that there is no consensus about the best indicator that must be chosen (Salvan et al., 2022). There's a gap in understanding how to select and prioritize indicators effectively. Additionally, ensuring the quality and relevance of indicators remains a challenge, indicating a need for research into developing standardized criteria for indicator selection and assessment. There is a gap in the literature about index development, the literature showing that weighting and aggregating indicators raises difficulties.

Research gap 5: Evaluating technological developments and their implications for long-term pathways is crucial, but there's a gap in understanding how to effectively monitor and analyze technological progress in the context of climate policy. Further research could explore methodologies for tracking technology deployment, cost trends, and innovation trajectories.

The second theme of the literature review has revealed several research gaps.

Research Gap 6: First, the investment needs assessment often lacks alignment with European policies. Notably, only two independent studies delve into the investment needs from the Fit for 55 regulation regarding Charging points (Tsiropoulos et al., 2022) and Hydrogen infrastructure (Ganter et al., 2024). Most papers discuss the general topic of decarbonizing the transport system, such as the IEA study. The European Commission's analysis is supposed to show the investment required for meeting the regulation it proposes but it faces several limitations (see below). Klassen & Steffen's (Klaaßen & Steffen, 2023) paper attempts to outline the impact of the increased emission objective, yet their meta-analysis reviews scenarios partly disconnected from policies, focusing solely on a general decarbonization target.

Research Gap 7: A comprehensive analysis of investment needs for the European Union is also missing with a sectorial breakdown is missing. Many studies provide estimates for specific technology or general scenarios but do not propose a bottom-up approach that summarizes the investment needs for transitioning the transport system.

Research Gap 8: Additionally, there is a missing information about the scope of the studies and to what extent the different part of the supply chain are concerned. Future research could provide more granular insights to inform policy decisions and investment planning effectively.

Research Gap 9: Finally, investment needs assessment with a regional breakdown is missing. (Charalampidis et al., 2019) propose a regional (i.e. sub-national level) of the impact of manufacturing electric vehicles. Further study would be require to understand better the impacts and investment needs at such scale.

Regarding the European Commission's measurement of investment needs for implementing the Green Deal, limitations arise. The study was based on the Commission's proposed policy package, lacking the regulations agreed upon by the European Parliament and the Council. Transparency, independence, and accuracy are crucial for public debate, yet these characteristics were missing in the Commission's study. It is made by the institution in charge of the policy proposal, the details of the modeling is not public and finally the modeling was done between 2019 and 2021, it is thus not up to date.

The research gaps identified (**6,7,9**) were also outlined by the literature reviewed. KlaaBen & Stessen (2023) states that "*detailed analyses on a granular technology level remain mostly restricted to power generation or other specific subsectors. Second many techno-economic studies focus on required capacity additions or transport volumes, not investment needs. Third, analyses of future investment and capacity needs typically assess future pathways only and refrain from comparing them to historic investment levels*". The lack of research on this topic is highlighted by the IPCC report which sources only scientific studies about infrastructure needs (Fisch-Romito & Guivarch, 2019). Also, a scientific group created by the EU Climate Law and attached to the European Environment Agency, the European Scientific Advisory Board on Climate Change, have recently called on the EU to 'strive for a more granular and accurate overview of required and actual investments in climate mitigation to monitor and assess progress' (European Scientific Advisory Board on Climate Change, 2024) confirming the existence of the research gaps.

2.4. Conclusion

In conclusion, the literature review underscores the complexity of monitoring climate mitigation progress and highlights several research gaps in the field. The decision to focus on tracking the implementation progress of European Regulation aligns with the broader objective of assessing emerging trends in climate policy monitoring. By emphasizing investment as a method to track overall progress, this thesis aims to contribute to filling the identified research gaps and provide valuable insights for policymakers and stakeholders involved in climate mitigation efforts.

3. Methodology

In this section, the methods for calculating the investment needs and the gap are presented.

The literature was first reviewed (section 3.1) to understand the different definitions of investment, the methods for calculating historical investments and measuring the investment needs created by European Regulation. This literature review was necessary for understanding the different choices that could be done.

The methodological choices are then presented (section 3.2) based on the results from the literature review, and discussed. The general research approach in term of definitions, methods for tracking historical investment and methods for measuring investment needs are detailed.

The design of the model for measuring investment needs for meeting European Regulation is thoroughly explained (section 3.3). If the general approach stays the same, the model differs based on the technology considered.

A great part of the work was to find reliable data sources. **The data collection is presented** in the section 3.4.

Finally, **a conclusion discussing the choices made and the limitations** of this approach ends the chapter (section 3.5).

3.1. Definitions and methods from the literature

To understand with more precision the different methods available to conduct the research, this review aims to understand: (I) What are the different definitions for investment? ; (ii) What methods can be used to measure investments made in the economy? (iii) What methods can be used to determine investment needs? This section is structured around these three questions and ends with a discussion.

As the literature review showed that only few studies were focused on transport investment needs, all studies about investment found were included whatever the sector. This set was considered enough with the time of the thesis. 16 studies were included.

3.1.1. Definitions review

After having presented the investment definition from the IPCC, the different questions that arose when comparing the definitions used in the literature are presented.

a. Investment definition from the IPCC

The literature reviewed does not often give an exact definition of investment. The IPCC report, Working Group III (Shukla et al., 2022), states that “Investment, in an economic sense, is the purchase of (or CAPEX for) a physical asset (notably infrastructure or equipment) or intangible asset (e.g., patents, IT solutions) not consumed immediately but used over time.” After reviewing the literature, all definitions would fall under this general one.

One should note that investment is different from cost, which "encompasses capital expenditures (CAPEX, or upfront investment value leveraged over the lifetime of a project), operating and maintenance expenditures (OPEX), as well as financing costs" (bis).

b. Net or gross investment

Investment can also refer to an investment difference between two scenarios. The IPCC refers to them as incremental investment or incremental cost: “ Incremental cost (or investment) accounts for the difference between the cost (or investment value) of a climate project compared to the cost (or investment value) of a counterfactual reference project (or investment).” The term "net investment" has also been found in the literature (I4CE, 2023; Jachnik et al., 2019). If in the scientific literature reviewed, only gross investment have been used, other studies used net investment. Notably both are analyzed in EU impact assessments.

c. Scope definition – (In)Tangible assets

Investment in capital expenditure is supposed to include intangible assets such as patent. In the literature review, no papers include this kind of capital expenditure. The chapter 15 of the Working Group III of the IPCC reviews papers from both tangible and intangible assets.

d. Scope definition – Level of supply chain details

In the papers reviewed, the definition of investment considered is done in an underlying way when defining the scope. The different definitions change based on the level of integration of the supply chain. For road transport, it can include (or not):

- Consumer cost: Capital cost of buying a vehicle.
- Infrastructure: Stations for refueling/charging the vehicle; development of the grid. The development of the road network has not been included in any of the papers found.
- Manufacturer cost: Cost of the manufacturing plants
- Energy: production of alternative fuels

For the first set of study , investment can be defined as the sum of investments all along the supply chain **in a macroeconomic measurement**. They are characterized by a comprehensive view of the system with a model including manufacturers and buyers as in Tamba et al. (2022). Charalampidis et al. (2019) includes the production of “infrastructure, manufacturing of new technology vehicles and production of alternative fuels”. Finally, the model used by the European Commission includes manufacturers, grids, fuels, and investment by the end-user (EU Commission, 2021). On the energy market, the World Energy investment also tracks all capital flows (IEA, 2023b) from the manufacturing to the installation. (I4CE, 2023) focuses on overall investment needs for meeting France’s emission targets.
The second set of studies focuses on investment at an exact point in the supply chain, that will be referred as **end-user measurements**. (Ganter et al., 2024; Peters et al., 2017; Tsiropoulos et al., 2022; Van der Zwaan et al., 2013) define investments from the formula: Volume * Price of the end-user. García-Olivares et al (2020) define explicitly investment as the gross investment excluding “additional costs required for new electric vehicle maintenance, the expansion of the general electrical network, the renewable energy production infrastructure, or investments in associated research and development.” Dobrinevski & Jachnik (2020) focus on the tangible fixed assets in the industry sector.

Finally, a third set of study proposes alternative scopes for the investment considered Klaaßen & Steffen (2023) provides a meta-analysis on infrastructure investment. However, their definition is dependant on the one used in the literature reviewed. They outline the fact that different definitions exist notably that “there is no universally valid definition for ‘infrastructure’, which leads to varying scopes across studies”. Dobrinevski & Jachnik (2021) defines investment from the gross fixed capital formation written in official statistics.

e. Investment gap

According to the IPCC (FAQ 15.3): "A financing gap is defined as the difference between current flows and average needs to meet the long-term goals of the Paris Agreement. " This definition could seem simple, but the time-horizon considered can lead to difficulties.

3.1.2. Methods for tracking historical investment - Review

The formula for measuring an investment gap depends on the current level of investment.

In this part, the different methods found in the literature for tracking investment flow are reviewed. The scope is limited to the definition of investment chosen: Capital formation of tangible assets (see 3.2.). Therefore, financial flows are not considered.

a. *From official statistics*

The first way to estimate historical investment is to use macroeconomic indicators. Some studies use aggregated figures from official statistics or national accounts. They use the Capital formation of the economy stated in the official document to estimate the historical investment for their sector. For example, Dobrinevski & Jachnik (2021) use the calculation for the Gross fixed capital formation for building from the UK National Accounts Blue Book. This approach is seen by the IPCC as an interesting proxy (WGIII, chapter 15): "Gross-fixed capital formation (GFCF), another SNA standard that covers tangible assets (notably infrastructure and equipment) and intangible assets, is a good proxy for investment flows in the real economy." I4CE (2023) uses such methodology for estimating buildings and railways investments.

Discussion - This method is useful for having an overview of a macro-sector. On the other hand it lacks granularity, and rely on numerous assumptions to estimate the climate friendly share of the investment made.

b. Unitary cost and volume deployed

At the opposite spectrum of solutions, some studies are using a micro approach. Applying unitary cost to deployed volumes, they can estimate total investments. This methods is used by the World Energy Investment or (I4CE, 2023) for electric vehicles.

Discussion - This method is useful for following with details both the technological improvement with the price and the uptake of the technologies with the volumes (Peters et al., 2017). On the other hand, it relies on the quality of the data sources and is time-consuming.

c. Project tracking

A third set of methods is based on projects. The method is to follow different projects and measure the expenses of all of them. It could be a direct industrial project as done by the EU for the deployment of high-speed trains (European Commission, 2020b) or I4CE for local transport. It can also follow specific loans as the work done by the European Investment Bank (European Investment Bank, 2023) or specific policies.

Discussion - This method is useful for following a specific set of projects. For mega-projects such as nuclear plants or high-speed trains, it is the most precise method. For smaller-scale project, there is no guarantee of exhaustiveness.

d. Rely on other sources

Finally, the last set of studies relies on other sources notably from industries. In this case, the historical investment is the sum of the investment reported by all the companies surveyed. This method is used in (Klaaßen & Steffen, 2023).

Discussion - This is an efficient method to gain a rapid overview of the investment needs. If the study reviews all the companies in one sector, it guarantees that the quality of the information goes directly to the sources. However, it lacks transparency and often exhaustiveness.

3.1.3. Methods for estimating investment needs - Review

As explained in the literature review, few studies have looked at investment needs to be induced by European regulation. This main research gap is addressed by the master thesis. However, other studies have looked at investment needs in the transport sector to meet decarbonization targets or transition the transport system.

This part the different methods found to understand if some could be adapted for this study. The results are presented based on the typology of methods. Two main approaches were found: macroeconomic modeling and the bottom-up approach.

Macroeconomic modeling simulates the economy as a whole. These models intertwine energy, population, and economics and estimate the effects of policies. These policies result in private agents re-allocating labor, capital, and energy along their production functions. They can also include the effects of CO2 emissions. needs based on projected demand due to population and GDP evolution Carraro et al. (2012) estimates the effects on investment of different level of carbon taxes. (McCollum et al., 2018) estimates the investment needs induced by the National Determined Contribution plans and check their alignment with global targets. (Tamba et al., 2022) studies the impact on manufacturers employment on the transition to electric vehicles based on general "equilibrium model that covers the interactions between the Economy, the Energy system and the Environment"..

Institutional organizations are also using such macro-economic model to test the effect of a general decarbonisation of the economy. The European Commission has done it for the fit for 55 package using the PRIMES model (European Commission, 2020b) and the International Energy Agency uses such a model for the publication of the World Energy Outlook (IEA, 2022b) and World Investment Outlook. (IEA, 2022a). Mixed approaches have also been found. For example, (Charalampidis et al., 2019) defines public investment in infrastructure as an exogenous variable in a Spatial General Equilibrium Model.

A second set of studies follows a **technology-specific, granular approach.** They decompose investment with price and volumes as proposed by Peters et al. (2017) . It consists of three steps: First, based on a scenario of deployment, the methods estimate the volumes to be deployed. Second, taking into account technological improvement, they estimate the price per unit, and finally, they calculate investment as the product of volumes per price.

García-Olivares et al., (2020) calculate the investment necessary with a 100% renewable transport system in a simple version of this method, keeping volumes and prices constant and just calculating the cost of replacing all the units. Tsiropoulos et al., (2022) uses a stock flow model to calculate the investment required for recharging infrastructure. In this case, the scenario is the electrification of the vehicle fleet. Fisch-Romito & Guivarch (2019) uses a complex version of this method by first developing different scenarios of transportation at the global scale based on population and GDP growth, then looking at ways to meet the demand, and finally outputting the investments required. I4CE is using this method for the different technologies based on the scenario included in the French Low-Carbon strategy. (I4CE, 2023)

Finally, a **review of results** from other sources has also been done by (Klaaßen & Steffen, 2023). They include all different sources from industry, Academics and institutional sources to estimate the investments needed to meet the EU targets.

3.1.4. Discussion on the literature review

The studies included in the review helped to get a quick grasp of different challenges in the definition. Notably, the IPCC definitions section underlined all the different meanings. However, limited exemplification in the literature reviewed was found, as it had been narrowly selected.

For tracking historical investment end estimating investment needs, the same limitation can be outlined. Also, a detailed understanding of the different kinds of models and their main differences in estimating investment needs was missing. With the limited time for this thesis, I decided not to delve deeper into this.

I also benefited from the knowledge from I4CE to gain an overview of the different methods that exist.

3.2. Methodological approach

Building on the results of the literature review, the methodological choices made based on the objective of the thesis are presented in this part, explaining the definitions and methods chosen.

The results of the review and the choices made are discussed in this part. The main challenge in the different definitions raised by the literature review is described, and the chosen definition is detailed. Similarly, the challenges of the different methods for tracking investments made in the economy are presented, and the one that will be used is identified. Finally, the methods for estimating investment needs are concluded with.

3.2.1. Definitions

There is a consensus in the literature for considering investment as capital formation. However, there are different subtleties in the exact scope of investment in the literature. Between net or gross investment, with or without intangible assets, and up to what part of the supply chain investments are considered.

The research question that this master thesis answers is: What are the investments required in the European Union economy for meeting the “Fit for 55” regulations for road and rail transport, and how do they compare with current levels ? The objective is to have the definition that fits the best for answering the research question.

Investment are defined as gross investment. According to Jachnik et al. (2019)gross flow “allow to identify the total value of investments contributing or undermining climate objectives”. On the other hand, focusing on net investment is useful for comparing scenarios or estimating the additional effort required by an actor, such as a public body. As the research question aims to assess the alignment of the European Union, gross investment is more suitable to see the progress in the implementation of the policies. Moreover, by using gross investment, there is no need to define the cost of an alternative scenario. With the limited time of the thesis, this option is thus preferable.

The scope of the definition chosen **excludes intangible assets.** The scope of the study is limited to policies of the Fit for 55. These don’t include intangible assets, and it has thus been decided to exclude them. With this choice, this study focuses on future long-term emissions and neglect actor decisions. As argued by Jachnik et al., (2019), "a large share of current and future emissions is embedded in the use of existing and new tangible fixed assets, primarily infrastructure and equipment." On the other hand, "financial assets are fundamental for influencing the decision-making of actors.". It is also important to note that the definition chosen doesn't include the financing cost of capital that is considered as an operational cost (Van der Zwaan et al., 2013).

Alongside the choice of excluding intangible assets, only **parts of the supply chain directly covered by European Regulation are included** (see 1.5). This choice has the benefit of tracking only the technologies covered by the regulation, thus helping to assess the progress of the implementation. On the other hand, some important investments could be underestimated and technological bottlenecks can be forgotten.

Finally, to highlight clearly the positive impact in the fulfillment of the regulation, the investments necessary for meeting climate regulation are called **climate investment.**

As a summary, the definition for investment is the definition of the IPCC limited to tangible assets. **Investment is the purchase of a physical asset, not consumed immediately but used over time.**

Climate Investment refers to investments that are necessary for meeting the objectives set in the Fit for 55 package.

Finally, the **Investment gap** is defined with a time horizon aligned with the research question. As the Fit for 55 package has a focus on 2030, the investment gap is defined "as the difference between the 2022 level of investment and average needs between 2024 and 2030".

3.2.2. Methods for tracking historical investments

From the literature reviewed, most studies use a patchwork of different methods to measure historical investments. This master thesis aims specifically at measuring investment for meeting the 2030 European Climate Target for some policies specific to transport.

Estimating historical investment from official statistics only provides aggregated figures that require numerous assumptions for extrapolating climate investment. This method hasn't been used as it doesn't provide refined results enough.

For road transport, the methods chosen is based on unitary deployment. This is linked to the choice of the model to estimate investment needs. The objective of European Law could easily be translated into units. Staying with the same method for historical investment is more logical.

For rail investment, this thesis only focuses on the infrastructure for high-speed rail included in the trans-European transport network (see III.3). This regulation includes a list of projects to be finished by 2030. Project-based tracking seemed initially to be the best method, but it requires access to multiple data sources. Instead, on official documents that mention the investment made will be relied on.

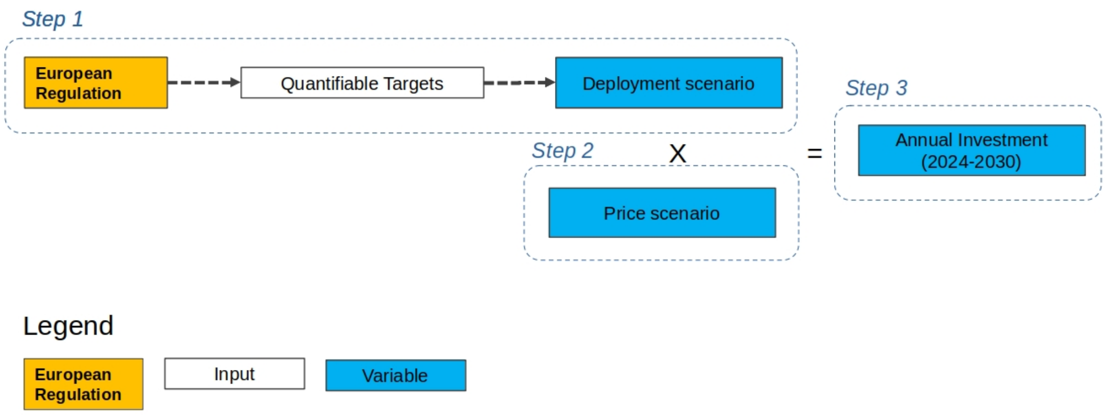
3.2.3. Methods for estimating investment needs

The literature studied revealed two main groups of methods useful for different purposes. Models that are useful for assessing global economic impacts and understanding the comprehensive effects of a policy set. The second set of studies is useful for understanding the specific needs of technology.

This master thesis aims to understand the investment needs for fulfilling the Fit for 55 package. It is only necessary to estimate the investment needs for the technologies covered in the scope of the study. A **technology-specific, granular approach** is more adapted for tracking individually the different policies. A model on the other hand was first not feasible in the time of this study and would not provide a separated tracking of the policies. Finally, only reviewing other studies would not provide a robust and transparent methodology.

The approach chosen is mainly based on the decomposition between volume and price. Doing so, it takes into account technological improvements. Figure 3.1 presents the approach.

Figure 3.1 – Summary of the approach for estimating investment needs



Source: Author. This figure presents the research approach chosen for estimating investment needs. As a first step, for each technology, quantifiable targets are extracted from the European regulation and then translated into a deployment scenario: units to be deployed every year. The second step of the approach is to define a price scenario, for measuring unit cost. Finally, by multiplying the unit cost by the volume deployed, annual investments for 2024-2030 are estimated.

3.3. Estimating investment needs

For estimating investment needs for meeting 2030 targets, a technology-specific method is followed. This method has been chosen to track individually the investment required with each text.

Two main methods have been used. For vehicles and charging points, the European policies are firstly translated into deployment scenarios in terms of volumes of units to be deployed. After having defined unit price evolution, yearly investment needs are estimated

For rail infrastructure, the method followed was to gather different estimates of investment needs in different time periods. Comparing with historical investment, the investment required to meet the European Targets could be estimated.

3.3.1. Passenger cars and light commercial vehicles

This section presents the methodological approach for estimating investment needs up to 2030 for passenger cars and light commercial vehicles. The method follows the three steps detailed in

Step 1: Translating European Policies into Deployment Scenarios

The first step is to construct a unit deployment scenario of electric vehicles. After presenting the European regulation, the approach used is explained.

a. Presentation of the Regulation strengthening CO2 emissions performance standards

The European Union has established CO2 emissions performance requirements for vehicles to contribute to achieving the Union's target of reducing its greenhouse gas emissions. The regulation strengthening the CO2 emission performance standards (2023) sets a reduction of emissions per km in 2030 of 55% compared to 2021 levels for passenger cars and 50% for light commercial vehicles. This regulation will be referred to as "*CO2 regulation*". For the years 2025 to 2029, the targets haven't been strengthened compared to the previous regulation.

The law has two main characteristics that will have to be overcome:

- The law is technologically neutral. As the law only sets emissions standards in terms of g/CO2, multiple technologies can be used to meet the targets. To explain it, let's take two manufacturers A and B. Manufacturer A could, for example, decide to have half of its fleet of zero-emissions vehicles and the other half producing twice the threshold. Manufacturer B could decide to have only vehicles exactly at the threshold. In this case, both manufacturers A and B are meeting the 2030 target. The scenario produced should decide on a technology mix.
- The standards set in the law are not continuous. During the period 2025- 2030, the standards for 2025 apply. This means that in 2030 the standards will be "instantly raised". This is however not realistic. This master thesis aims to measure the investment required to meet the 2030 target, a pathway leading toward the 2030 target should be proposed

b. Hypothesis and presentation of the approach

In this part, the approach followed to calculate the annual deployment required for meeting the target in 2030 is described. The model will be presented for passenger cars. The one for light-commercial vehicles is the same with different values. The figure 3.2 summarizes the approach.

Only technologies contributing to the reduction of emissions were considered, as they are the only on necessary for meeting the standards. When compared to the different levels of gCO2/km in 2030 this includes battery electric vehicles (BEV) (0g/CO2) and efficient plug-in hybrid vehicles (PHEV) (under 50 gCO2/km). Hydrogen vehicles have been disregarded because of limited volumes, as their expected uptake is around 1% of the annual car sales in 2030 (European Commission, 2021b).

The model has a granularity at this technology level.

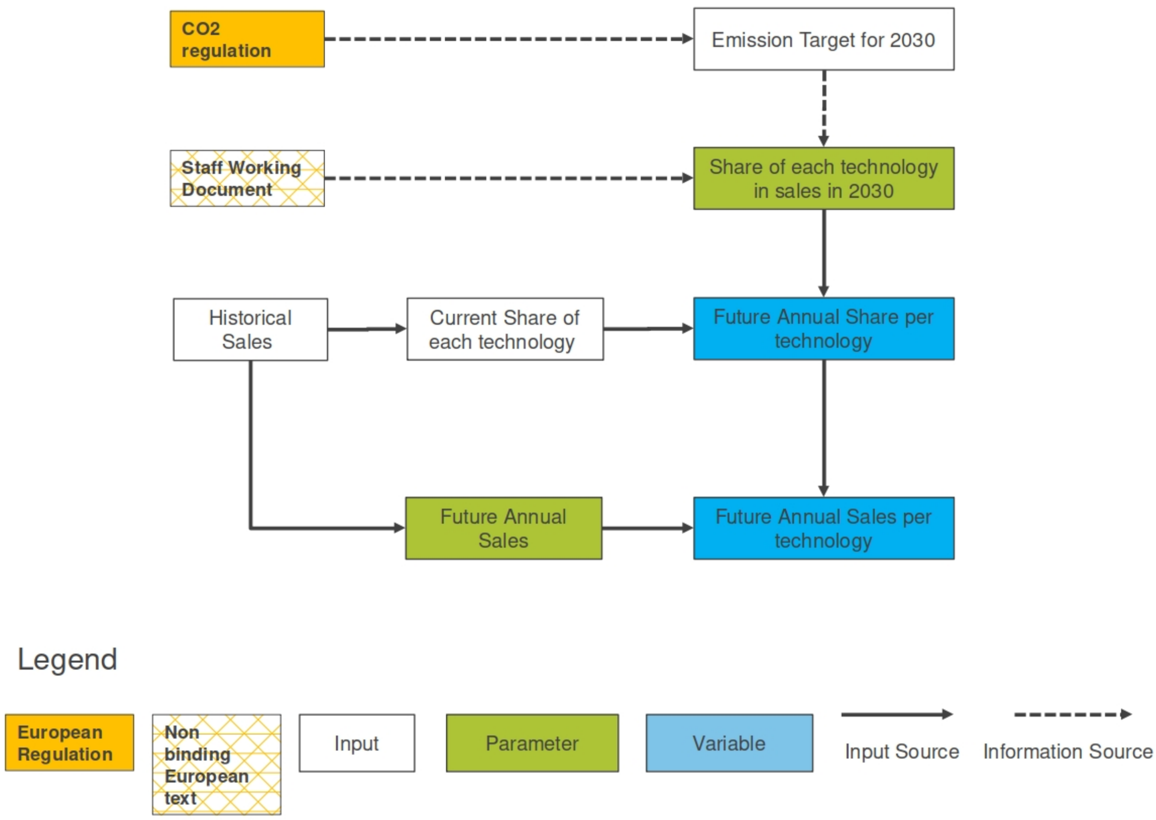
As the law does not set an official target for each technology, the *Staff Working document* (European Commission, 2021a) accompanying the proposal was used as a reference. This is not an official text but still represents the plan of the European Commission. This Staff Working document indicates share per technology at different dates according to the PRIMES model: *Share of each technology in* sales in 2030*.*

To extrapolate between 2030 and now, **a linear uptake is assumed** for each technology, for estimating *Future annual sales per technology. Future Annual Sales* in the model are estimated in a Business-as-usual scenario, meaning that the average sales of the last ten years are used as a reference.

Future *Annual Sales per technology* is then the product of the *Future Annual Sales* with the share of each technology.

As a summary, the model outputs the *Future annual sales per technology* and takes as main input the *Share of each technology in sales in 2030.*

Figure 3.2 - Passenger cars and Light-Commercial vehicles volume model



Schematic representation of the method to transpose the Regulation setting CO2 standards for passenger cars and light-commercial vehicles into yearly sales

Step 2: Price scenario for future vehicles

For passenger cars and light-commercial vehicles, a model developed by I4CE for the French market has been used. It outputs the expected average annual price of BEV and PHEV for passenger cars and light-commercial vehicles. It takes into account technological improvement of the battery and the expected behavior of consumers. The model is presented in Annex 2.

Step 3: Calculating investment needs

Finally, the last steps of the calculation is to multiply the average annual price per technology and the Future annual sales per technology.

3.3.2. Trucks

This section presents the methodological approach for estimating investment needs up to 2030 for trucks. The method follows three steps detailed above.

Step 1: Translating European Policies into Deployment Scenarios

The first step is to construct deployment scenarios from the European regulation. Figure 3.3 summarizes the approach.

a. Presentation of the Regulation strengthening CO2 emissions performance standards

After the standards for light—vehicles, the European Commission has proposed to strengthen CO2 emissions performance requirements for heavy-duty vehicles to contribute to achieving the Union's target of reducing its greenhouse gas emissions. The proposal for a regulation strengthening the CO2 emission performance standards sets a reduction of emissions per km in 2030 of 45% compared to 2019 levels for the new heavy-duty vehicle fleet (European Commission, 2023c). If the proposal is still under discussion, the target proposed by the European Commission will be used in this work.

In the scope of this thesis only trucks have been included. This leaves out buses covered by the regulation. They represent around 10% of the segment sales (ACEA, 2023b).

As for light vehicles, there is no strengthened target before 2030 and the law is technologically neutral. It is also important to point out that the law doesn't include truck size-specific targets. The different sizes of trucks can contribute differently to the target as long as the overall target is met.

b. Hypothesis and presentation of the approach

In this part, the approach followed to calculate the annual deployment required for meeting the target in 2030 is described. As the law does not set an official target per truck size or technology, the Staff Working Document accompanying the proposal was used as an official source.

3 sizes of trucks were considered: vehicles under 7.5 Tons of Gross Weight Vehicle Mass, between 7.5T and 16T, and above 16T. The split between vehicle sizes is necessary to have a correct estimation of the investment needs. These different vehicles are used for different distances of transport and thus do not require the same amount of investment.

For the technology considered, I initially wanted to align with the light-commercial vehicles and the Staff Working Document including Plug-in Hybrids vehicles and Battery Vehicles. However expert, interviewed during the process of thesis[1], have considered that plug-in electric trucks are very unlikely to exist. **Thus only battery-electric vehicles (BEV) and hydrogen vehicles were included. Hydrogen vehicles have been modeled as battery vehicles.**

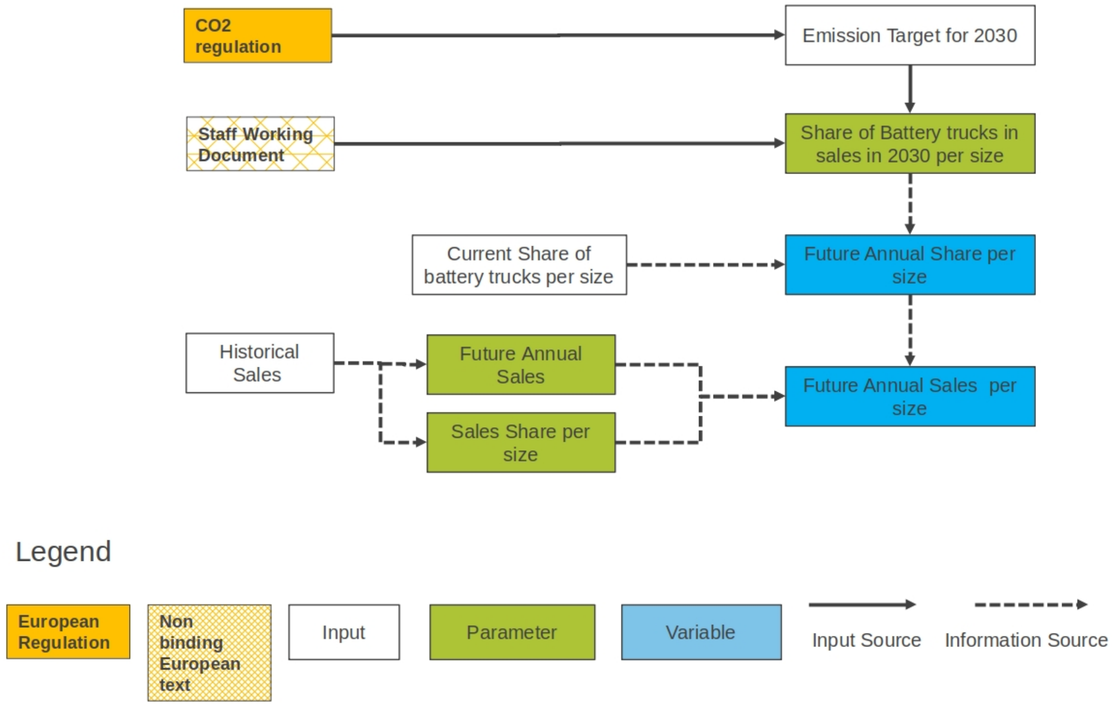
The *Annual sales of battery trucks per size* are required sales to meet the objective of the Regulation setting CO2 emissions standards for heavy-duty vehicles *C02 regulation.* They are calculated as the double-weighted product of *Total Annual sales*, representing the number of trucks sold per year, *by Share of each size in total sales* and the *Annual share of battery trucks per size*

- *Total Annual Sales i*n the model are estimated in a Business-as-usual scenario, meaning that the average of sales of the last years is used as the reference. Weighting this value by the *Share of each size in total sales*, the number of sales of trucks per size can be estimated (with all power trains including the fossil fuel one)

- *Annual Share of battery trucks per technology takes as main (indirect) input CO2 regulation. The Regulation monitoring CO2 emissions indeed only set an Emissions target for 2030.* The translation of these emissions in a technology mix is extracted from the Staff Working document accompanying the proposal, used in the parameter *Share of Battery trucks in sales in 2030 per size.* To extrapolate between 2030 and the *Current share of battery trucks per size*, a linear projection between current shares and 2030 target is assumed.

[1]Different discussions were hold with The International Council on Clean Transportation and Transport& Environment, two major think-tank on road transport

Figure 3.3 - Trucks volume model



Schematic representation of the method to transpose the Regulation setting CO2 standards for heavy-duty vehicles into yearly sales

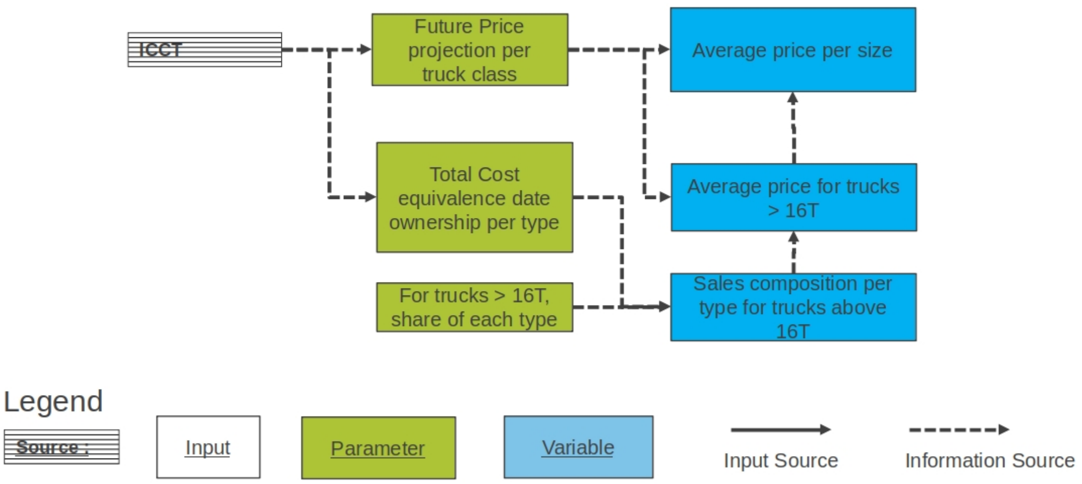
Step 2: Creating price scenario for trucks

In order to align with the volumes deployment scenario, prices for the different trucks sizes was calculated. The figure 3.4 summarizes the approach.

The *Average price per size* is calculated mainly using the study from the International Council on Clean Transportation (Basma & Rodríguez, 2023). This study gives price projections for different class types of trucks, *Price Projection per type of truck*. For trucks under 16T, the *Average price* was directly taken from the ICCT study as only one class type was available. For trucks over 16T however multiple types of trucks exits. This segment represents 80% of the market and should therefore be treated with caution.

The share in the segment above 16T of each type, has been assumed as constant in the 2022 situation, represented in the parameter: *For trucks > 16T, the share of each type*. The source used is representing the French market (Commissariat Général au Développement Durable, 2023). It is assumed that every type of battery electric starts being sold when the *Date of equivalence of the Total Cost of ownership per type* (meaning the expected date when a battery-electric truck and a fossil truck will cost the same over the lifetime of the first owner). This produces a *Sales composition per type for trucks above 16T* for battery electric trucks per year before 2030. Considering the *Price projection per size and type of vehicle*, the *Average price for trucks above 16T* can be calculated.

Figure 3.4 – Price model for trucks



Schematic representation of the method used for calculating the price of the different class of trucks.

Step 3: Estimates investment needs

Estimating investment needs is then the multiplication of yearly sales of each trucks sizes multiplied by the estimated price per year.

3.3.3. Charging points

This section presents the methodological approach for estimating investment needs up to 2030 for charging points. The method follows the three steps detailed above. Figure 3.5 summarizes the methodology.

Step 1: Translating European Policies into deployment scenarios

a. Presentation of the Alternative Fuel Infrastructure Regulation

To support the uptake of electric vehicles, the European Union has agreed upon targets for charging points and refuelling stations. In this study, the scope is limited to electric charging points. The Regulation on the Deployment of Alternative Fuel Infrastructure (2023) AFIR- has set a target of a minimal power deployment per electric vehicle. It also sets deployment targets on the main European highways (defined in the Trans-European Transport Network regulation) for light and heavy-duty vehicles. This regulation does not include private charging points also necessary for electric vehicle deployment.

The AFIR regulation sets two main objectives that were accounted for:

- A *Minimal power output per light-vehicles*(Article 3). The AFIR regulation defines that for each battery electric vehicle, 1,3 kW of output should be available and for each plug-in hybrid vehicle, 0,8 kW of output should be available. This objective is decomposed by Member State. The simplification is done, only looking at the European scale.
- Required deployment on highways (Articles 3 and 4 of the regulation). The AFIR regulation defines the objective of the deployment of charging points on crucial nodes of the network for light-duty vehicles and heavy-duty vehicles. The number of these charging points has been calculated (see Data Collection)

b. Hypothesis and presentation of the approach

To translate this regulation into a deployment scenario, the process follows different steps:

1. Estimate the power output required annually based on electric vehicles projection, taking into account current stock of charging points
2. Translate this power output to a number of charging points of different power sizes
3. Consider the mandatory deployments.

1. Calculate additional power output required annually

The p*ower output required annually* is defined as the power output meeting the requirements of the regulation based on the stock of electric vehicles to date. It is the product of the number of BEV and PHEV, light vehicles by the *Minimal power output per car* (set in the law).

The stock of electric vehicles is extracted from the flow of new vehicles *Annual sales of Electric vehicles* input taken from the passenger car and light-commercial vehicle model. It is transformed into a stock by adding up the sales value for the previous years. No scrapping of cars is supposed. This assumption has been corroborated by comparing to the average age of passenger cars of around 12 years (currently in Europe) (ACEA, 2022) to the sale date of an EV (mainly after 2020).

$$Power\ output\ required\ (year) = Number\ of\ BEV\ (year) * Minimal\ power\ per\ BEV + ¿$$
$$Number\ of\ PHEV\ (year) * Minimal\ power\ per\ PHEV$$

This figure is subtracted from the power output already deployed to calculate the *additional power output required annually.*

$$Additional\ power\ output\ (year) = Power\ output\ required\ (year) - Already\ deployed\ power\ (year)$$

2. Translate required power output to deployment units

The power output can be satisfied by a different combination of charging stations with different power.

This effect is considered in the parameter: *Share of power delivered by different charging point sizes*. 4 categories of charging points were used: 3.7 kW, 7.4 kW, 22kW, 250 kW. (see data Collection for more information). The mix was extracted from the French Transition plan called: Stratégie Nationale Bas-Carbone: *French NDCP* (Ministère de la Transition Ecologique et Solidaire, 2020).

The variable *Additional charging points required annually for power output* expresses the number of charging points required to meet the *additional power output required annually* based on the *Share of power delivered by different charging point sizes.*

3. Consider mandatory power deployments

The AFIR regulation set mandatory deployment on highways for light and heavy-duty vehicles. The number of charging points was estimated from the regulation is presented in Annex 3.

I made sure that the parameter *Share of power delivered by different charging point sizes* was set to provide sufficient charging points for meeting both requirements: of power output and on highways for light-duty vehicles.

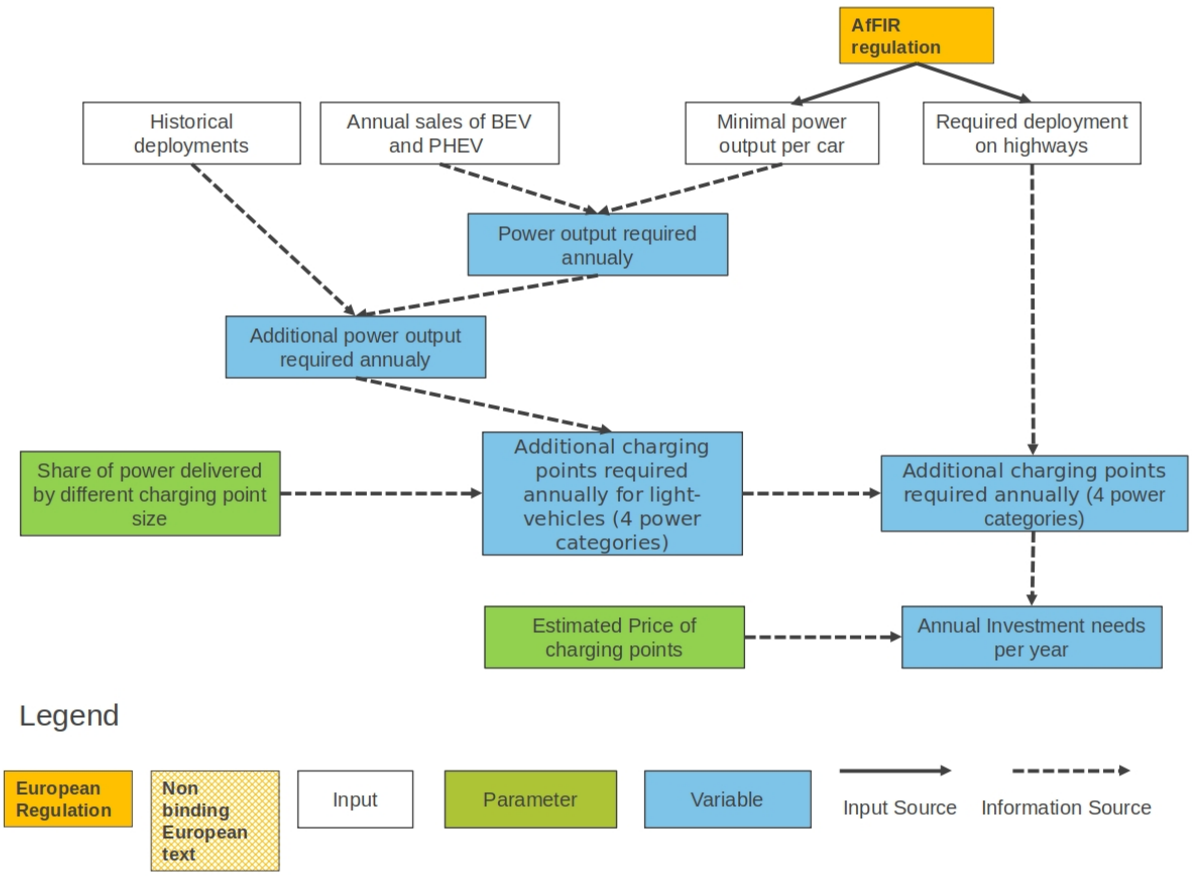
Step 2: Creating price scenarios for charging points

Price scenario for each charging point size were based on different sources (See Data Collection).

Step 3: Calculate investment needs

The required investment is then the sum of price for each power size of the charging points times their required deployment.

Figure 3.5 - Charging points model



Schematic representation of the model to estimate investment needs from the AFIR regulation (2023).

3.3.4. Railways

For railways, a different method has been chosen. Contrary to road transport, the European regulation focusing on projects could not be transformed into deployment scenarios. A simpler approach based directly on other sources has been followed. The figure 3.6 summarizes the approach.

a. Presenting European regulation.

The Trans European Transport - Network (TEN-T) regulation (2013) aims to develop transport infrastructures at the continental scale. It defines high-priority infrastructures that must be achieved by 2030, called Core TEN-T. For railways, it mainly includes the development of fast and long-distance rail transport and sets European standards. It is currently under revision (European Commission, 2021c), to increase its ambition.

b. **Investment needs**

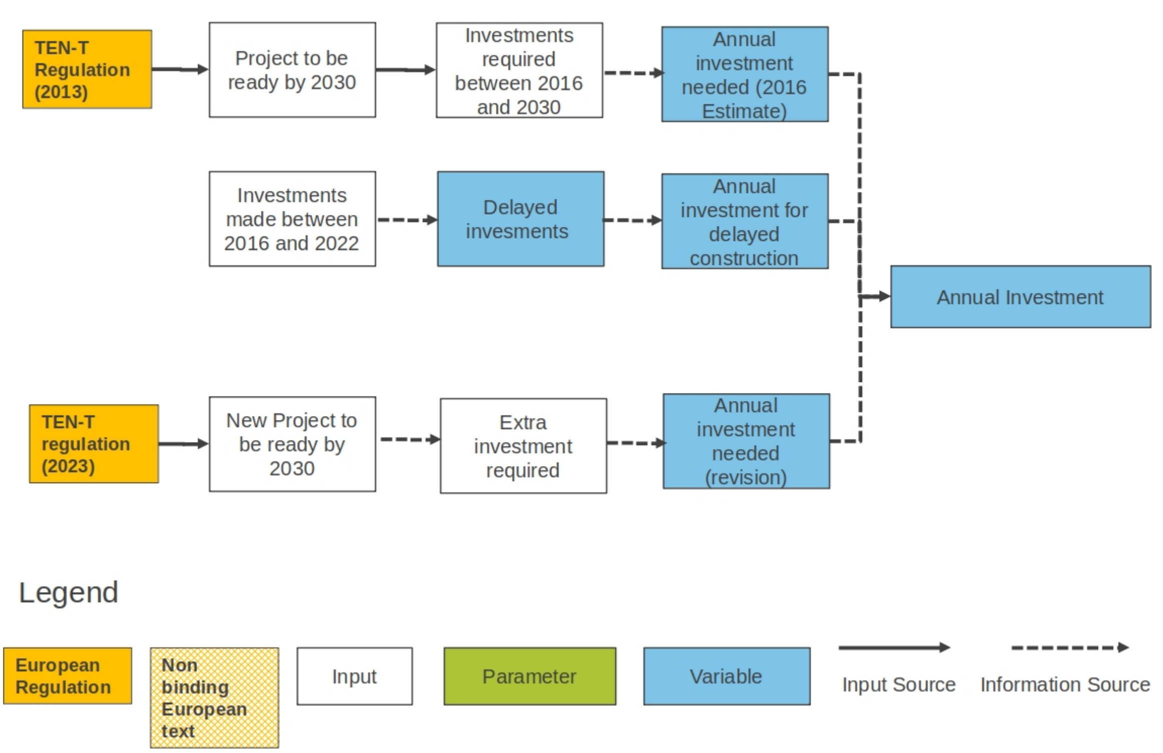
Most of the work was about collecting investment needs associated with:

1. Yearly investment is required to meet the 2013 Regulation. This was decomposed between the situation in 2016 and an up-to-date analysis of the remaining investment:
    1. Annual investment based on 2016 estimates
    2. Accounting for delayed investments
2. Yearly investments required to meet the future proposal

The *Annual Investment* variable measures the total investment required between 2023 and 2030 to meet the TEN-T regulation requirements. It is calculated as the sum of 3 terms *Annual Investment needed (2016 Estimate)*, *Annual Investment for delayed construction*, *Annual Investment needed (revision)*

$$Annual\,Total\,Investement = Annual\,investment\,needed\left(2016\,Estimates\right) + Annual\,investment\,for\,delayed\,construction + Annual\,investment\,needed\left(revision\right)$$

Figure 3.6 – Railways model



Schematic representation of the model to estimate investment needs for regulations concerning railways.

The *Annual Investment needed (2016 Estimate)* accounts for the investment required from the TEN-T regulation approved in 2013, *TEN-T Regulation* (2013). This regulation defines a set of projects that must be completed by 2030 (the Core-Network), *Project to be ready in 2030*. These projects are translated into investment requirements from an estimate made by the European Commission (2017), *Investments required between 2016 and 2030*. These investments are average annually in the variable (*Annual investment needed (2016 Estimate)*).

Some of these investments haven't been realized between 2016 and 2022. Extra investments are then required between 2023 and 2030, *Annual Investment for delayed construction*. The annual Investment for delayed Construction is the annual average value of the Total of *Delayed Investment*. The detail of the calculation is given in section 3.3 Data Collection. They are extracted from the IRG-Rail Dataset and EU Commission.

$$Annual\ investment\ for\ delayed\ construction = ¿ \frac{(Total\ investment\ initially\ needed\ between\ 2016 \wedge 2022 - Total\ Investment\ made)}{Number\ of\ years\ before\ 2030}$$

The *Annual Investment needed (revision)* accounts for the revision. This regulation defines a set of projects and standards that must be completed by 2030 (in the Core Network), *New projects are to be ready in 2030*. These projects are translated into investments from the Staff Working Document of the Commission, *Extra investment is required*. These investments are average annually in the variable (*Annual investment needed (revision)*).

3.3.5. Expressing in a single currency

To compare the different years, it's necessary to measure all investment in the same unit. Accounting for inflation, all investment made before 2022 were transformed in €2022 when necessary. This is made based on the GDP Deflator for the European Union from the World Bank.

Prices and investment after 2022 do not take any inflation into account neither.

3.4. Data collection

In this section, the data collection process is presented. Annex 3 complements this part by detailing the different parameters. The data collection aims to gather sources on:

- Parameters for estimating investment needs in 2030.
- Measure historical investments

3.4.1. Parameters used for estimating 2030 investment needs

In this section, the different sources and parameters are described. The general process for the data collection could be described as follows.. For tuning parameters, the main sources used are the International Energy Agency, the International Council on Clean Transportation – Renowned think-tank working on electric vehicles, or studies gathered but I4CE on the French situation.

The process for collecting the data was to review the studies found by I4CE. However, these studies were often specific to the French Market. In this case, the studies with other sources. The Annex 3 present in details the different parameters used and the reasons for choosing. The table below summarises the inputs of the model for estimating investment needs

Table 3.1 - Summary of the inputs used for estimating 2030 investment needs

Section	Input Name	Used for	Source
Light vehicles - Deployment scenario	Historical Sales	Setting parameter of future total sales	(ACEA, 2023)
	Current share in sales of each technology	Interpolating share of each technology between 2023 and 2030	(ACEA, 2023)
Trucks – Deployment scenario	Historical Sales	Setting parameter of future total sales	(ACEA, 2023) and (Mulholland, 2021)
	Current share in sales of each size	Interpolating share of each technology between 2023 and 2030	(ACEA, 2023)
Charging points - deployment scenario	Historical deployments	Used for calculating already installed power output	(International Energy Agency, 2023)
	Future annual sales of Battery Electric Vehicles (BEV) and Plug-in hybrid vehicles (PHEV)	Used for estimating yearly power output required	Own modeling
	Annual power output per car	From the AFIR regulation, Used for estimating yearly power output required	REGULATION (EU) 2023/1804 - Alternative Fuel Infrastructure Regulation, Article 3.1.

	Required deployment on highway	From the AFIR regulation, Used for calculating charging points stations required	AFIR Regulation, Article 3.4.
Railways Investment needs	Investment required between 2016 and 2030	Used for estimating the baseline of investment required	(EU Commission, 2017)
	Investment made between 2016 and 2022	Used for estimating delayed investments	Own estimate based on (European Commission, 2020b)
	Extra investment required	Used for estimating the cost of the future regulation	(European Commission, 2021c)

Table 3.2 - Summary of the parameters used for estimating investment needs in 2030

Section	Parameter Name	Used for	Source
Light- Vehicles	Share of each technology in sales in 2030	Setting the target in 2030	(European Commission, 2021b, p. 34)
	Future annual Sales	Transform share in sales to volumes	Estimated based on historical sales
	Future average price of BEV and PHEV	Estimate investment form volumes	(I4CE, 2023)
Trucks – Deployment scenario	Share of Battery trucks in sales in 2030 per size	Setting the target in 2030	(European Commission, 2023b, p. 116)
	Future annual sales	Transform share in sales to volumes	Estimated based on historical sales
	Sale Share per size	Refine the target by adding granularity of different truck size	Assumed to be constant to the 2022 situation
Trucks – Price scenario	Future price projection per truck class	Transform volumes into investment	(Basma & Rodríguez, 2023)
	Total cost equivalence date ownership per type	Adapt the price of trucks of 16T to technological improvements	(Basma & Rodríguez, 2023)
	For trucks > 16T, Share of each type	Adapt the price of trucks of 16T to technological improvements	(I4CE, 2023)

Charging points	Share of power delivered by different charging point sizes	Transform power output into unit of charging points	(I4CE, 2023)
	Estimated price of charging points	Transform unit volumes into investment needs.	(European Commission, 2021d; I4CE, 2023)

3.4.2. Sources used for tracking historical investments

Tracking historical investment was done in parallel than estimating investment needs for 2030.

For road transport and charging points, unit cost was multiplied by the volume deployed. For rail transport, investment for railways was estimated based on other sources. The table below presents the sources and the details are given in Annex 3.

Table 3.3 - Summary of the sources used for tracking historical investment

Section	Used for	Source
Passenger cars and light-commercial vehicles	Electric vehicles sales	After 2018: (ACEA, 2023) Before: (ICCT, 2023)
	Average price of cars sold	(I4CE, 2023)
Trucks	Electric vehicles Sales	(ACEA, 2023)
	Average price of trucks sold	Own estimate
Charging points	Installed capacity per year	(International Energy Agency, 2023)
	Price of charging points	(I4CE, 2023)
Railways	Spendings on TEN-T railways project	Own estimate based on (European Commission, 2020)

3.5. Discussion and limitations of the methodology

In this section, the overall methodological approach is discussed.

3.5.1. Difficulties encountered

Modeling the European Policies and filling the data gaps were significant challenges in this work, leading to a reduced scope of study.

a. European Regulation

The first main challenge faced was navigating through the different European Regulations, and understanding the amendments considered. This was especially the case for railways that are not covered by an adequate regulation but included in the regulation for European Connection.

In addition, these complex texts had different versions between proposals from the European Commission and the version adopted by the European Parliament and of the Council. The texts are also at different stages in the policy process, some are not yet agreed on. The sources were thus mixing both proposals and adopt regulations. Also, the Staff Working Documents don't correspond to the regulation adopted but only to the proposal. It was necessary to first understand the modeling of the European Commission to be able to adapt their findings.

Translating European policies to specific numerical outcomes requires the use of multiple parameters. Including scenarios as discussed in section C below would have been beneficial for the approach. But besides the parameters, numerous data gaps in the inputs of the model were found.

b. Data gaps

For Railways, the data found were only about aggregated figures on investment at the EU scale, not providing information about specific projects. Also, such aggregated figures for investment in high-speed railways (TEN-T) at the European Scale were not available after 2018 and had to be estimated. The historical investments in the TEN-T infrastructure have been estimated from total railway spending based on the 2016 and 2017 share of investment in railways going for TEN-T. This constant estimation doesn’t fit the reality where policymakers are spending money on projects. It is possible that TEN-T spending was higher or lower. However, the order of magnitude of the spending is correct. It is indeed majorated by the total spending on railways in Europe.

The other main gap is in the details of the prices of cars for historical sales. Prices for electric passenger cars and light-commercial vehicles are estimated based on the French market. Indeed, no open source of prices could be found. And numerous methods were tried to find ways to extrapolate the total market. The assumption to keep the French car price was finally preferred. Indeed, price variability for the same car inside Europe is limited. Dvir & Strasser (2018) found that for a same car difference between countries could be up to 20%, mainly due to pricing strategies by car manufacturers. Moreover, the electric car market is very concentrated in Western European countries. In 2022, the five largest countries: German, France, Sweden, the Netherlands and Italy, represented around 80% of the sales of passenger cars battery electric vehicles (ACEA, 2023a). Consumers in these countries have similar buying power than In France, so price differences are limited.

c. Scope

Finally, I had to limit the scope of the studies to only some of the technologies and sub-objectives covered by the Regulation. Table 3.4 presents the exact scope of the technologies considered. The assessment proposed is thus not exactly the one necessary for meeting the regulation. The main comments for excluding some technologies should be outlined:

- For road transport, only technologies contributing to the reduction of emissions were considered: when compared to the different levels of gCO2/km in 2030 this includes battery electric vehicles (0g/CO2) and efficient plug-in hybrid vehicles (under 50 gCO2/km). Hydrogen vehicles have been disregarded because of limited volumes. Their expected uptake is around 1% of the annual car sales in 2030 (European Commission, 2021b)

- For heavy-duty vehicles, only trucks have been analysed. This leaves out buses, representing around 10% of the segment sales (ACEA, 2023b). After conducting expert interviews[2], plug-in electric trucks have not been included as this technology is very unlikely to exist.
- As hydrogen and gas haven't been included in the scope of the study for road vehicles, only electric charging points have been included in the scope. Only public charging points were covered by the AFIR regulation, disregarding private charging points.
- Only objectives for 2030 (and not 2040 and 2050) for railways for the TEN-T have been included and aligned with the time horizon of the study. The TEN-T regulation also includes standards about highways, Because of, the limited utility for reducing CO2 emissions of such objectives, they have been excluded from the scope of the study. Airports and ports were not in the scope of land transport.

Table 3.4 - Summary of the perimeter of the regulation considered

Regulation	Perimeter of the regulation considered	Perimeter of the regulation not considered	Reason for exclusion
Regulation monitoring CO2 emissions from passenger cars and light-commercial vehicles	Passenger cars and light commercial vehicles: Battery electric vehicles Plug-in hybrid vehicles	Hydrogen vehicles	
Regulation monitoring CO2 emissions from Heavy-duty vehicles	Battery Electric Truck	Plug-in hybrid trucks Buses and coaches	No data on prices Limited time
Regulation on the deployment of alternative fuel infrastructure	Public electric charging points	Infrastructure for maritime and aviation Hydrogen and gas stations	Out of the scope of the study Very limited needs by 2030
Regulation on the trans-European transport network	Railways Projects for 2030	Railways project for 2040 and 2050 Infrastructures for highways, ports and airports	After the time horizon of the study Out of the scope of the study

[2] Different discussions were hold with The International Council on Clean Transportation and Transport& Environment, two major think-tank on road transport.

3.5.2. Discussion on the parameters and the model

In this part, the choices made in the design of the analysis and the parameter choices are discussed.

a. Spatial granularity

It is important to acknowledge that the analysis developed in this study operates at the European level and does not account for the national scale. This is a simplification of the reality on several elements. First, the situation represented doesn't correspond to the European regulation. For example, the targets set in the AFIR regulation are at the National scale but the values were averaged at the European scale. The parameters are also simplified at the European scale, it thus does not account for different decarbonization strategies that could be decided by the Member states. The results will also miss this overview, not showing national challenges. Future research could explore national-level considerations into the model to provide a more holistic understanding of the investment challenge.

b. Cost underestimation for charging points

It is essential to acknowledge that the price estimations for charging points presented in this study may not fully capture the complete cost spectrum associated with infrastructure deployment. Specifically, the analysis focused solely on the direct costs of purchasing and installing charging points, not considering additional expenses such as network connection fees. This limitation implies that the true financial burden associated with expanding charging infrastructure may be higher than indicated in the findings. I decided to exclude this cost due to the difficulties of the methods.

3.5.3. Discussion on the research approach

This part discusses the research approach, emphasizing the limitations of the technology-specific method, the lack of scenario modeling, the simplicity of the model, and the lack of ex-post assessment.

a. Technology specific analysis vs Energy-Economy model

The research approach adopted in this study centers around utilizing a technology-specific scenario. It offers several advantages, notably in its ability to tailor projections and investment estimations to specific technologies, thereby providing targeted insights into the needs for meeting the European 2030 target and ensuring compliance with legal frameworks. However, it is important to acknowledge that while the technology-specific scenario provides detailed insights, its narrow focus may limit the breadth of analysis. On a political note, a simple model is useful for transparency purposes. Everything is stated and it has no hidden assumptions (Robinson, 2004). By simplifying the reality, it helps to communicate the main drivers.

A more comprehensive approach, employing an economy-energy model for example, could have offered numerous benefits. Notably, it would have guaranteed coherence between assumptions and hypotheses in a broader scenario context. Such a model could have facilitated the exploration of alternative scenarios and their implications, under different external conditions such as GDP influence, and population. This model seemed not necessary for answering the research question but would have supported the analysis.

b. Lack of scenarios

Even without testing the influence of external parameters, scenario modeling would have helped to test different hypotheses and conduct some sensitivity analysis. The importance of the different parameters is unknown. Conducting sensitivity analyses on critical parameters such as total sales and market share, could have provided insights into the robustness of the model to fluctuations in these parameters, offering a more comprehensive understanding of the potential impacts on the results. However, due to the time constraints faced, this aspect remained unexplored limiting the readability of the results.

c. Limitation of model for extending the analysis

For the technology-specific approach, the model utilized in this study is relatively simple in its design and implementation, which may have implications for the depth and accuracy of the analysis. For example, the model doesn't include feedback loops or outflow in the stock evolution. The scrapping of cars was considered negligible for the 2030 target as the lifetime of cars is around 15 years in Europe currently (European Commission, 2021b). However, designing a stock-flow model with scrapping would have enabled to test of the longer-term comportment of the model. The current version is limited to 2030.

Finally, the analysis outputs the investment needs for meeting European regulations. There is no ex-post assessment that guarantees that making these investments would deliver the expected CO2 emissions reduction. Incorporating such metrics into future iterations of the model could enhance its capacity to provide a more holistic evaluation of European policies. This was however not the objective of the master thesis.

4. Results

This part presents the results of the analysis. The presentation follows the different texts covered by the European regulation and ends with the presentation of the overall investment gap decomposed by sector.

4.1. Passenger cars and light-commercial vehicles

This section presents the results for two transport means: passenger cars and light-commercial vehicles covered by the Regulation setting CO2 standards for passenger cars and light-commercial vehicles (2023). The presentation follow the step presented in the Methodology. First the results about deployment scenarios are presented., followed by the evolution of vehicles prices and finally the overall investment needs are shown and compared to historical investment.

Light-vehicles refer to both passenger cars and light-commercial vehicles.

4.1.1. Translating European Policies into deployment scenario

The first step is to translate European policies into yearly sales volumes as explained in the Methodology. Using a constant volume of total vehicles sold with increasing share of vehicles, the sales in 2030 and resulting stock of vehicles are modeled. Graphs are presented in Annex 4.

Table 4.1- Results of volumes deployment for light-vehicles

Technology	Sales in 2023	Sales in 2030	Stock in 2030
Battery electric Passenger cars	1.7 Million unit (M)	4.5 M	27.9 M
Plug-in hybrid passenger cars	0.9 M	1.7 M	12.8 M
Battery electric light-commercial vehicles	0.13 M	0.5 M	2.8 M
Plug-in hybrid light-commercial vehicles	7 300 unit	0.2 M	0.9 M

Source: Author. The table presents the yearly sales for 2023 based on historical data (ACEA, 2023) and the sales in 2030 estimated from the study. The stock in 2030 corresponds to the number of vehicles existing in the European Union.

For all technologies considered an increase in volume sold is necessary for meeting the 2030 obligation. However, the difference in terms of increase varies between the different categories. For passenger cars, a multiplication of volumes sold by almost three is necessary for Battery electric Vehicles (BEV) and more than 2 for Plug-in hybrid vehicles (PHEV). But the electrification effort is largely higher for light-commercial vehicles, notably PHEV light-vehicles which are almost at 0 currently.

In 2030, passenger cars especially BEV will represent the highest proportion in terms of stocks. This is due both to more passenger cars than light-commercial vehicles sold and also a higher electrification.

4.1.2. Defining price of future vehicles

Price of future vehicles are modeled by I4CE (2023) based on technological improvements in batteries and accounting for a shift in consumer preferences (see Annex 3). The table below presents the price of different vehicles in 2030 modeled and the price in 2023 for comparison. The Annex 4 shows the evolution of prices.

Table 4.2 – Price for light-vehicles of the model

Technology	Price in 2023	Price in 2030
Battery electric Passenger cars	35,280 €	34,278 €
Plug-in hybrid passenger cars	46,952 €	45,271 €
Battery electric light-commercial vehicles	34,317 €	29,123 €
Plug-in hybrid light-commercial vehicles	52,548 €	40,000 €

Source: (I4CE, 2023). This table present the price used for the model based on (I4CE,2023) split by technology.

The results for car prices show a global stagnation of prices for passenger cars. In this case, the progress in terms of battery performance is outbalanced by consumer preferences for the longer driving range modeled. Light-commercial vehicles observed a higher price decline. For this category, the model doesn't take into account the effect of consumer preferences or sizes of vehicles sold explaining that prices are decreasing thanks to technological improvements.

4.1.3. Total Investments

The table below present the results in term of investments for meeting the European regulation based on the deployment scenario and price scenario presented above.

Table 4.3 – Investment results for the different segments of light-vehicles

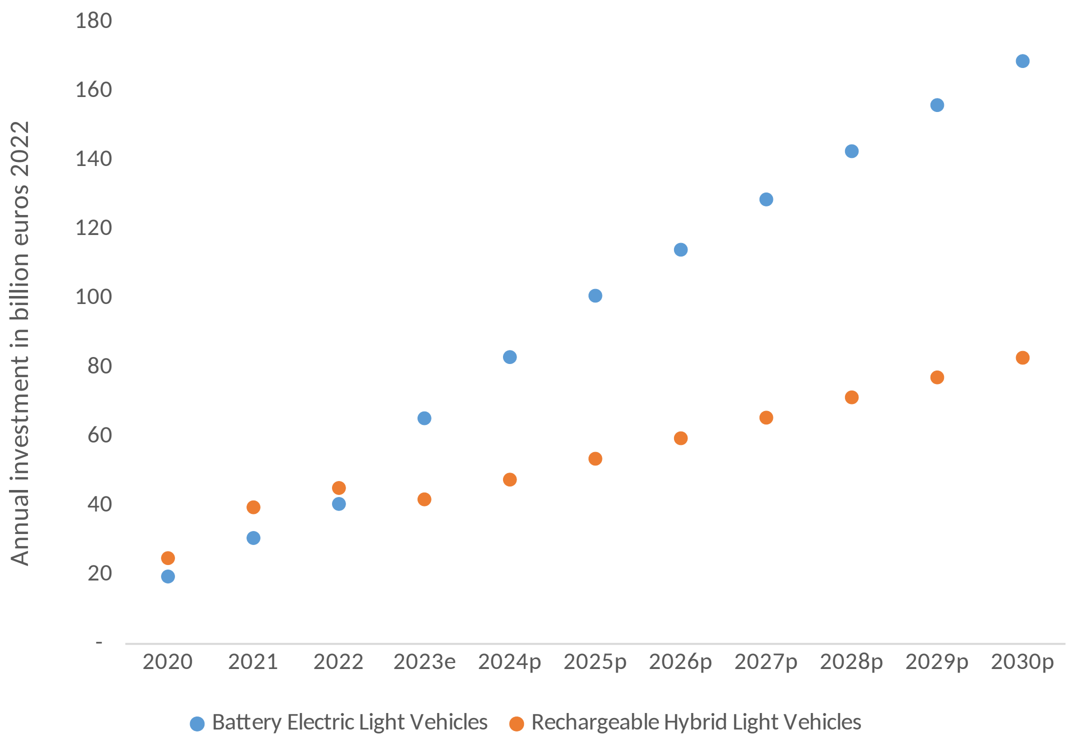
Technology considered	Investment realized in 2022 (in billion euros)	Average investment needs between 2024 and 2030 (in billion euros)	Investment need in 2030 (in billion euros)
Battery electric Passenger cars	38.4	117.3	153.5
Plug-in hybrid passenger cars	44.6	60.4	75.0

Battery electric light-commercial vehicles	2.2	10.8	15.3
Plug-in hybrid light-commercial vehicles	0.5	5	7.9

Source: Author. This table present the yearly investment made in 2023 and compare them with average annual investment needs and 2030 investment needs for light vehicles.

The figure 4.1 presents the results aggregated for passenger cars and light-commercial vehicles split by technology.

<u>Figure 4.1 - Evolution of historical investment and yearly investment needs for meeting 2030 objectives</u>



Source: Author. Investment realized between 2020 to 2023 are estimated from actual data (see Methodology). After 2024, the figure depicts the projected investment needs for meeting the objectives set in the regulation.

From 2020 to 2023, investments in Battery electric vehicles have been increasing in recent years, from 20 billion euros in 2020 to 63 billion euros in 2023. In 2030 for meeting the objective set in the regulation, the investments should reach 169 billion. Compared to the 83 billion euros necessary for meeting the objectives for PHEV vehicles, it is more than double.

On the other hand, recent investment in hybrid vehicles is showing that the sales for this kind of vehicle have decreased, with a decreasing number of sales impacting the overall investment made; 2023 levels are lower than 2022.*Source: Author. This table present the yearly investment made in 2023 and compare them with average annual investment needs and 2030 investment needs for light vehicles.*

4.2. Trucks

This section present the results for battery electric trucks following the approach explained in the Methodology.

4.2.1. Translating European policies into deployment scenario.

The first step is to translate European policies into yearly sales volumes as explained in the Methodology. Using a constant volume of total vehicles sold with increasing share of vehicles, the following sales in 2030 and resulting stock of vehicles are modelled.

Table 4.4 - Results of volumes deployment for the different trucks sizes

<table>
<tr><td>Truck size category</td><td>Sales in 2022</td><td>Projected sales in 2030</td></tr>
<tr><td>Under 7.5 T</td><td rowspan="2">4,680 unit</td><td>1,370 unit</td></tr>
<tr><td>Between 7.5 T and 16T</td><td>9,145 unit</td></tr>
<tr><td>Above 16 T</td><td>2.800</td><td>55,400 unit</td></tr>
</table>

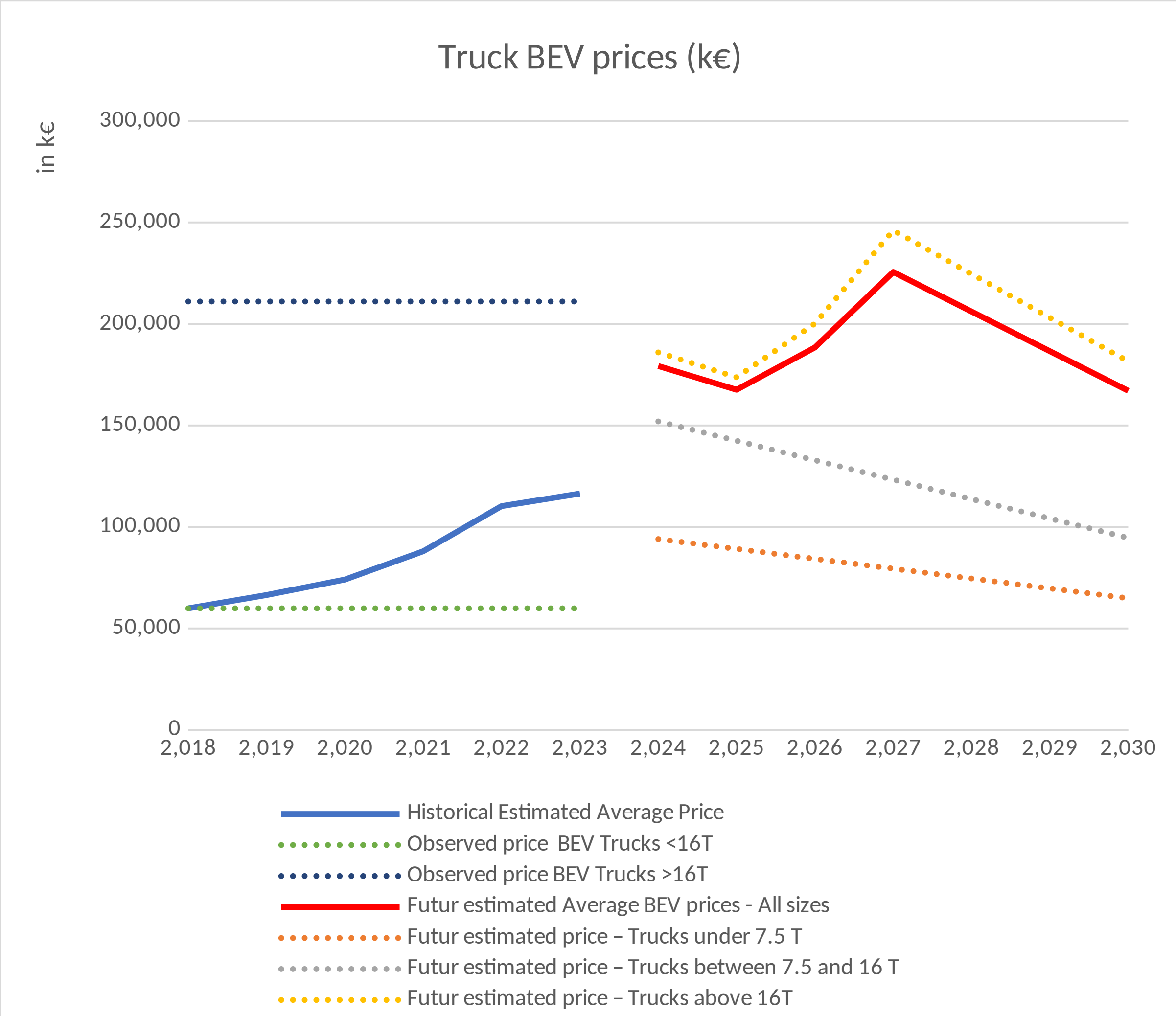
For 2022, sales are estimated from actual data (see Methodology). Sales in 2030 are a result from the model.

The results show that under the scenario from the European Commission, most of the electrification should be in the trucks segment over 16T. It is however an under-electrified segment with current numbers. On the other hand, the supplementary effort for smaller trucks is limited.

4.2.2. Defining a price scenario

Resulting from the Methodology explained, Figure 4.2 depicts the historical average selling price and the projected price of the different trucks class size.

Figure 4.2 – Historical prices and future prices for battery electric trucks



Source: Author. Data before 2023 are based on actual data (see Methodology). Data between 2024 and 2030 are estimated by the author. Dashed line represent sub-size categories price evolution and normal lines the average price of a battery electric trucks.

The historical price evolution reported shows the importance of sales of bigger trucks on the average price. With more bigger vehicles getting electrified, the average price increased.

On the right side of the figure, the prices for each category show an overall decreasing pattern, thanks to technological improvement. The case of trucks above 16T should be outlined. As explained in the Methodology, the model for calculating the price of >16T trucks takes into account different threshold dates. For every “bump" in the curve” is associated with a year trucks with longer driving ranges are getting electrified.

It is also necessary to note that historical prices don’t match with future prices. This is probably due a incorrect data collection on historical prices. Because very limited information was found, the price is based on only one truck model that doesn’t represent the whole segment.

Finally, the important share of the trucks above 16T in the Commission scenario can be seen in the average price of trucks with value and patterns following very closely the line of the >16T trucks.

4.2.3. Investment

The table below present the results in term of investments for meeting the European regulation based on the deployment scenario and price scenario presented above.

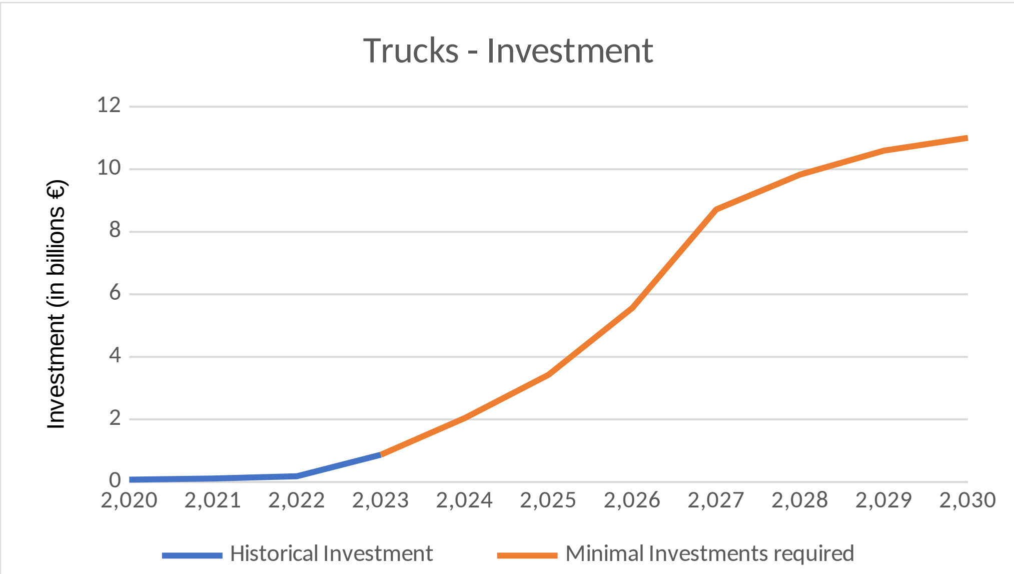
Table 4.5 - Investment results for battery electric trucks

Technology considered	Investment realized in 2022 (in Bn€)	Average investment needs between 2024 and 2030 (in Bn€)	Investment need in 2030 (in Bn€)
Battery Electric Trucks	0.2	7.3	11

Source: Author. This table present the yearly investment made in 2023 and compare them with average annual investment needs and 2030 investment needs for trucks.

The figure presents the results for total investment based on a multiplication of annual volumes and annual price.

Figure 4.3 – Evolution of the historical investment and required investment for meeting the 2030 regulation



Source: Author.

Investments in electric heavy-duty vehicles have shown an acceleration since 2020 from 0.1 billion euros to 1 billion euros in 2023. On average between 2024 and 2030, 7.7 billion euros are needed, up to 11 billion euros in 2030. Looking more closely at volumes, the needs are driven by the electrification of trucks above 16 tons.

The curve shows an S-Shape. It's due to the balancing effects of decreasing prices taken in the hypothesis considered for the analysis.

4.3. Charging points

This part presents the results for charging points.

4.3.1. Scenario deployment

The model for charging points includes charging stations of different power size. The table below presents the results

Table 4.6 - Deployment scenario results for charging points

	Charging point power size (in kW)	Yearly installation (in unit)
Historical sales In 2022	> 22	120 000
	< 22	18 000
Future sales in 2030	3.7	70 000
	7,4	795 000
	22	5 000
	150	6 400 for light vehicles 8 700 for heavy-duty vehicles
	350	1 200

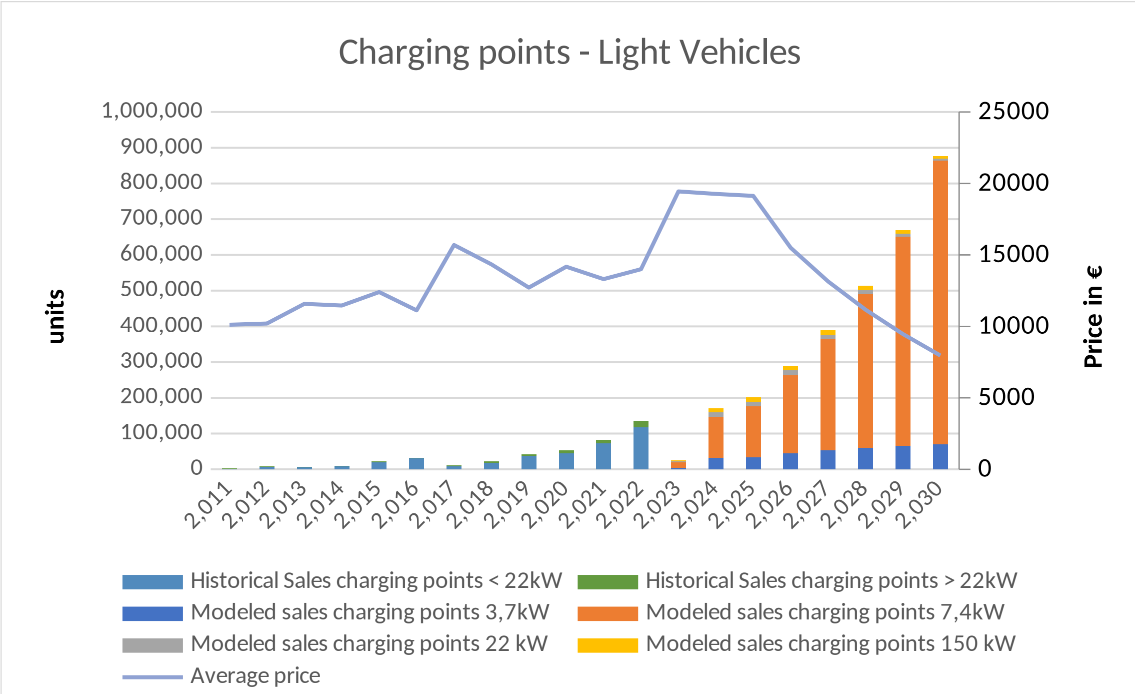
Historical sales are taken from the IEA (2023), Future sales are results of the model.

This table is commented with the accompanying Figure 4.4.

4.3.2. Price

The different power stations have price that were collected from I4CE and the EU Commission. The values are presented in Annex III – Data Collection. Figure 4.4 shows the historical and future installation of charging point per power size and the average expected price.

Figure 4.4 – Price evolution of the average charging point stations and yearly installations for light-vehicles



Source: Values before 2022 are based on actual data (see Methodology). Values after 2023 are results from the model.

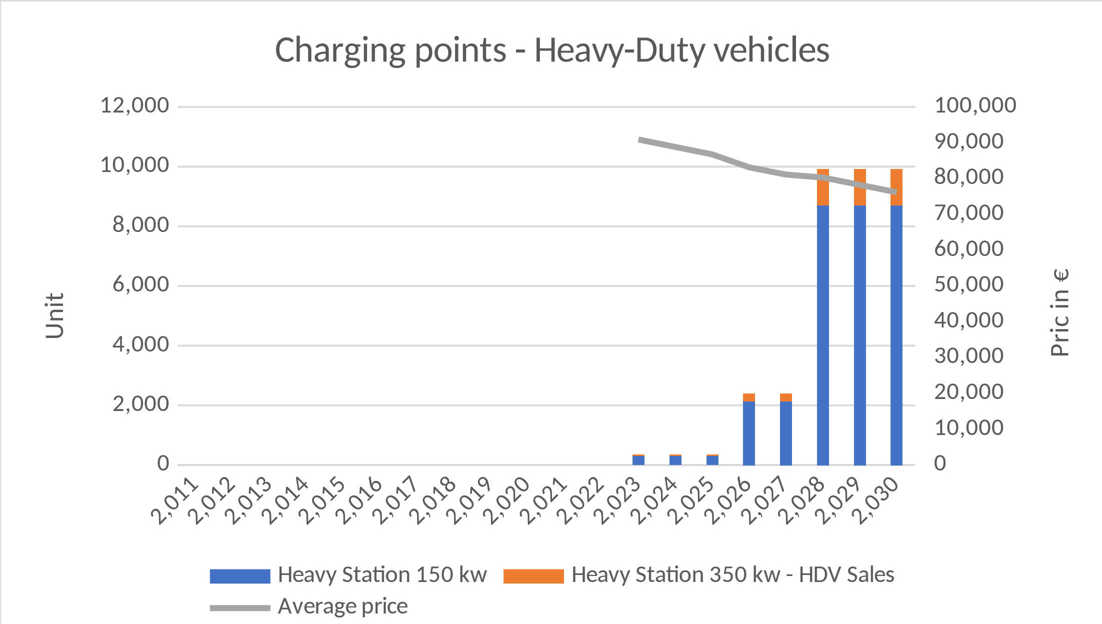
The figure shows that historical installations have seen an increase in volumes over time. Moreover, the average capacity has increased as shown by the increasing trends of the average price meaning that stations with more power output were installed.

In 2023, the values that have to be installed to meet the requirements of the AFIR regulation are close to zero. This indicates that compared to the requirements, the current level of installation is almost enough to meet the targets one year in advance.

Figure 4.4 shows that the deployment scenario supposes that first more high-speed charging points are installed and then the shift goes towards low-power charging points. This can be seen in the average price of charging points installed which is declining throughout time after an initial increase between 2023 and 2025.

The figure 4.5 presents the results for charging point for heavy-duty vehicles.

Figure 4.5 – Price evolution of the average charging point stations and yearly installations for light-vehicles



Source: Author.

For heavy-duty vehicles, the regulation has mandatory deployment objectives every two or three years. This explained the shape of the curve with different stages.

A continuously decreasing average price is observed. On the other hand, the proportion of 350 kW stations in the newly installed stations increase. It means that the technological improvements on 350 kW stations more than compensate the need for more power output.

4.3.3. Total investments required

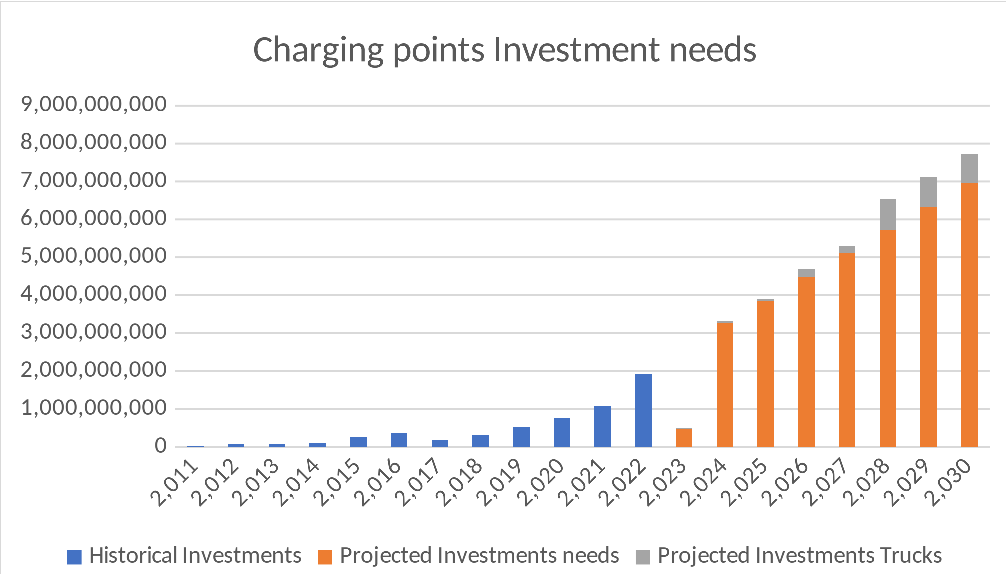
The table 4.7 presents the results in term of investments.

Table 4.7 - Investment needs for charging points deployment

Charging point	Investment realized in 2022	Average Investment needs between 2024 and 2030	Investment needs in 2030
For light vehicles	1.9 billion €	5.1 billion €	7.0 billion €
For heavy-duty vehicles	0	0.4 billion €	0.7 billion €
Total	1.9 billion €	5.5 billion €	7.7 billion €

Source: Author.

Figure 4.6 – Historical investment and future investment needs for meeting the AFIR regulation for charging points



Source: Author. Historical investment are estimated from actual data (see Methodology). Investments needs after 2023 are results of the study.

Alongside the rise in electric vehicles (EV), electric charging points investment needs are accelerating. On average between 2024 and 2030, 5.5 billion euros are required to be invested. In 2030, it increases to 7.7 billion euros. On average, compared to current investments, an additional 3.6 billion euros should be invested for public charging points, with an average increase of 19% per year. On average, light vehicles account for more than 90% of the needs for meeting the targets. But the infrastructures dedicated to heavy-duty vehicles have needs increasing faster, accounting for less than 1% in 2025 to almost 10% of total investments in 2030

4.4. Railways

Meeting the Trans-European Transport regulation objectives for railways in 2030 requires investments on the network. Investments are decomposed between the investment required for meeting the 2013 initial regulation and the investment for meeting the proposal of a new regulation. Investments required for meeting the 2013 regulation are splitted between the 2016 assessment of investment needs and delayed investments compared to this baseline. Table 4.8 details the results.

Table 4.8 - Investment needs for high-speed railways European Infrastructure

Object	Investment in billion euro
Historical investment reported in 2022 for the Core Network	18.4
Yearly investment to meet the 2013 regulation without delayed investment (2023-2030) (EU Commission, 2017)	29.0
Extra investment accounting for delayed	8.3

investment to meet the 2013 regulation (2023-2030)	
Investment need for meeting the future revision (starting in 2025-2030) (European Commission, 2021d)	11.6
Sum: Average annual investment need for meeting 2030 target	**47**

Source: Author. Historical investment are estimated from multiple source (see Methodology). Other sources are specified.

Building rail infrastructures for long-distance travel requires 47 billion euros annually between 2024 and 2030, i.e. 0.3% of EU GDP in 2022[3]. The estimated investments for 2022, of 18 billion euros, represent 39% of the investments needs. An additional 29 billion euros should be invested annually.

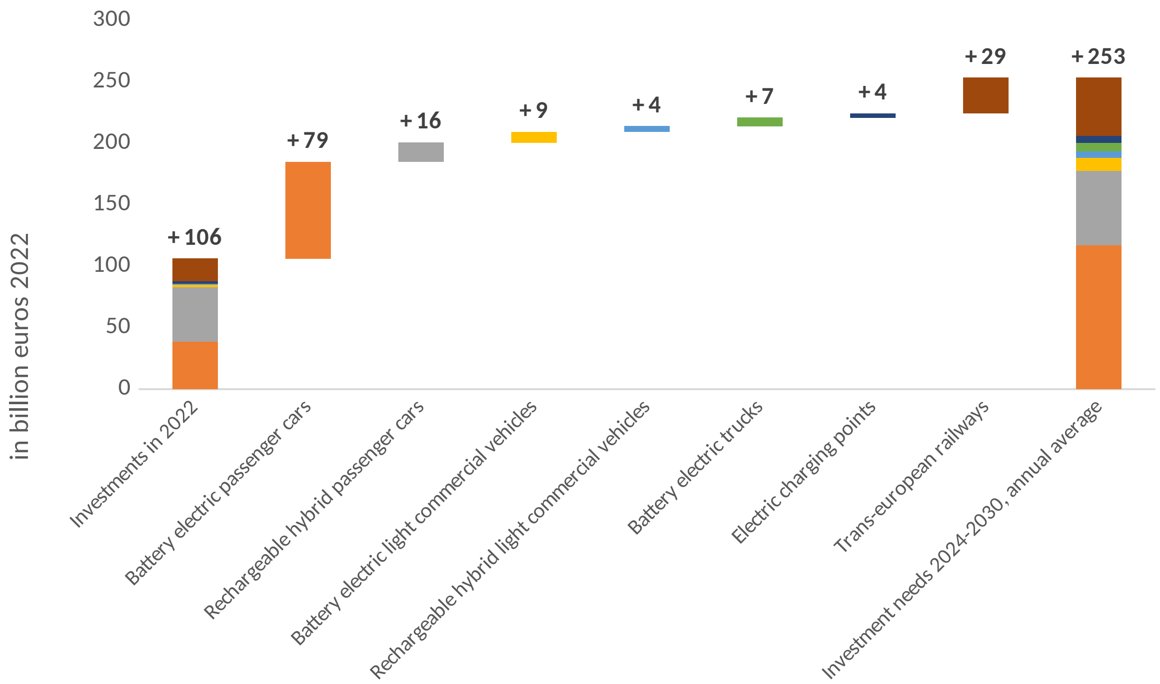
For comparison, the EU-economy has spent 48 billion euros on all its total railway infrastructure in 2021 (IRG-Rail, 2023). The future revision of the TEN-T 11 accounts for 10 billion euros, representing 22% of the investment needs for the Core network. The remaining 78% of the needs are attributed to the previous regulation. In comparison to the 2016 estimates made by the European Commission (2017), this estimates accounts for delayed investments spanning from 2016 to 2022. Between 2024 and 2030, catching up on these investments cost 8 billion euros annually

4.5. Overall investment gap

In this section, the different investment needs found are presented and compared to the estimate the historical level of investment for the transport sector at the EU scale. The Figure 4.6 presents the investment gap distributed between the different technologies considered.

Figure 4.6 – Decomposition of the investment gap between the different technologies considered

[3] EU-27 GDP: 15 905.3 billion euros in 2022. Eurostat, 2024 https://ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table?lang=en



Source: Author. 2022 investments are based on actual data (see Methodology). This graph represents the distribution of the climate investment gap for the transport system. For each technology, the investment deficit compares the investment required to meet the European regulation with 2022 investments.

Overall, between 2024 and 2030, making EU targets in the transport sector require 253 billion euros of investments per year or 1.6% of the EU GDP. In 2022, 106 billion euros, or 0.7% of EU GDP, were invested primarily in battery electric cars, chargeable hybrid cars and long-distance rail infrastructure, covering 42% of overall investment needs. The transport investment deficit reaches 147 billion euros, or 0.9% of EU GDP per year between 2024 and 2030.

Investment needs between now and 2030 are primarily driven by the electrification of vehicles, accounting for 78% of the total deficit or 115 billion euros. Supporting this technological shift, charging points additional investments represent 3.6 billion euros, or only 2% of the total deficit. Trans-European Railways, with a deficit of 29 billion euros, have the second-highest need of additional investments (20%). This ignores investment needs in key transport systems for reducing CO_2 emissions not covered by this report due to lack of data, such as urban public transport.

5. Discussion & recommendations

This section discusses the results and provides policy and scientific recommendations.

The results of the analysis are first discussed. Building on this, the discussion extends to the European regulation in a second part. The use of the investment gap as an indicator for monitoring policy progress is then discussed. Finally, policy and scientific recommendations are proposed.

5.1. Discussion on the results

In this part, the results presented above are discussed. Firstly, a qualitative analysis of the alignment of historical investment with future investment trends is proposed. Secondly, the investment gap and how it could be filled are discussed. Finally, the limitations of the analysis are described, and the results are compared with other studies.

5.1.1. Alignment of historical investment with investment needs

In this section, the investment gap is qualitatively discussed for each technology based on recent evolution in investments.

Overall, investment in electric vehicles is showing an increasing trend, but current investments are not aligned with future needs. Scrutinizing the separate technologies, the capacity of PHEVs and trucks to meet their respective investment needs is uncertain:

• The recent uptake in battery electric vehicles (BEV) investments makes meeting minimum deployments more likely, but they should continue to increase (see Figure 4.1). To meet the 2030 target, investments need to grow at an average rate of 15% per year. 2023 growth exceeded this value, increasing by 61% compared to 2022.

• On the other hand current trends in plug-in hybrid vehicles (PHEV) investments are not aligned with increasing needs. The scenario proposed by the European Commission requires an increase in investments in PHEV of about 10% per year compared to 2023 levels. However, current investments in PHEV are stagnating. If this trend continues, an extra effort for BEV would be required to maintain the same overall CO2 emission reduction.

For trucks, current investments are at a low level close to zero. Moreover, the electrification is mainly concentrated in small sizes, under 16T while the future objective requires the rapid electrification of bigger-size trucks. Above 16T trucks represent more than 80% of the sales of all battery trucks in 2030. This category, however, represents around 40% of the electric sales of trucks for 2022 (Mulholland & Rodríguez, 2023). The long-term flattening shape of the investment needs curve is due to great technological improvements that could be uncertain.

The charging points investments trend shows that the current installations are above the required level for light-duty vehicles. In the analysis, this is shown by a small investment need in 2024 due to already installed capacity (see Figure 4.6). Historical investment seemed aligned with future needs. One should analyze that investment needs for trucks are smaller than for light-duty vehicles but increase faster. Considering the limited scope of the AFIR regulation for heavy-duty charging points, it's hard to conclude.

Finally, for railways, current investment has been stagnating at the same level. Filling the investment gap would require a leap of investment. The recent trends raise doubts about the capacity of the European Union to meet the 2030 target.

For rail transport, historical investment have been stagnating in the recent years. But The Core TEN-T network require by itself more than what is currently invested in all the European railways infrastructure. Thus, only on Trans-European network, the volume of investment is not on track for meeting the target set in the regulation.

5.1.2. Filling the investment gap

The total investment gap described is concentrated in road transport. From the regulation considered road sector covered almost all of the investment needs. Infrastructure deployment for road transport requires a small investment of "only" 7.7 billion euros. The rest of it is for the electrification of new vehicles. However, one should note that these investments are defined as gross investments. In terms of net investment, the gap would be much smaller. Thus filling the gap for the electrification of new vehicles will be mainly done by redistributing from fossil investment to climate investment.

For redistributing investment towards climate investment, the role of public investment is limited. Subsidies could help trigger the buying of electric vehicles. For infrastructures, accelerating public electric charging points is necessary to remove the main barrier to buying electric cars (Patt et al., 2019). Support from the government on this topic could be an efficient way of spending public money.

Finally, for railways, the investment gap would require a leap in public investment. The highly capitalist nature of this project and the importance of public companies throughout Europe makes it necessary for Member States to support the development of new infrastructure.

It is important to note that the investment gap presented in Figure 4.6 is defined compared to the period 2024-2030. However, for every technology considered the investments required are increasing during the period. Filling the investment gap will thus be met with a continuous increase in spending.

5.1.3. Results limitations

The first limitation in the results proposed comes with the definition of the study. The investment needs assessment proposed here corresponds only to the European regulations. The scope is therefore reduced compared to the investment required for decarbonizing the transport sector. Moreover, for each regulation, the scope has been limited to the 2030 target and sometimes excludes some technologies.

It is thus possible to compare regulations, but not between transport technologies. Notably, for rail transport, the regulation doesn't cover most of the national lines, only focusing on high-speed infrastructure. Also, maintenance expenses are not covered in the assessment.

Moreover, the analysis of the capacity of the European Union to meet its target is limited to a qualitative assessment. The model in itself is too limited to properly "test", the likelihood of the targets of the European Union. The decomposition between price and volumes, however, helped to gain a more precise understanding of what was happening.

In addition to the limitations mentioned, it's crucial to recognize that the absence of scenario-based analysis in this approach also restricts the general analysis. Scenarios play a pivotal role in exploring various future trajectories, including shifts in consumer preferences, adoption rates of new technologies, and changes in mobility patterns. Without scenario-based analysis, it's not possible to understand how these factors could influence investment requirements and shape the trajectory of climate policy implementation. For instance, shifts towards electric vehicles or changes in travel behavior could significantly impact the demand for infrastructure and alter investment needs over timee. Therefore, while the analysis provides valuable insights into investment deficits from a static perspective, it fails to capture the dynamic interplay between policy measures, technological developments, and consumer behavior that could shape the effectiveness of climate policies in the long term. Incorporating scenario-based analysis in future research endeavors will be essential for gaining a more holistic understanding of investment requirements and addressing the uncertainties inherent in climate policy planning.

5.1.4. Comparison with other studies

To check the number found, the results found are compared with the studies from the literature review. The table below presents the value of investment needs found only for the papers clearly associated with European targets or policies. The results can't however be compared with this work. Indeed as shown by the research gap, most of the studies were not directly linked with European Regulation. Also the scope difference complicates the comparison between studies.

Table 5.1 - Review of annual investment needs found in the literature reviewed

	Study	Scope	Date range	Investment
Transport	(European Commission, 2021c)	Includes: Purchase of vehicles, rolling stock, vessels, aircraft, and recharging/refuelling infrastructure	2021-2030	649 billion €
Road transport	Garcia-Olivares	Light-Vehicles Trucks Charging Stations	2021-2050	220 billion USD 52 billion USD [7,6 – 21.3]
EV Charging points	(European Commission, 2021)	Public and private charging points	2020-2040	4-6 bn€
EV Charging Points	(Klaaßen & Steffen, 2023)	Meta-analysis	2021-2025 2026-2030	3.68 billion € [1.89 – 16.63] 7.92 billion € [3.19 – 25.83]
EV charging points	(Tsiropoulos et al., 2022)	Fit fo	2021-2030	8.7 – 16.2 billion €

Rail infrastructure	(Klaaßen & Steffen, 2023)	Meta-analysis	2021-2025 2026-2030	78.27 billion € [58.41 – 101.94] 81.77 billion € [58.41 – 101.94]

For EV Charging points, (Klaaßen & Steffen, 2023) *have reviewed 5 sources. The EU impact assessment, one study from a think-tank, and 3 studies from consultancy firms. For rail infrastructure, they have reviewed 5 sources: 2 from institutions and 3 from industries. The Staff Working Document from the European Commission doesn't detail the price decomposition.*

Different points can be concluded from this comparison.

Firstly, the perimeter or data ranges considered are very different, making it hard to compare results. The range of results is very broad, from the general estimate from the European Commission to the precise estimates for Electric charging points.

For charging points, the value found of 5.5 annual billion euros is of the same order of magnitude as the others. For this technology, all estimates provide close numbers. This is probably because this Master's Thesis and other studies are very aligned with the Fit for 55 scenario. The variability in terms of modeling doesn't seem to impact the results too much.

For rail transport, the figures provided by Klassen& Steffen, are more than double than thre results of this study. But their analysis shows that the overall investment needs to meet the TEN-T regulation. The investment considered are thus significantly larger. If no conclusion can be made on the investment needs, this gives an order of magnitude of the total amount for European railways.

The overall investment needs for transport in this study are smaller than in the impact assessment of the European Commission. But the scope considered in the Master's thesis is also more narrow, making it hard to conclude without more granular details. Finally, the results from Garcia and Olivares for light vehicles are of the same order of magnitude (195 billion euros compared to 220 billion euros). However, the study from Garcia doesn't include PHEV explaining why both studies give the same results even with very different time ranges. For trucks, the difference is important. This could be explained by the fact that the electrification of trucks in 2030 is still in its early stages.

5.2. Discussion on the European regulation

The master thesis aims to translate the European regulation into investment needs. In this part, the discussion revolves around how the master thesis could provide insights about the European regulation beyond the analysis already proposed.

In the first part, the realism of the targets considered is discussed. In the second part, investment deficit is used as a proxy for measuring the ambition of the law.

5.2.1. Analysis of the European regulation on CO2 standards for light-commercial vehicles

As explained, the overall investment gap is driven by the light-vehicle electrification. A key parameter in the model is the share of Battery-electric vehicles in 2030 for meeting the target of -55% of gCO2/km of the new vehicle fleet compared to 2019. Here, the ambition of the the target is assessed.

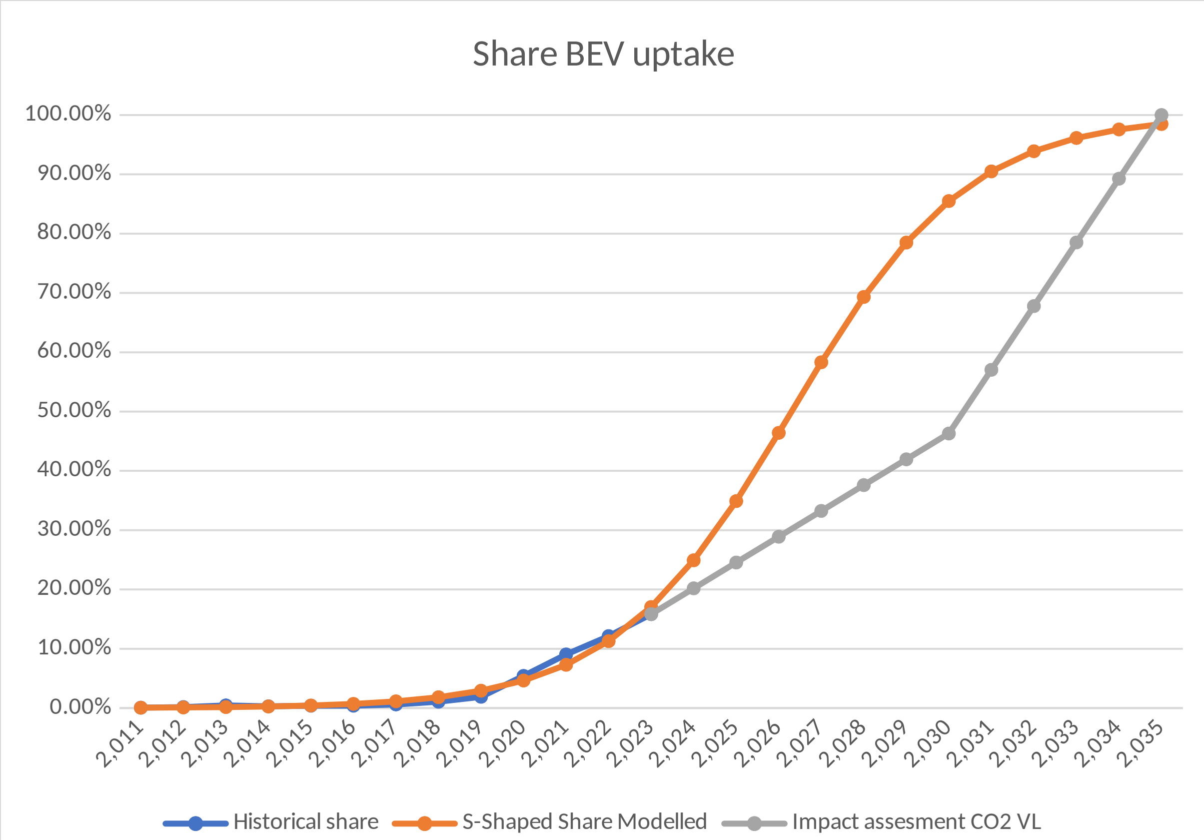
The work from Hopeaketo (2023) was used as an inspiration. The author estimated the deployment of electric vehicles in Finland based on what happened in Norway. Norway is indeed the most advanced country for the electrification of its vehicle fleet. More than 80% of the vehicles sold in 2022 that are battery electric. They have ruled out new fossil fuel cars by 2025.

Knowing that the European Union has ruled out fossil cars by 2035, a technological S-Shaped curve was fitted for the uptake of battery electric car. In the European Union based on what happened in Norway. The details of the method are explained in Annex 5.

Figure 5.1 depicts the results. It shows the historical share of battery electric vehicles, the share assumed by the Commission Staff Working document (European Commission, 2021a, p. 34) and the share modeled with a technology diffusion curve.

The results show a paradoxical situation. The uptake of electric vehicles required to meet the 2030 objective is not putting the European Union on track for the 2035 objective. It is observed that the grey curve assumes that most of the growth of the electric car segment will be made between 2030 and 2035. On the other hand, if the uptake of electric vehicles in the European Union follows what happened in Norway, the share of electric vehicles could be twice as much as what is assumed by the European Commission.

Figure 5.1 - Share of battery electric vehicles in the market under different scenario



Source: Author. This figure shows the share in the number of sales of Battery electric vehicles. Historical share are based on actual data (ACEA, 2023). S-Shaped share represent the estimate made by this study in a technology-diffusion scenario. The grey curve represents the share reported in the Staff Working document of the regulation setting CO2 standards for light vehicles(European Commission, 2021a, p. 34).

5.2.2. Analysis of plug-in hybrids electric vehicles uptake

The Staff Working Documents accompanying the proposal for light vehicles and heavy-duty vehicles proposed a scenario using extensive plug-in hybrids electric vehicles (PHEV) technology.

Our results show that investments in PHEV light vehicles are stagnating or even decreasing. Recent trends make it unlikely that the sector will meet its target. Moreover, for some segments the use of this technology in the future is uncertain. For light-commercial vehicles, only one model that is being sold could be found (see Annex 3). However the results found show that 200k units should be sold in 2030. For trucks, I wasn't able to find any current model existing, while the Staff Working Document simulates this. Thus based on the current market and recent trends, PHEV is unlikely to meet its target.

Moreover, the utility of PHEV for reducing emissions can be discussed. This technology is indeed more expensive than BEV while leading to less emission reduction. In the different expert discussions that I had (with the Think-tanks: Transport& Environment and the ICCT) both were very critical of the technology.

Overall it seems that the current scenario of the European Commission is both unrealistic and not positive for the environment.

5.2.3. Sufficiency of European policies

The third part of the analysis aims to evaluate the effectiveness of European policies in achieving climate objectives. The regulations set standards for CO2 emissions from new vehicles, but not for existing ones. However, since emissions in 2030 will come from existing vehicles, reducing emissions by 55% in 2030 should consider existing vehicles too.

The analysis is limited here to light-vehicles as this segment represent the most of the investment to be made. This hypothesis was tested by constructing a separate model for passengers cars and light-commercial vehicles (see Annex 5).

The objective in term of climate objective were found in the *Climate Target Plan 2030* (European Commission, 2020a, p. 73) a document that defines the plan for meeting 2030 climate target. This plan defines share of the stock of vehicles that should be electrified in 2030.

Investment will be used as a metric for testing the sufficiency. The Table below chose the difference in term of investment comparing the two references. A difference of 120 billion euros can be note. This represents around 60% variation from the original figure.

Table 5.2 – Average investment needs between 2024 and 2030 when different regulations of the European Union are taken as reference.

	Light BEV – Regulation setting CO2 standards	Light PHEV – Regulation setting CO2 standards	Light BEV – European target of emissions reduction in 2030	Light PHEV – European target of emissions reduction in 2030
Average investment needs	128 bn €	65 bn €	177 bn€	125 bn€
Total	183 bn€		302 bn €	

Source: Author. This table show the different when switching the t regulation considered as a reference. The regulation setting CO2 standards (2023) impacts the flow of new vehicles whereas the target on emission reduction is about the stock of vehicles.

The results show that investments for meeting the 2030 climate target for passenger cars and light-commercial vehicles amount to 300 billions euros. Comparing it to the amount of investment required for meeting the regulation setting CO2 standards, the regulation setting CO2 standards has a lower ambition.

Using investment as a indicator, it can be concluded that only meeting the target set in the Regulation setting CO2 standards won't provide enough CO2 emissions reduction to meet the 2030 climate target. An extra effort is thus required, meaning that the regulation doesn't cover all the needs for 2030. This conclusion is aligned with the conclusion above, stating that the target for 2030 in the law wasn't ambitious compared to the S-Shaped curve.

5.3. Discussion on the use of investment deficit for monitoring policies

Finally, in this part, the method of using investment deficit as a tool to monitor progress is discussed.

5.3.1. Discussion on the definition about investment

Below, the review of the different choices made in the definitions is conducted to understand how they have impacted the analysis.

Opting for gross investment over net investment offers the advantage of simplicity and comparability across different contexts, as it provides a common metric for assessing investment levels. Unlike net investment, which depends on underlying scenarios and assumptions, gross investment presents a straightforward picture of total financial commitments. Using this single metric, it was possible to compare the results between sector and with other studies. However, this approach may present a limited perspective, as it fails to account for the cost effectiveness of new transport technologies. Moreover, politically, focusing solely on gross investment may create concerns among policymakers, as it could overstate the scale of investment required without providing a nuanced understanding of the underlying dynamics.

Limiting the analysis to capital expenditures (CAPEX) without considering operational expenditures (OPEX) fails to capture the full life cycle costs of investments, potentially masking the true economic viability of projects. This is notably apparent of electric vehicles that have higher CAPEX but lower OPEX than fossil fuel vehicles.

By concentrating solely on tangible assets, the analysis excludes significant investments in intangible assets, particularly in industries such as electric vehicles where research and development (R&D) expenditures play a crucial role (around 60 billions euros a year in Europe). Neglecting intangible investments can underestimate the total financial commitments required for innovation and technology development, thereby providing an incomplete picture of investment needs.

The definition of investment used in this analysis overlooks manufacturer investments, which constitute a significant portion of overall investment in the transport sector. By focusing exclusively on infrastructure-related investments, such as charging stations and rail electrification, the analysis neglects investments made by manufacturers in production facilities, supply chains, and research and development. Incorporating manufacturer investments into future iterations of the analysis could provide a more comprehensive assessment of investment needs and opportunities for collaboration across industry stakeholders.

5.3.2. Discussion on the definition of the indicator

In this part, the specific use of investment and investment deficit as indicators for monitoring policies is discussed.

1. Using investment as an indicator

The metric proposed is based on the use of investment as a tool to monitor the policy implementation. The pros and cons of using investment as an indicator are underlined here.

Investments possess key characteristic of a good indicator, described in (Sartor, 2016):

- Uniqueness: By using the same unit in €, it avoids weighting difficulties between different indicators.
- Selectivity: It provides a simple and unique number, easy for policy maker to use
- Reliability: It gives an overview of key phenomena happening for the progress of regulation: price development and technology deployment

- Policy Relevance: It is aimed to support a political debate at the European scale about how to invest in the transition. (give example of list of papers cited)

On the other hand, tracking only climate investment bears several limitations:

- It provides only a limited picture as numbers are not compared to their fossil equivalent (Jachnik et al., 2019)
- It misses the udnerstandign about the reasons for the investment to be made, (Peters et al., 2017) and the financial instrument supporting them (Jachnik et al., 2019).
- It disregard the economic conditions for the investment and notably the capacity of the economy to do them (Naastepad & Storm, 2022)
- It weights equally all the different technologies and thus could under estimate the importance of future breakthrough technology (Grubb, 2004)
- Focusing on the indicator leaves out about the implication of the plan for the economy and the society and the long-term feasibility (Wiese et al., 2022).

2. Using investment deficit as an indicator for monitoring policies

Utilizing the investment gap or deficit as a metric for tracking progress in European climate policies on transport offers several advantages. Firstly, it provides a tangible measure of the gap between current investment levels and those required to meet climate targets, offering policymakers and stakeholders a clear indication of the scale of investment needed to drive decarbonization efforts. Additionally, the investment deficit serves as a useful benchmark for evaluating the effectiveness of policy interventions and assessing whether current initiatives are sufficient to achieve desired outcomes. By focusing on investment, this method emphasizes the importance of financial commitments in driving sustainable transportation transitions, thereby highlighting areas for targeted intervention and resource allocation.

However, there are challenges in defining investment deficit, particularly in terms of determining what constitutes investment and establishing a suitable time horizon for measurement. The definition of investment varies depending on factors such as infrastructure type, technology, and project lifecycle stages, leading to inconsistencies in measurement and interpretation. Furthermore, setting an appropriate time horizon for assessing the investment gap is complex, as climate policies often operate on long-term horizons while investment decisions may be influenced by shorter-term considerations. Consequently, the lack of standardized definitions and timeframes complicates efforts to quantify investment deficit and undermines the reliability and comparability of results.

Another limitation of using the investment deficit as a metric is the potential for distortion in investment volumes towards the most expensive technologies or those with the largest deployment potential. In prioritizing investment in deficit reduction, policymakers may incentivize investments in technologies that offer short-term cost efficiencies or have established market dominance rather than those with the greatest potential for long-term climate benefits.

Finally, using the investment deficit as a metric implicitly assumes that all technologies contribute equally to climate mitigation efforts. Different technologies exhibit varying degrees of effectiveness in reducing greenhouse gas emissions, with some offering greater emissions reductions per unit of investment. By focusing solely on investment deficits, this method may overlook the differential contributions of different technologies to overall climate objectives.

Finally, while investment deficit provides a broad indicator of progress towards climate goals, it comes at the expense of precision and granularity. In order to understand specific effects and dynamics within the transport sector, additional analysis beyond investment deficit may be necessary. For instance, examining investment volumes and prices can help identify specific trends and drivers within the market, such as the impact of electrification on truck fleets. However, this deeper level of analysis requires additional data and resources, and may not always be feasible within the scope of tracking investment deficit. As a result, while investment deficit offers a valuable high-level indicator of progress, it may lack the precision needed for climate policy implementation.

5.4. Beyond investments, discussion about the transport policy plan

This section discusses European transport policies beyond the investment lens. The challenges in implementation, the impact of the carbon price, and potential outcomes in CO2 emissions mitigation and alternative policies are analyzed.

5.4.1. Implementation challenges

Delivering the required investment is not the only constraint to meet 2030 climate targets. The implementation of transport policies faces numerous challenges, such as producing and delivering electricity, manufacturing electric vehicles, answering technological uncertainties, and guaranteeing the effectiveness of the modal shift towards rail.

For decarbonizing road transport, electrification is the main solution to the policy plan. In 2030, it is estimated that 24% of the final energy in the transport sector will come from renewable sources (European Commission, 2020a). Overall electricity consumption is expected to increase by 60% between now and 2030. This increase in electricity use will have to be met with adequate electricity production and distribution. The Netherlands is currently facing a congested Grid network (TenneT, 2023). For transport, connecting the charging network will be a challenge. Notably, to provide enough power all along the main transport routes, even in remote areas.

This electrification requires rapid changes in the methods for manufacturing vehicles and the industrial chain has to adapt. China is currently the leading country for EV manufacturing. Europe's capacity and willingness to on-shore most of the value chain of battery manufacturing will be a challenge in the implementation of the European Policy package. Notably, it could reduce CO2 emissions in manufacturing (Transport&Environment, 2024b) and limit employment reductions in car manufacturing (Tamba et al., 2022).

For fret transport, the plan proposed by the European Union is technologically neutral. In this master thesis, I have focused on battery electric trucks, as they seem to be the dominant technology for now. However, different solutions for decarbonizing fret road transport are co-existing, notably battery-electric trucks, hydrogen trucks, or electric road systems. The Plan, notably the Regulation for Alternative Fuel Infrastructures (2023), will create co-existing systems. However, it risks duplicating the costs, creates stranded assets in the long run, and gives uncertainty to potential buyers (Agore Verkehrswende, 2020).

Finally, for railways, the plan focuses on the creation of an international transit solution for fret and passengers. However, the success of the implementation is dependent upon a lot of factors. It requires notably a better service quality, network connections to end -point and better connection between modes (Islam et al., 2016). To this end, the success of the implementation is dependent on the capacity of States to develop smaller scale networks to ensure a comprehensive European railway network.

5.4.2 Carbon price: Discussion on its outcomes and social impacts

The set of transport policies presented by the European Commission has to be considered along with the carbon market, called the Emission Trading Scheme. It sets different emissions ceilings for land, maritime, and aviation transport inside the EU. Under this ceiling, emissions are traded (Aldy & Stavins, 2012). The Extension of ETS to road transport will happen in 2027. It is thus the combination of standards and carbon pricing that aims to trigger structural changes in the economy. The extension of this system to road transport (and buildings) was the subject of fierce debate, as it will impact all Europeans in their daily lives. This part discusses the pros and cons of this system.

The benefit of this dual system is that it guarantees that emissions will not overshoot the carbon ceiling. Theoretically, prices could increase to the point where nobody could afford to move. The regulations are there to guide the transition and prepare it to be smooth. In this policy mix, agents under price incentives and regulation, will either change their way of traveling or reduce their consumption.

However, the capacity of this policy mix to trigger rapid structural changes is uncertain. On the one hand, the Regulation Setting CO2 Standards (2023) guarantees that a minimum share of electric cars enter the market. The carbon market could also incentivize agents to buy electric vehicles, as it changes the total cost of ownership of a fossil car. On the other hand, the cap-and-trade system is uncertain for customers (Haar & Haar, 2006). If customers are not able to anticipate prices, the existence of a price signal may not exist.

Another challenge in implementation lies in the extra upfront investment in electric cars. Even if electric cars could be worth it in the long run, there is no guarantee that people will have the means to afford the extra cost. Currently, electric sales are stagnating due to the lack of affordable vehicles (Transport&Environment, 2024a). The social risk of having a carbon market without the possibility of electric vehicles is important, as the poorest people may be forced to limit their movements.

This situation could last for years, as the system takes time to balance. Indeed, the secondhand market is of equal importance (in terms of value) to the new car market (Bain&Company, 2023). With an average age of cars of 15 years in Europe (ACEA, 2022), having affordable second-hand cars will happen long after the implementation of the carbon market. Poorer people and people in East European countries, where most of the cars are bought second-hand (Held et al., 2021), will thus struggle to cope with the carbon price without having the capacity to buy secondhand cars.

Finally, the fairness of the carbon price is a complicated matter (Todd, 2024). The current policy package, with little redistribution of the benefits towards citizens (Defard, 2021) and no ambitious development of alternative transport solutions could be criticized as a not a fair policy. Indeed, the burden is equally shared as everyone is paying a certain extra cost per liter of gasoil. However, the necessity of cars is not equal in Europe, as some people could just not live without cars. If the price skyrockets, these people would be left in a deadlock. Also, the purchasing power is different between countries and within countries. The capacity for buying alternatives is not taken into consideration with a carbon price. A fairer policy mix could be to reinforce standards, that can even be cost-efficient (Statharas et al., 2019) or guarantee a fair redistribution of benefits to the poorest citizens.

5.4.3. Outcomes for CO_2 emissions and possible alternatives

The expected outcome of these policies is to reduce CO_2 emissions. In this part, the uncertainties of the policy package to deliver its outcome are discussed.

Stepping back from land transport, there is an important loophole in the transport policy scheme of the European Union. International transport from and to the European Union is not included in the ETS. The total emissions from the European Union are thus not capped. However, the number of flights is currently increasing, driving up emissions (European Environmental Agency, 2023). International transport could undermine the objective of the EU to limit its emissions. Notably, there is a risk of spill-out effects from continental transport to international transport because of the introduction of a carbon price inside the EU but not outside. Including international transport in the Emission trading scheme could have limited this loophole.

Another main uncertainty in meeting CO_2 emissions standards lies in manufacturing emission and the total deman. Producing EVs reduces CO_2 emissions compared to fossil cars over their lifetime (MIT Climate Portal, 2022). CO_2 emissions from electric vehicles are mainly embodied in the manufacturing process. However, the current policy package has no objective or ceiling on the number of vehicles produced or the emissions associated with them. This uncertainty could impact the outcomes of the policy plan. For cars, policies could have included the existence of a weight limit, notably to reduce material consumption and CO_2 manufacturing emissions.

Finally, the system thinking of transport is missing in the policy plan. The lack of a detailed plan to guarantee a positive modal shift is crucial. Notably, the interconnection between transport modes is barely thought of and the capacity to favor a general modal shift, notably towards rail is not assessed . And also, the spilling-out effect between one to another transport mode is not conceptualized. Notably, the effect of the modal shift towards long-distance rail is very uncertain (Nordenholz et al., 2017) as it may just increase the total number of passengers without reducing airplane use.

5.5. Recommendations

In this section, policy recommendations based on the analysis of the investment deficit are proposed. Further research ideas based on the different research gaps identified during the Master's thesis are then proposed.

5.5.1. Policy recommendations

This study is useful for policymakers as it provides a comprehensive overview of the investment needs for the transition. It shows that current investment level is not enough to trigger sufficient structural changes in the European economy. Here are the main recommendations.

1. <u>Prioritize investment in infrastructure.</u>

In advancing the adoption of electric vehicles, European policymakers should prioritize investment in charging infrastructure. Therefore, initial investment should primarily focus on expanding charging infrastructure, ensuring widespread accessibility for EV owners. This is justified by the relatively low investment for charging points required compared to the volumes of investment for the other sectors.

Beyond investment considerations, other factors are key to the success of the transition. It is essential to establish a robust network of charging stations across the continent to alleviate range anxiety (Santos & Davies, 2020) and incentivize consumers to buy electric vehicles confidently. The literature also suggests that the availability of public charging points (Patt et al., 2019) and transparency of cost (LaMonaca & Ryan, 2022) could increase the number of people buying electric.

The advancement of railway infrastructure is crucial for promoting sustainable and efficient transportation across Europe. To achieve this, policymakers must commit to a significant increase in public investment across the entire railway network. The Core TEN-T network requires by itself more than what is currently invested in all the European railways infrastructure.

Alongside deployment of the Core TEN-T, policymakers should consider the rest of the network, notably to avoid a split-out effect on budgets. Indeed, there should be a concerted effort to prioritize underdeveloped or neglected regions within the railway network to promote equitable access to transportation resources. Indeed, all the networks should be considered. Notably sub-urban and urban networks are key for decarbonising local transport. For a global modal switch, all scales have to be considered not only the Trans-European scale. It is also necessary to understand all the means of transportation together. For example, Poland's plan of infrastructure (Ministerstwo Infrastruktury, 2023) mainly relies on highways which bears a risk of carbon lock-in of the infrastructures.

2. <u>Promotes battery electric vehicles for all Europeans</u>

To fill the investment gap, policymakers should prioritize the deployment of battery electric vehicles (BEVs) over plug-in hybrid electric vehicles (PHEVs). BEVs offer superior environmental benefits due to their zero-emission nature and lower additional investment compared to PHEVs. Stricter emissions controls for PHEV could also limit the use of this technology in the short term. Indeed, following the

Diesel gate, the method for measuring emission has been changed, and impacts PHEV emissions (Transport&Environment, 2023).

Current limitations to buying electric vehicles are numerous notably range anxiety and affordability (Santos & Davies, 2020). If the range anxiety can be addressed by a wider network of charging points, the affordability question is also key. The need for smaller and cheaper battery electric vehicles has been spotted both for economic reasons and environmental (Peiseler & Cabrera Serrenho, 2022). It is also a way to limit the bill of the transition. A switch in the commercial practice of manufacturers seems necessary for reducing prices to promote smaller vehicles (Vijay Govindaraju, 2023). Smaller vehicles could be incentivised or quotas could be set. Also, R&D on battery cost is still necessary for the price decrease to continue.

Finally, the uneven distribution of electric vehicles through Europe should be considered as a risk for the transition. On average, cars tend to flow from Western to Eastern Europe, and Eastern markets are mainly constituted of second-hand cars (Held et al., 2021). For battery electric cars, Western Europe is more advanced. In 2022, Germany, France, Sweden, and the Netherlands account for more than 75% of the sales (ACEA, 2023). There is thus a risk of a delay in the transfer of electric cars to Europe. Making the targets in the transition notably for 2050 requires a faster renewal of the fleet that is not permitted with the current architecture.

3. <u>Reinforce monitoring of the climate policy progress;</u>

With this work, the requirements of the CO2 regulation have been found to not provide enough emissions reductions by 2030 for meeting consecutive climate targets and the ban of fossil cars in 2035. Thus beyond the implementation of policies, it's also the overall climate policy progress that should be monitored. The current monitoring is only done every five years for all Member States (see I.2), which is a long period compared to the time period before 2030.

For this monitoring, European Policymakers should consider tracking climate investments, which can be followed almost in live. Using a common unit between countries would help to easily follow the progress of all sectors of the economy in the transition. It makes also comparisons between countries possible.

Finally, it seems important that the European Commission increases its transparency. The results from the EU modeling should be fully made public to help the different stakeholders through the EU to understand better the impacts of the regulation and prepare for the combined effects of the climate transition.

5.5.2. Need for further research

During this research, multiple needs for further investigation have been identified.

a. Research on Investment Deficit:

Further research on investment deficit is crucial for several reasons. Firstly, with the rapid evolution of battery costs and other technology-related factors, there is a need for sensitivity analyses to understand how fluctuations in these parameters may impact investment requirements. Previous work by Tsiroupoulos et al. (2022) has demonstrated the importance of sensitivity analysis in providing robust insights. Such work would complement this master thesis by helping to understand the main ways for “limiting the bill”.

Additionally, there is a significant gap in understanding the investment deficit from a European perspective, particularly concerning railways. Notably, there is a lack of comprehensive data on maintenance costs at the European level, making it challenging to accurately estimate investment needs. While attempts have been made to estimate maintenance costs, such as through country-level analyses in Germany and France, the absence of data for other countries like Belgium and Spain highlights the need for further research.

b. Means to Reach European Targets:

As shown by the limitations in this Master's Thesis, there is a need for research to explore the feasibility of reaching European targets and the means to achieve them. Key questions that require investigation include assessing whether the European economy has the capacity to deliver the necessary investments and understanding potential crowding-out effects that may occur. Additionally, research should understand the role of public bodies in facilitating investment and determining the optimal allocation of public resources to support sustainable transportation initiatives. Finally, mapping the financial constraints faced by individuals and businesses in shifting their transport use is also essential to uncover barriers to investment and identify strategies to overcome them.

c. Investment Deficit as an Indicator:

Further research is needed to evaluate the effectiveness of using investment deficit as an indicator for monitoring policies. This Master's Thesis has shown that investment could be helpful to provide a granular overview of investment needs. Questions are left to explore include the extent to which investment deficit aligns with the application of policy measures and whether it can serve as a direct tool for policy implementation.

6. Conclusion

If the literature about solutions for decarbonizing the economy is crowded, little attention has been drawn to the investment needs. Notably, no independent assessment of the needs of the European economy for meeting the transport policies of the Fit for 55 package has been made. This thesis filled this gap by providing a measurement of the investment required to meet the regulations for road and rail transport. The results are also compared to historical levels to inform about the progress yet to be made.

The key findings are at three levels, answering the main and sub-research questions: the European investment needs have been analyzed, the methodological approach and definitions chosen could enlighten future works, and the theoretical use of indicators for monitoring policies has been debated.

Based on the assessment of the investment gap, the capacity of the European economy to meet its target was estimated. An apparent contradiction was found between the stagnating investment in plug-in hybrid technology and railways, contrary to the expected increase. In all sectors, investment needs to increase to fill the investment gap, notably for battery-electric vehicles. However, the analysis lacks a better overview of the drivers and enablers for meeting the target, for example, through an integrated assessment model, showing the limits of the approach chosen.

This bottom-up approach, on the other hand, gives a granular overview, technology by technology, of the investment gap. This approach is helpful to complement macroeconomic models that do not track precisely the investment required by each policy. This approach is dependent on the scope chosen: gross investments in tangible assets. However, in the literature reviewed, discussion on the definition is often missing. This work fills this gap by discussing the different possibilities. The definition chosen seemed the best for evaluating the overall transition required, but it has limitations. Notably, the extra investment required to fill the investment gap could not be analyzed

Finally, this work provides a use case for a novel indicator for monitoring the implementation of climate policies through the use of the investment gap. It was found that it provides, in a single metric, the evolution of the economy, taking into account both technological progress through prices and technological deployment. However, it could suffer weighting issues between the technologies considered. All technologies have the same weight based on their cost, even though they can produce different emissions reductions.

From a policy perspective, this work shows the magnitude of the money flow redistribution required for the different sectors of land transport. Several questions are now in the hands of policymakers and researchers.

While attention often centers on investment amounts, the mechanisms of investment demand consideration. For private actors, the financial tools supporting investment should be considered to facilitate investment. For public investment, multiple approaches can be taken. The recent example of the Inflation Reduction Act in the US demonstrates the potential for public investment to trigger private investment. Moreover, the economy's capacity to deliver the transition must be evaluated. Significant changes, for example, within the automotive industry or in travel patterns, are necessary. Thus, the transition is not merely a monetary issue but also a question of practical implementation.

The materiality and usefulness of investments should also be discussed. For instance, as outlined in the thesis (Section 3.2.2), certain investments, like Plug-in Hybrid vehicles, may prove less efficient compared to investment in battery electric vehicles. For infrastructure, a just balance should also be found between having a widespread network and a dense one. This is a political question of who should be prioritized for the transition.

Unanswered questions persist regarding the equitable distribution of funds between private entities, the EU, and national and regional sources. While this study primarily focuses on European-scale investment, most investment will happen at a smaller level, such as the national and local tiers. Coordinating policy action in such a political area will be a challenge.

The social distribution of the transition's costs and impacts across different countries and demographic sectors is a significant parameter in the success of the transition. With the strengthening of the European Trading Scheme, the cost of emissions will increase for all. How to propose a fair transition for all?

Finally, while climate concern has been the primary motivation behind this work, there are numerous reasons to bolster the European transition, including geopolitical influence. In the forthcoming negotiations for the 2040 targets of the EU, climate action should be considered as part of a wider policy program. It's imperative not to view climate policies as a threat but as an opportunity for Europe to maintain its leadership position.

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Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J., Cox, P. M., Daly, M., Dasandi, N., Davies, M., Depledge, M., Depoux, A., Dominguez-Salas, P., Drummond, P., Ekins, P., … Costello, A. (2018). The Lancet Countdown on health and climate change: From 25 years of inaction to a global transformation for public health. *The Lancet*, *391*(10120), 581–630. https://doi.org/10.1016/S0140-6736(17)32464-9

Annex I. Reporting obligation of the European Commission

Table Annex 1.1: List of documents published by the European Commission and reporting obligations

Report published	Legal origin
State of the Energy Union Report (COM/2023/650) and 28 Country Sheets	Governance Regulation (2018/1999) (GovReg), Art. 35: summary report showing the state of the EU's progress towards the objectives of the Energy Union.
Climate Action Progress Report (COM/2023/653) incl. Technical Annexes	GovReg, Art. 29.5: assessment of EU and Member State progress on Paris commitments, ESR targets, and NECP objectives GovReg, Art. 29.1: based on SWD/2023/646 EUCL, Art. 6.1: progress assessment towards climate neutrality
Technical Assessment of the National Energy and Climate Progress Reports (SWD/2023/646)	GovReg, Art. 29.1: assessment of EU and Member State progress towards the 2030 climate and energy targets
Bioenergy Sustainability Report (COM/2023/650 Annex I)	GovReg, Art. 35.2 (d): a report on EU bioenergy sustainability in accordance with Annex X
Report on Building Renovation (COM/2023/650 Annex II)	Energy Performance of Buildings Directive, Art. 2A: progress assessment of building renovation
Report on the Implementation of the Common Rules for the Internal Electricity Market (COM/2023/650 Annex III)	GovReg, Art. 35.2 (f): progress report on the application of the Internal Electricity Market Directive
2023 Competitiveness Progress Report (COM/2023/652)	GovReg, Art..2 (m): progress report on competitiveness
Report on Energy Subsidies (COM/2023/651)	GovReg, Art. 35.2 (n): Member States' progress towards phasing out energy subsidies
Recommendation on Energy Poverty (C/2023/4080) and Accompanying Document (SWD/2023/647)	GovReg, Art. 35.2 (b): recommendations to Member States pursuant Article 34
Report on the Quality of petrol and diesel used for Road Transport (COM/2023/655)	GovReg, Art. 35.2 (l): overview of fuel quality in the Member States reported pursuant the Fuel Quality Directive
Report on implementation of Geological Storage	GovReg Art. 35.2 (p): assessment of implementing

of Carbon Dioxide (COM/2023/657)	the Directive on the geological storage of carbon dioxide
Report on the Functioning of the Carbon Market in 2022 (COM/2023/654)	EU ETS Directive, Art. 10.5 and 21.2

Source:The table is copied from the ECNO project (ECNO, 2023).

Annex 2. Presentation of the passenger car and light-commercial vehicle price model

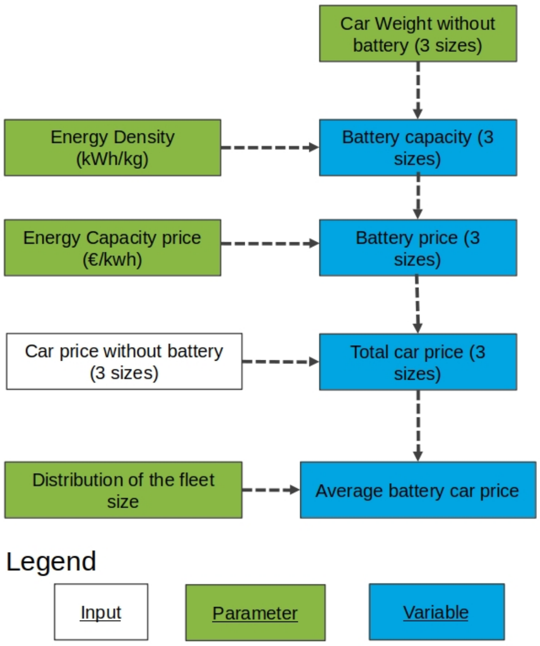
A separate model to calculate the average price of an electric vehicle has been created by I4CE. It calculates the price for battery electric vehicles and plug-in hybrid electric vehicles for both passenger cars and light commercial vehicles. All models have similar architecture.

Figure A2.1 shows the model used to estimate the average battery electric passenger car price.

The final variable is *the Average car price*. It is calculated as the weighted product of the *Total car price* for 3 sizes categories: small, medium, and large cars by the *Distribution of the fleet size* giving the share of each category in different scenarios. The study by the ADEME (2022) has been used as a reference for all the sources of this model.

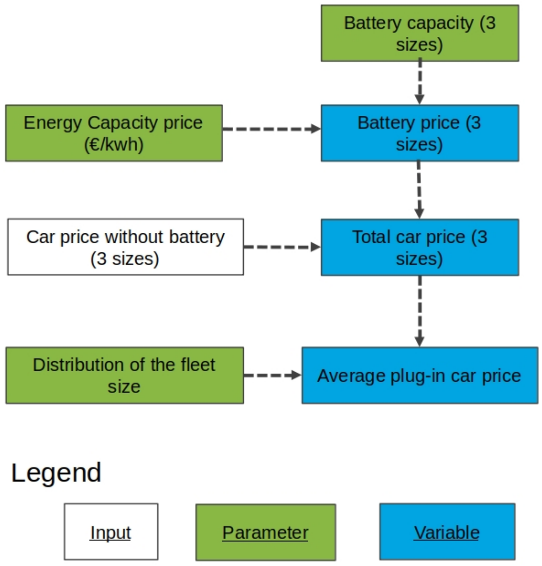
The Total car price is calculated as the sum of the *Car price without a battery* for each category and the *Battery price* for each category. The Battery price is calculated by multiplying the *Battery capacity* and the *Energy capacity price*. The *Battery capacity* is taken as the necessary battery capacity for a car weight of 300 km capacity. *Energy density* and *car weight without battery* are estimated from the ADEME.

Figure A2.1 - Battery electric passengers car price module.



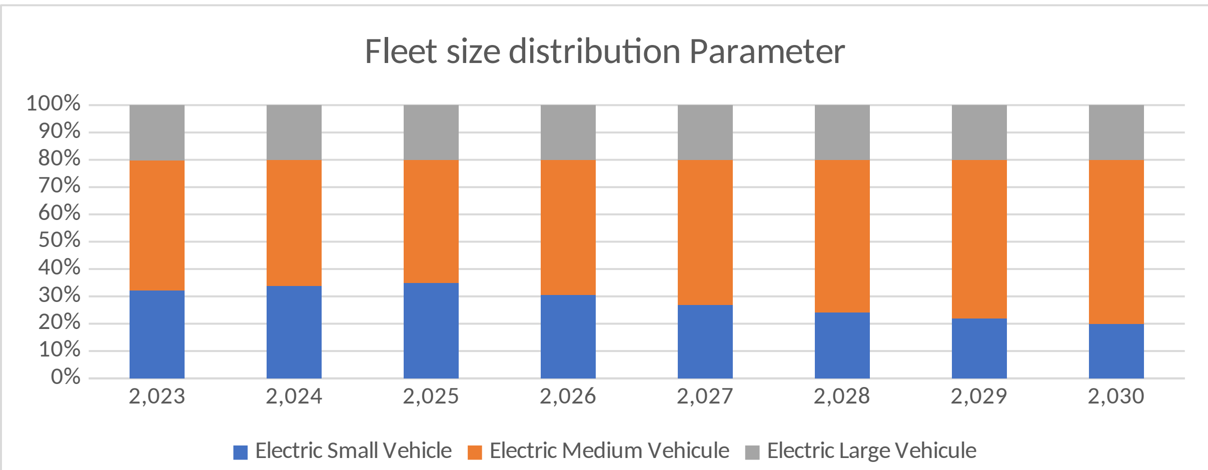
The model for calculating the average battery price of light-commercial vehicles is the same with only one car size. For plug-in hybrid vehicles, the model is simpler, taking as input the battery capacity from the ADEME (see figure A2.2)

Figure A2.2 - Model for plug-in hybrid vehicle price.



Future car prices are based on numerous parameters in the I4CE model. For modelling purposes, the most interesting parameter is the share of different sizes of vehicles, as this is dependent on consumer choices. The values were collected from ADEME (2022). Figure A2.3 shows the evolution of this parameter. It can be concluded that the model assumes bigger vehicles through time.

Figure A3.3 - Evolution of the historical price of light-commercial vehicles.



Source: ADEME (2022)

Annex 3. Data collection details

In this Annex, all the parameters and inputs used in the model are presented, the sources, the treatment of information and the check of their consistency is done.

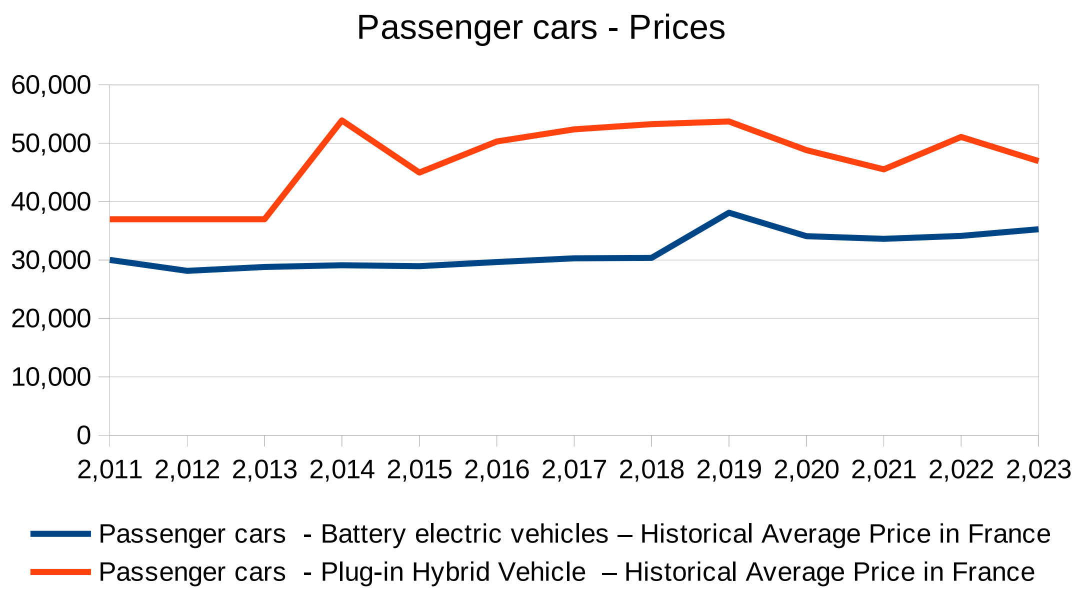
A3.1. Passenger cars and light-commercial vehicles

A3.1.1. Historical car prices

Historical car prices are estimated by I4CE (2023). It is based on a detailed analysis of the French market per car type. It is assumed that the European price follows the French price market. Figure A3.1 and A3.2 show the price evolution.

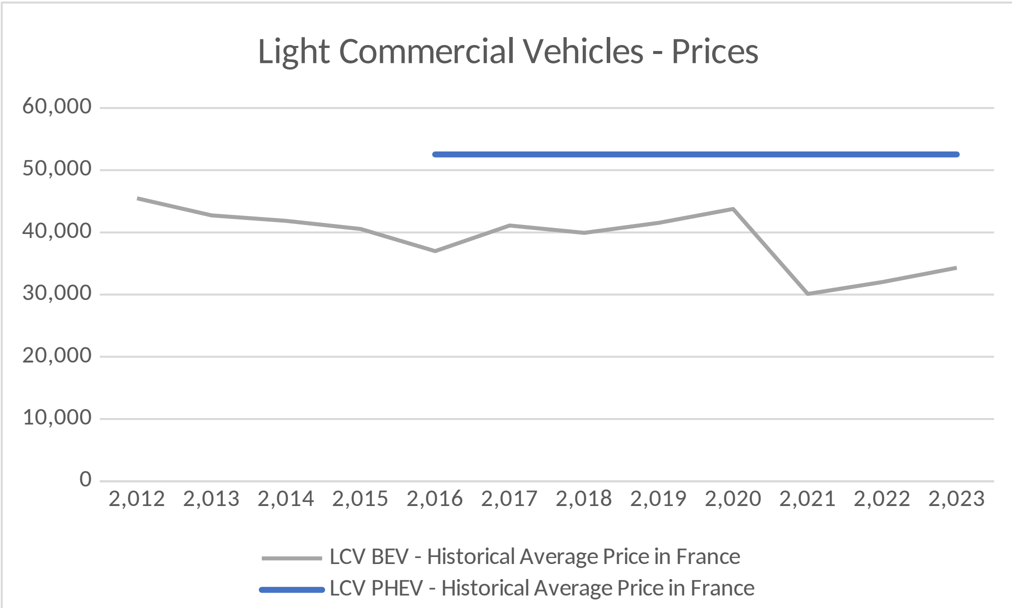
For light-commercial vehicles, the technology plug-in hybrid was not considered by I4CE. It is assumed that the vehicles sold were all Ford Transit. This vehicle is indeed the best seller in Europe (ICCT, 2023); the price was taken from Automobile Propre (2023).

Figure A3.1 - Evolution of passenger car prices on the French market.



Source: I4CE (2023)

Figure A3.2 - Evolution of light-commercial vehicles prices on the French market.



Source: I4CE (2023) and own estimate

A3.1.2. Historical sales

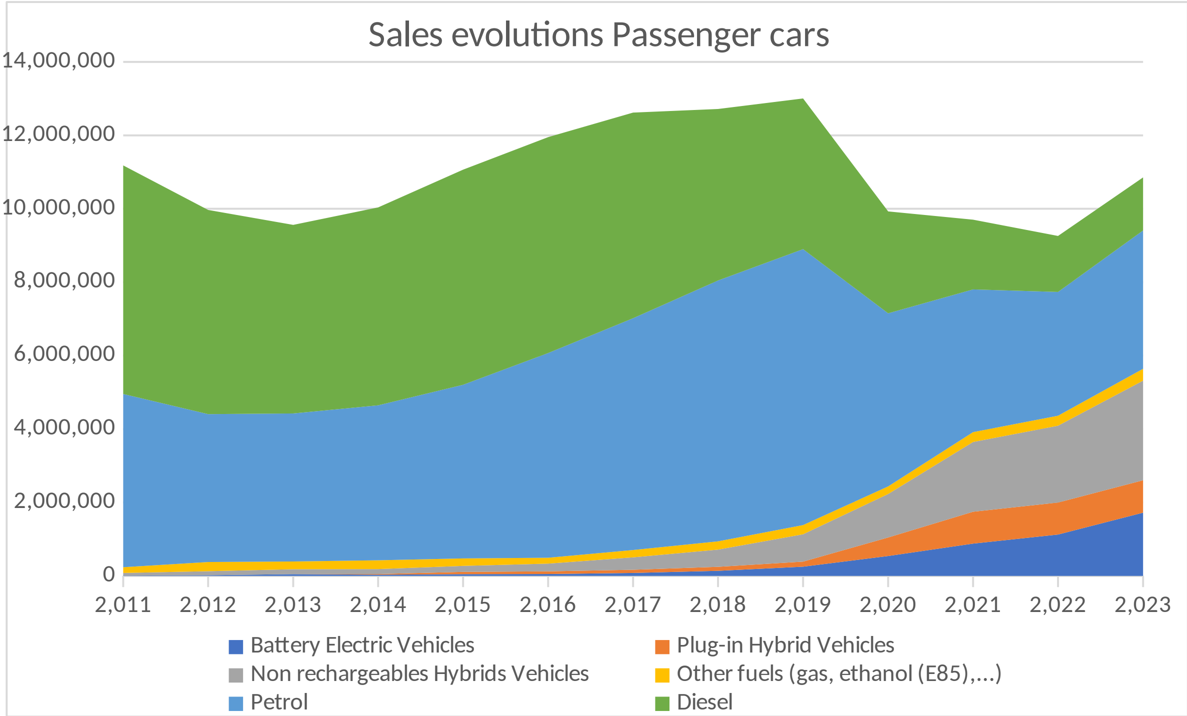
Two sources were used to estimate the number of sales for passenger cars and light-commercial vehicles, the ICCT and the ACEA. The ICCT provides a study referencing historical sales based on a dataset provided by the European Environmental Agency (ICCT, 2023). The ACEA is the European lobby of car manufacturers. They provide a quarterly and yearly analysis of the sales par category (ACEA, 2023).

The two datasets were found to diverge from 2020. The total volume of sales had only a difference of around 1% but the volumes of electric vehicles were different (around 150k for 2022). The reasons were not clear, but probably due to a slightly different definition. Without extra information, it has been preferred to not do any correction and keep the ACEA dataset for 2018 and after and the ICCT dataset before 2018. For the ICCT Dataset, hybrids and battery electric cars were merged before 2016. Data before this date have thus been removed. Also, values for the United Kingdom have been removed when the scope was still EU 28 to take into account the Brexit.

At the date of the study, the datasets were incomplete for 2023. 2023 volumes were estimated based on the sales of the three first quarters of the year assuming a growth similar to in 2022. Other methods have been tried to estimate figures for 2023 based on exponential technological growth calibrated on last year's figures. However, the number of battery-electric vehicles found was too low compared to the sales up to date in 2023.

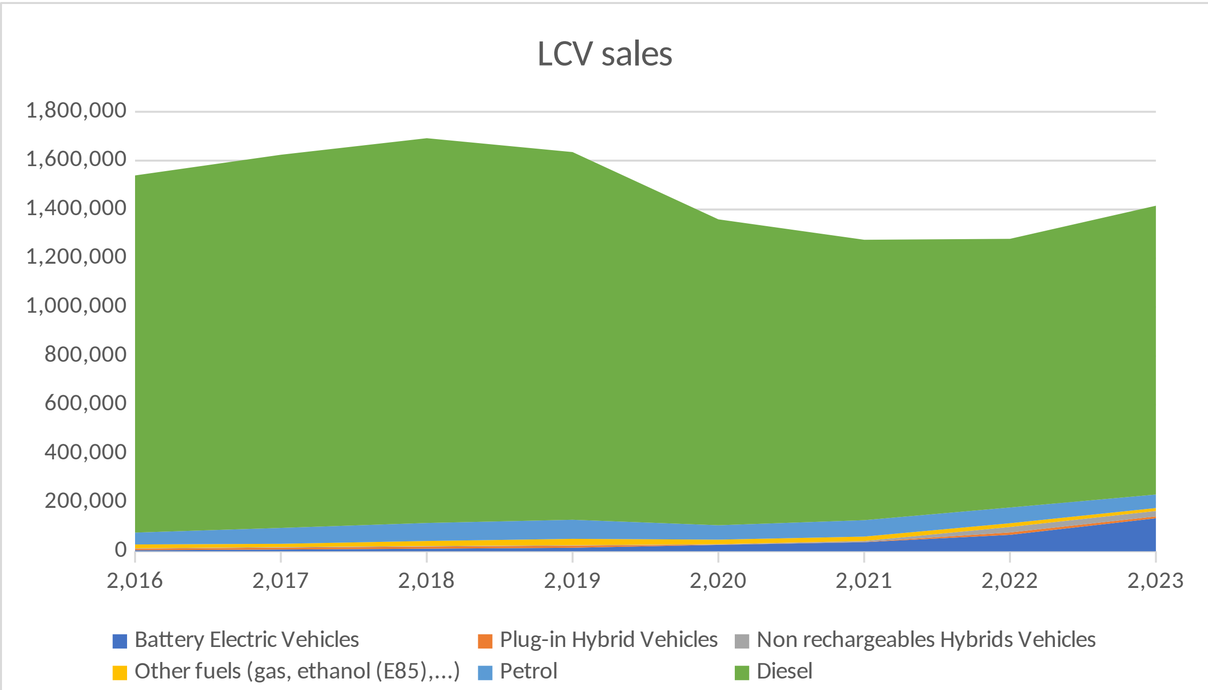
Figures A3.3 and A3.4 present the historical sales for respectively passenger cars and light commercial vehicles.

Figure A3.3 – Evolution of historical sales for passenger cars separated by technology



Source: (ICCT, 2023) and (ACEA, 2023)

Figure A3.4 – Evolution of historical sales for passenger cars separated by technology



Source: (ICCT, 2023) and (ACEA, 2023)

A3.1.3. Future sales for light-vehicles

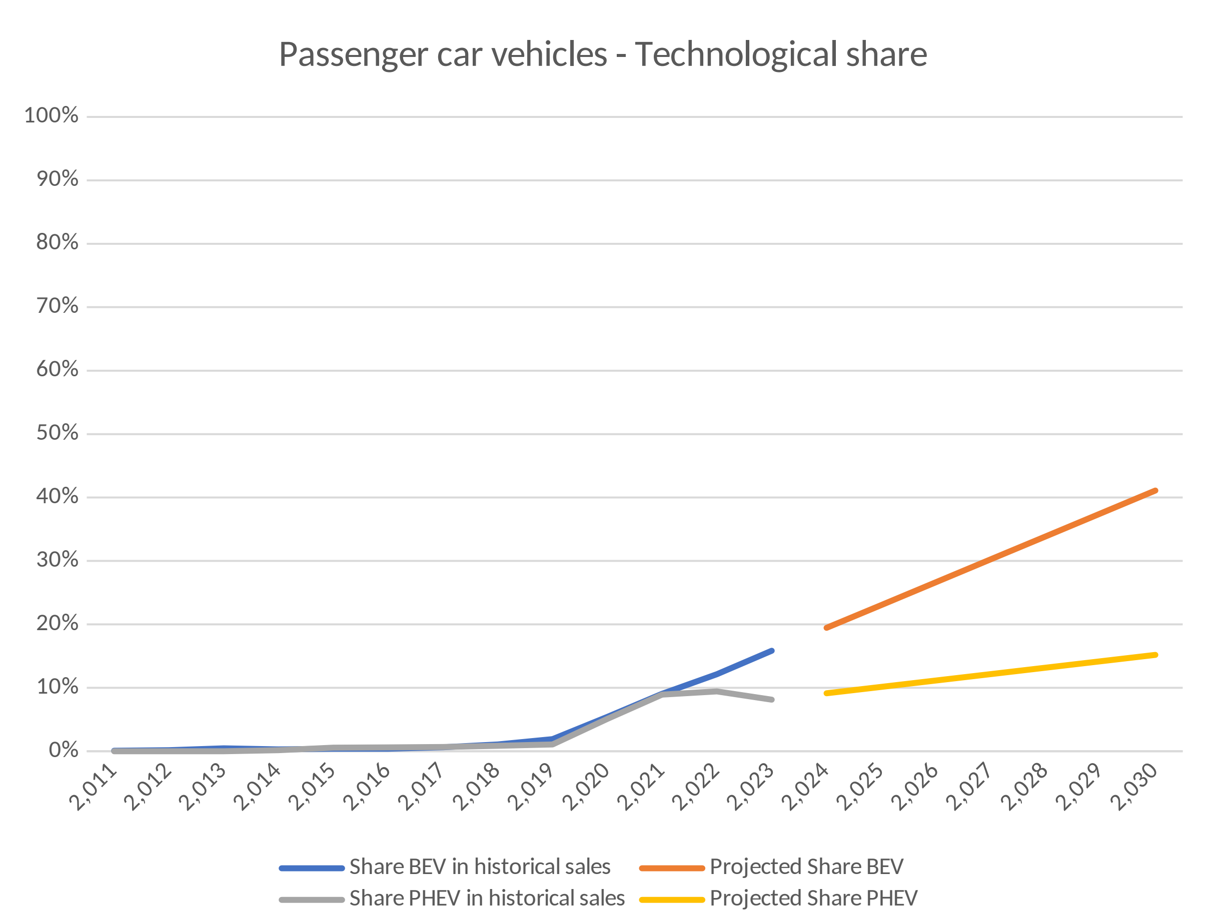
Future total annual sales

Total Annual sales were estimated as the average of the last ten years. Such a hypothesis could be considered as business-as-usual assuming that the figures are stagnating.

Share of each technology.

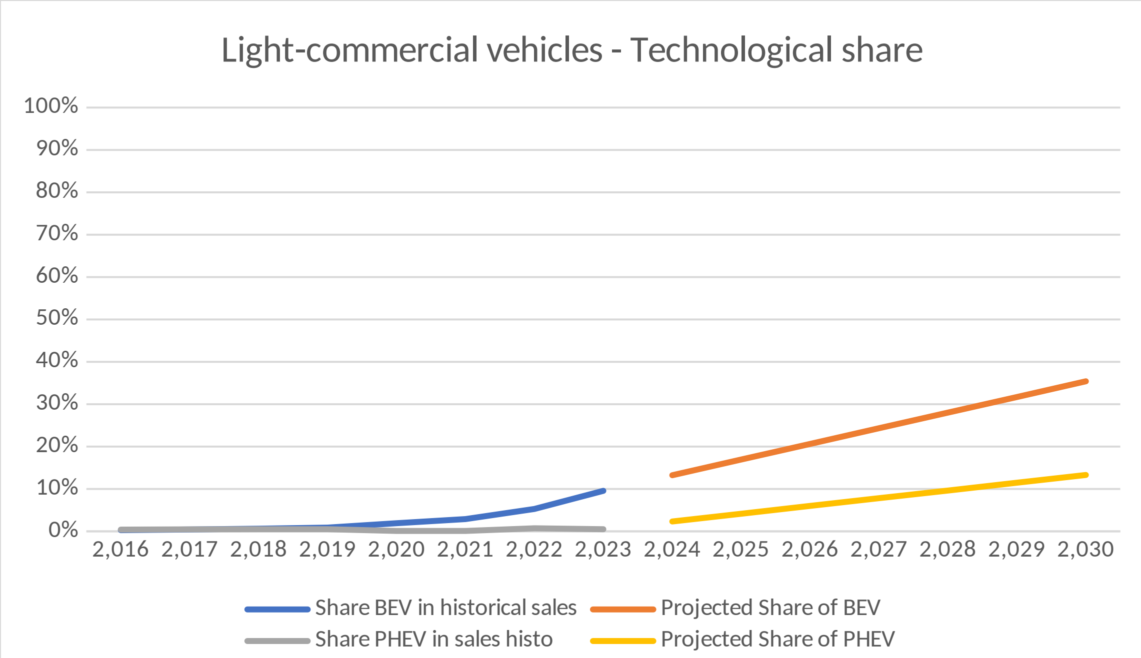
The technological mix has been used to meet the objective for 2030 of the CO2 regulation (European Commission, 2021a, p. 34) . The difference between Staff Working Document and the current share has been linearly projected between now and 2030 for accounting for the progressive uptake of electric vehicles. Figures 18 and 19 depict the technological share of passenger cars and light-commercial vehicles according to these sources.

Figure A3.5– Historical share and projected share in sales of battery electric passenger cars and plug-in hybrid passenger cars.



Source: Multiple

Figure A3.6– Historical share and projected share in sales of battery electric light-commercial vehicles and plug-in hybrid light-commercial vehicles



Source: Multiple

A3.2. Trucks

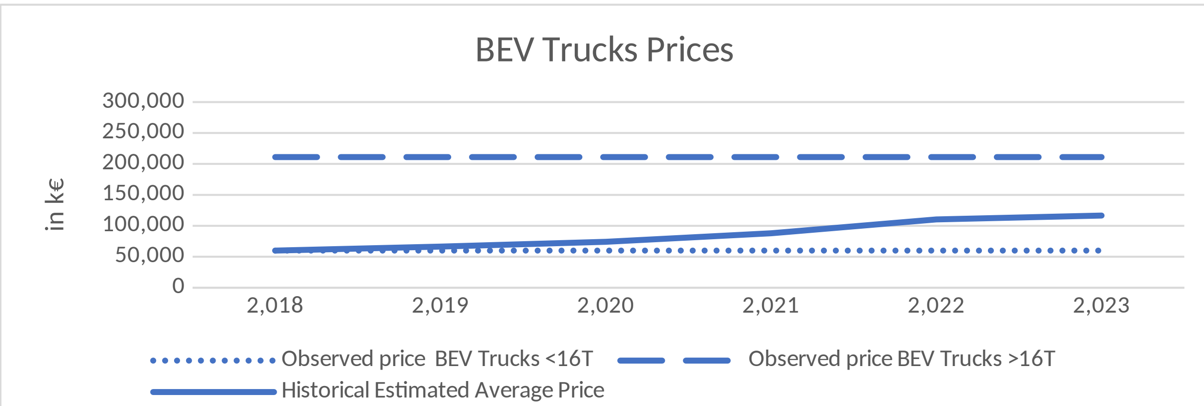
A3.2.1. Historical average price per truck size

Historical average prices were estimated based on the fleet compositions included in the report from the ICCT (Mulholland, 2021; Mulholland & Rodríguez, 2022). This report splits the sales of trucks under 16 T land above 16T. This report also describes the main brand sold.

Analysing the result, it was found that Street Scooter with the Street-Scooter XL (StreetScooter, 2019)and Ford with the e-Transit (Carrie Hampel, 2024) were both selling more than 80% of the under 16 T segment. As both vehicles are based on the same architecture, the price of the e-Transit 350 was taken as the assumption for trucks under 16T. For trucks above 16T, Volvo with the FH electric represents around 25% of the sales. This truck has been taken as a reference for price (Flanders News, 2023).

The average price of the electric trucks sold was then estimated as the weighted average (see Figure A3.7).

Figure A3.7 - Historical price of trucks



Source: Own estimate

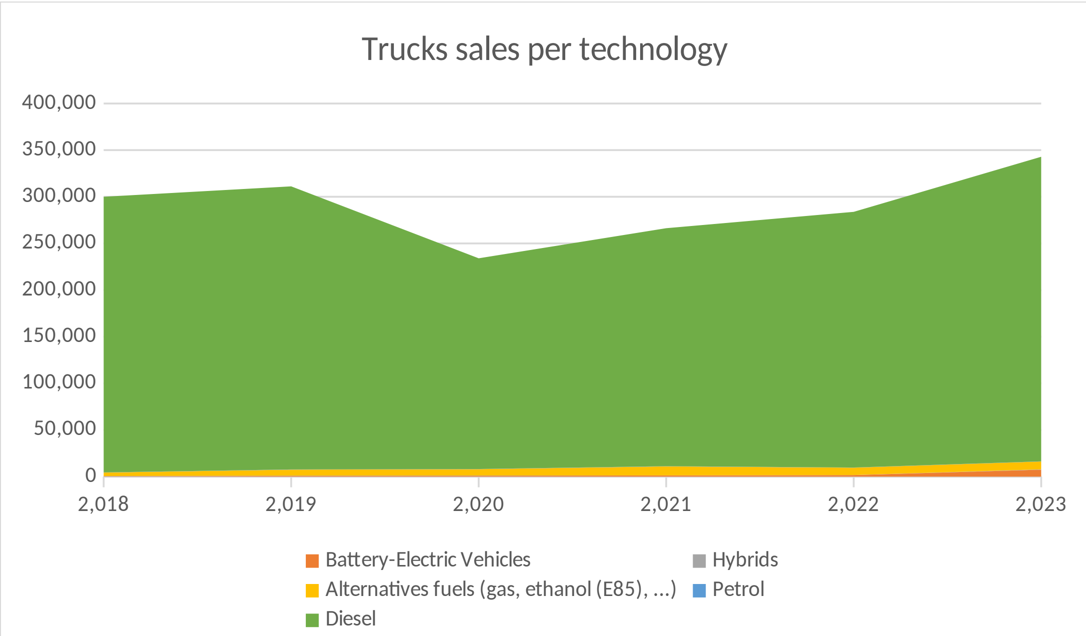
A3.2.2. Historical trucks sales

The ACEA (2023) has been used as a source for the truck's sales. They provide a quarterly and yearly analysis of the sales per category, from 2018 to now.

At the date of the study, the datasets were incomplete for 2023. 2023 volumes were estimated based on the sales of the three first quarters of the year assuming a growth similar to in 2022. Other methods have been tried to estimate figures for 2023 based on exponential technological growth calibrated on last year's figures. However, the number of battery-electric vehicles found was too low compared to the sales up to date in 2023.

Figure A3.8 presents the historical sales for the trucks segment.

Figure A3.8 - Annual historical sales for trucks



Source: (ACEA, 2023)

A3.2.3. Future trucks sales

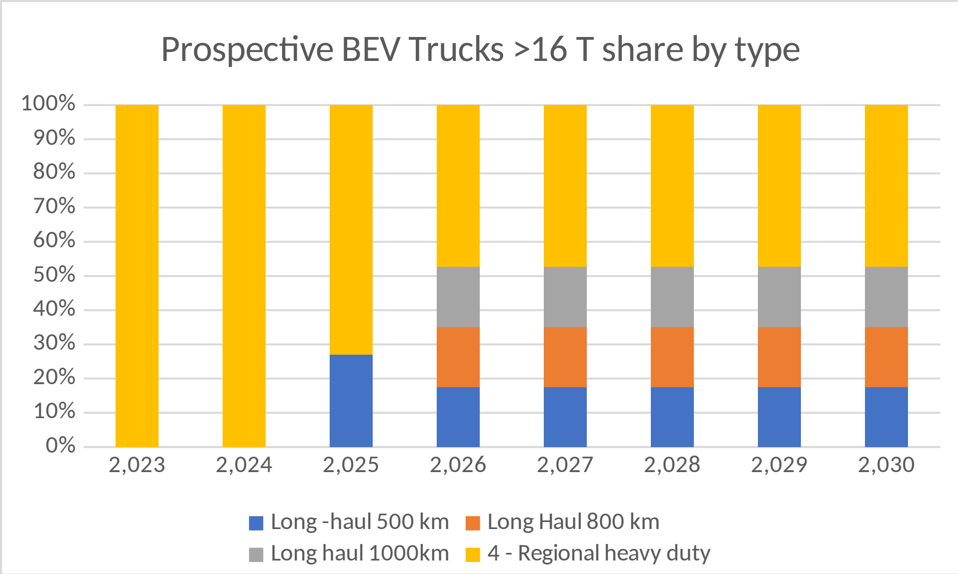
Total sales

Total sales are supposed constant, equal to the average value between 2018 and 2023.

Share Composition per type for trucks above 16T

The share composition per type for trucks above 16T was estimated as explained in the 3.3.2. Figure 21 shows the fleet composition for trucks above 16T through time. Before 2025 only for Regional heavy-duty vehicles, battery electric trucks have a lower total cost of ownership. Progressively trucks with longer driving ranges and bigger sizes enter the segment.

Figure A3.9 - Annual fleet composition for trucks above 16T

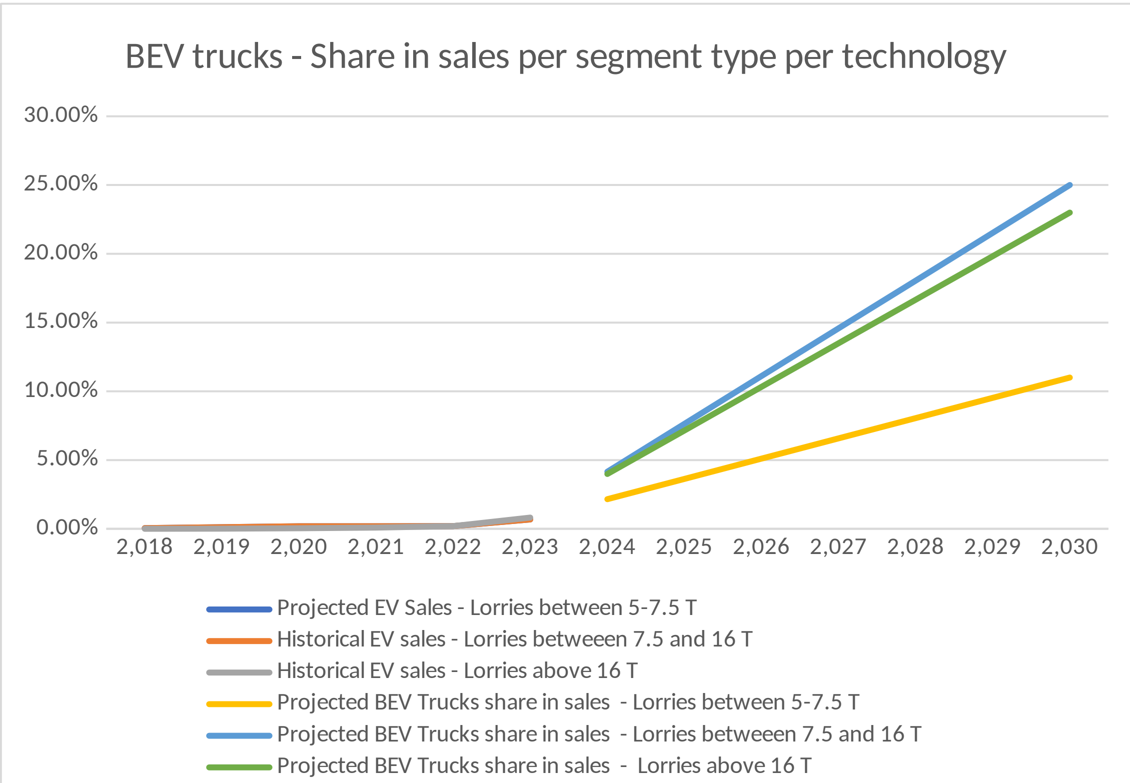


Source: Own estimate

Projected Share in sales by truck size.

The technological mix has been used to meet the objective for 2030 of the regulation setting CO2 standards for heavy-duty vehicles. For 2030, the figures were estimated from the Staff working document (European Commission, 2023b, p. 116). The difference between the Staff Working Document and the current share has been linearly projected between now and 2030 for accounting for the progressive uptake of electric vehicles. Figures A3.10 depicts the technological share for trucks separated by size segment.

Figure A3.10 – Share in total sales of battery electric trucks per size segment



Source: Multiple

A3.3. Charging points

A3.3.1. Historical price of charging points.

The price of historical charging points are of interest to track historical investments. For charging points under 22kW and charging points above 22 kW, a discussion with an expert from the AVERE, held by I4CE has been used as the main source. Two constant costs of 10 k€ and 40 k€ have been used.

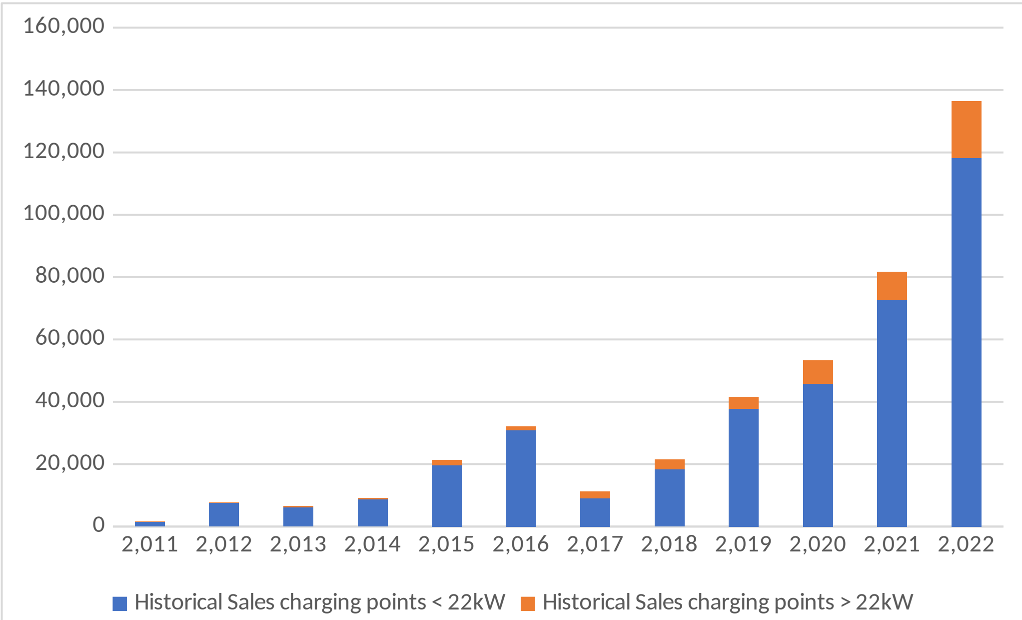
A3.3.2. Historical deployments

A dataset by the International Energy Agency (International Energy Agency, 2023) describes the number of charging points deployed by country. This dataset has been analysed using Python to extract the number of charging points deployed in the European Union. Outliers have been removed filtering values under 10. After cleaning the dataset: no data was available for the 14 countries: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Romania, Slovakia, and Slovenia. These countries were found to be secondary markets for EVs, compared to other countries. They represent less than 5% of the EV sales in 2022 ((ACEA, 2023c)). It has been decided to continue with the dataset.

This dataset has two categories of charging points: under 22 kW and above 22 kW.

Figure A3.11 presents the number of charging points available per year.

Figure A3.11 - Public Charging points installed per year in the European Union.

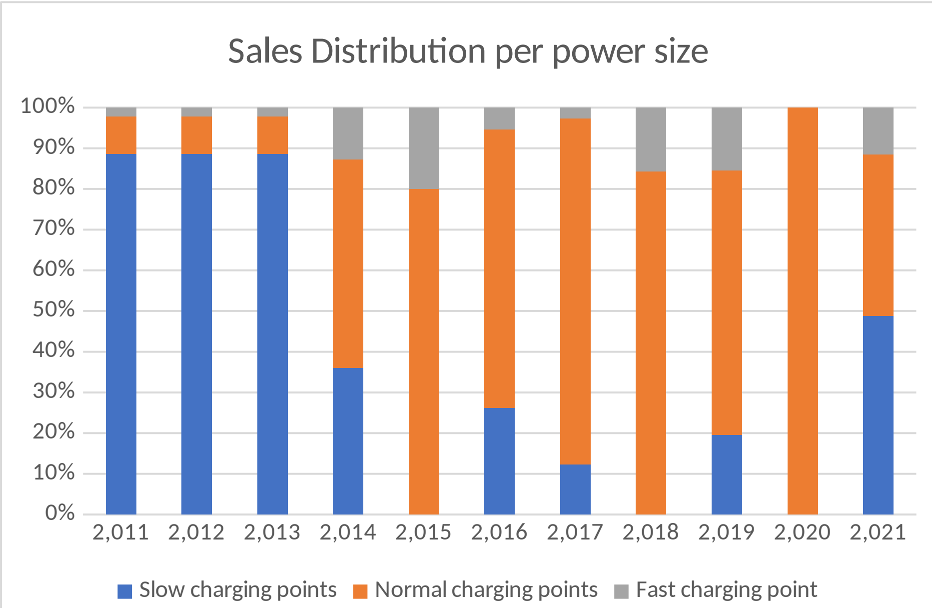


Source: Estimated from the International Energy Agencgy (2023). Slow & Normal charging points refer to chargers under <22 kw and fast charging points refer to charging points of a power output above 22 kw.

Power delivered by different charging points for historical deployments.

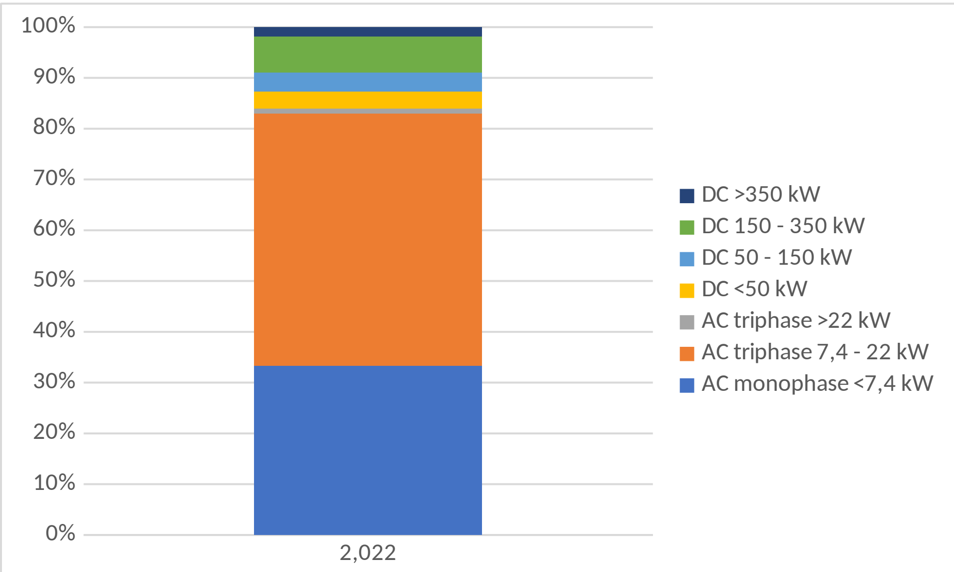
To transform the value of deployment into power, it was necessary to account for the increasing power of charging points sold. The power distribution of the stock of charging points has been analyzed, to try to estimate the power of charging points sold every year in France. The dataset from French NDCP was used before 2021 (Ministère de la transition écologique, 2020). For 2022 a refined dataset was used, notably considering the uptake of charging points for trucks of 350 kW. Figures A3.12 and A3.13 show the power distribution.
These deployments were transformed into power output by using the average power of the category. It is assumed that the power distribution in Europe follows the one in France to estimate the power installed every year.

Figure A3.11 - Sales distribution per power size of charging points in France between 2011 and 2021



Source: (Ministère de la transition écologique, 2020)

Figure A3.13 - Sales distribution per power size of charging points in France in 2022



Source: I4CE

A3.3.3. Future deployments

Required deployment on TEN-T for light-duty vehicles.

The AFIR regulation set objectives of charging point deployment for light-duty vehicles in both power output and minimal size of stations. At different dates, different shares of the main European highway network (TEN-T) must be equipped. Comparing the regulation with the Staff Working document accompanying the proposal of the European Commission, the number of charging points that should be deployed could be estimated.

The distribution of charging points size to deliver the power was taken as the most conservative one. When the objective for 150 kW charging points was met, all the remaining charging points were considered as 50 kW stations. After having derived the length of the TEN-T from the Staff Working Document, the following necessary deployment were found:

Table A3.1 – Mandatory deployment for light-duty vehicles for meeting the AFIR regulation (2023)

Date	2025	2027	2030
The number of 50 kW Stations required at the time		12359	18332
The number of 150 kW Stations required at the time	3124	4120	6111

Source: Own analysis based on (European Commission, 2021a)

Annual sales were derived from these numbers assuming a linear deployment between two consecutive targets.

Required deployment on TEN-T for heavy-duty vehicles.

The AFIR regulation set objectives of charging point deployment for heavy-duty vehicles in both power output and minimal size of stations. At different dates, different shares of the main European highway network (TEN-T) and Urban nodes must be equipped. Comparing the regulation with the Staff Working document accompanying the proposal of the European Commission, the number of charging points to be deployed could be estimated.

The distribution of charging points size to deliver the power was taken as the most conservative one. When the objective for 350 kW charging points was met, all the remaining charging points were considered as 150 kW stations. After having derived the length of the TEN-T and the number of urban nodes from the Staff Working Document, the following necessary deployment are estimated:

Table A3.2 – Mandatory deployment for heavy-duty vehicles for meeting the AFIR regulation (2023)

Date	2025	2027	2030
The number of 150 kW Stations required at the time	933	5192	31286
The number of 350 kW Stations required at the	133	666	4319

time			

Source: Own analysis based on (European Commission, 2021)

Annual sales were derived from these numbers assuming a linear deployment between two consecutive targets. It can noted that the increase in requirements for 150 kW station in 2030 comes from the objective of 1800 kW available per urban node in 2030 and ambitious targets for highways.

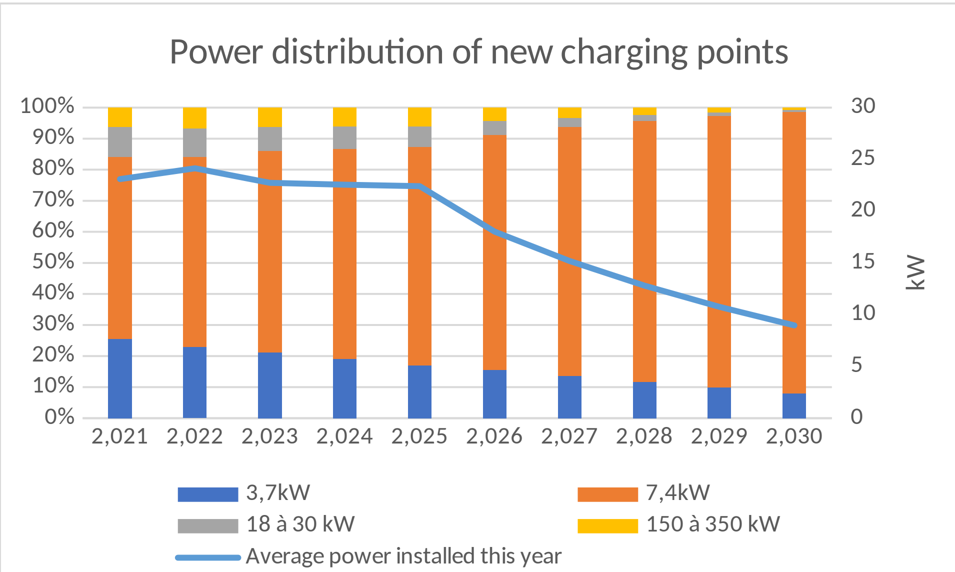
Share of power delivered by different charging points for future needs deployments.

Two different sources were tried to estimate the share of power delivered by the different charging points.

Transport & Environment conducted a study (Transport&Environment, 2020) based on expert interviews estimating the charging behaviour of EV customers at different dates. Assuming a power output per type of station, the distribution required for each year is estimated. The sales required are then derived. This method however not provide enough fast chargers to meet the minimal requirements of the TEN-T light-duty vehicles requirements and was thus not used.

A second source was tried. The French NDCP (Ministère de la transition écologique, 2020) provided the expected deployment of different sizes of charging points. This scenario proposes a rapid uptake of fast charging points to equip the network and then a more continuous uptake of slow charging points. The share for this scenario was used and assumed them constant for the European Union. The deployment of fast charging points was sufficient for meeting the required deployment on the TEN-T and this source was then preferred. Figure A3.14 shows the distribution of the new power charging stations and the average power associated with the mix.

Figure A3.14- Sales distribution per power size of charging points in France in 2022



Source: Author.

A3.3.4. Future prices of charging points

For light-duty vehicles stations prices have been collected by I4CE.

Table A3.3 – Price of charging points for light-duty vehicles

Charging station per power output	Future price

3,7 kW	4 705 €
7,4 kW	6 589 €
22 kW	18 788 €
150 kW	205 894 €

Source: (I4CE, 2023)

For heavy-duty vehicles, 350 kW power stations. Prices were interpolated between 2015 and 2030 from the value of the EU reference scenario 2020 -Technological assessments (European Commission, 2019)

Table A3.34– Price of charging points for heavy-duty vehicles

Charging point power output	2015 Price	2030 Price
350 kW	229 950 €	164 850€

Source: (European Commission, 2019)

A3.4 Railways

A3.4.1. Current & past investments

To estimate the investment realized on the TEN-T between 2016 and 2022, no data could be found except for the years 2016 and 2017 (European Commission, 2020b).We cross-checked the amount of investment reported for the TEN-T on these dates to the total amount spent on railways in Europe reported in the IRG rail market monitoring report (IRG_Rail, 2023). Based on these two sources, it has been estimated that 100% of the investment for new deployments and 35% of investments for upgrades and renewals of tracks reported in the IRG-Rail documents were for the deployment of the TEN-T. Using these shares, the amount that has been spent on the TEN-T and the delayed investments could be estimated. Investments for 2022 were estimated equal in volumes than for 2022.

A3.4.2. Investment needs

Investment needs for railways are the sum of (1) the yearly amount necessary for meeting the 2013 regulation, (2) the yearly amount necessary to meet the future revision and (3) the delayed investments between 2016 and 2022 compared to (1). The investments needs were converted into 2022 euros. The delayed investments are expressed as the difference between (1) and past investments reported.

The total amount required to meet the 2013 regulation for the Core network TEN-T was extracted from a publication of the European Commission (European Commission, 2017). It amounts to 607 billion euros in 2015 price levels. As this amount includes all projects and not only railways infrastructure, the specific share of railways should also be estimated. Analyzing the different projects listed in the document, 60% of the total needs were originated by railways.

The total amount required by the revision of the TEN-T was estimated from the Staff Working Document accompanying the proposal (European Commission, 2021c, p. 144). Only measures for the Core Network for 2030 were taken into account. A discussion with Nicolaï Coulombez, Parliamentary Assistant to Dominique Riquet, rapporteur of the European Parliament was held to understand which of the measures was in the scope of the study.

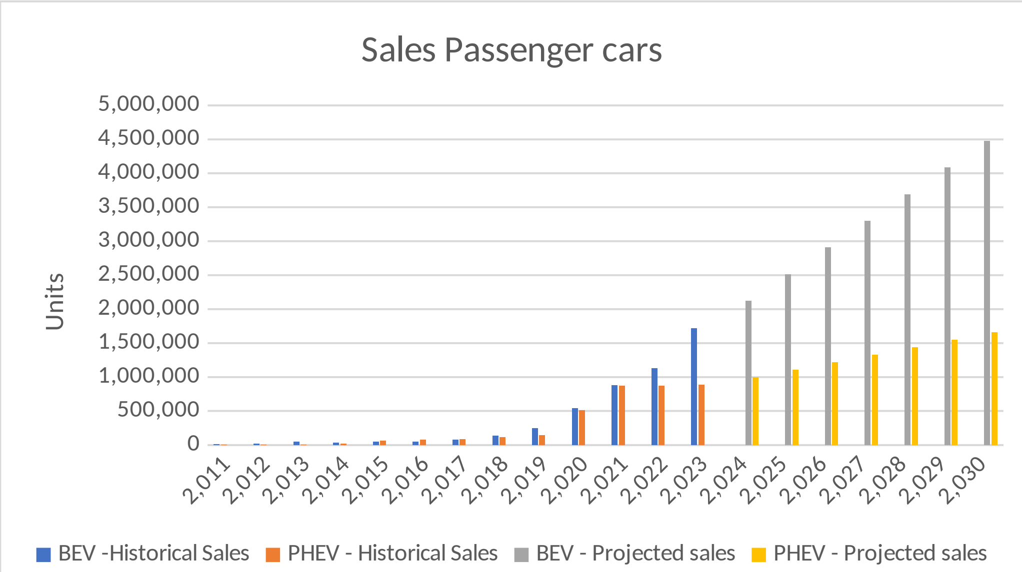
Annex 4. Additional results figures

This annex gives detailed results, completing the one presented in section 4.

A4.1. Sales volume

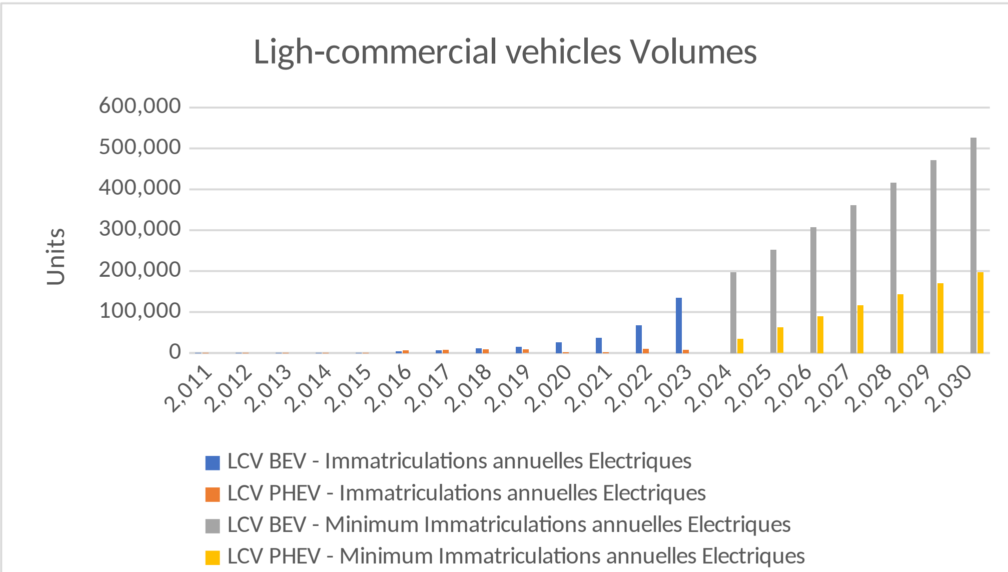
The figure 4.1 and 4.2 show the yearly distribution of sales for passenger cars and light-commercial vehicles.

Figure A4.1 – Historical and modeled annual sales of passenger cars separated by technology.



Source: For historical sales (ACEA, 2023). For future sales, author.

Figure A4.2 - Historical and modeled annual sales of light-commercial vehicles separated by technology.

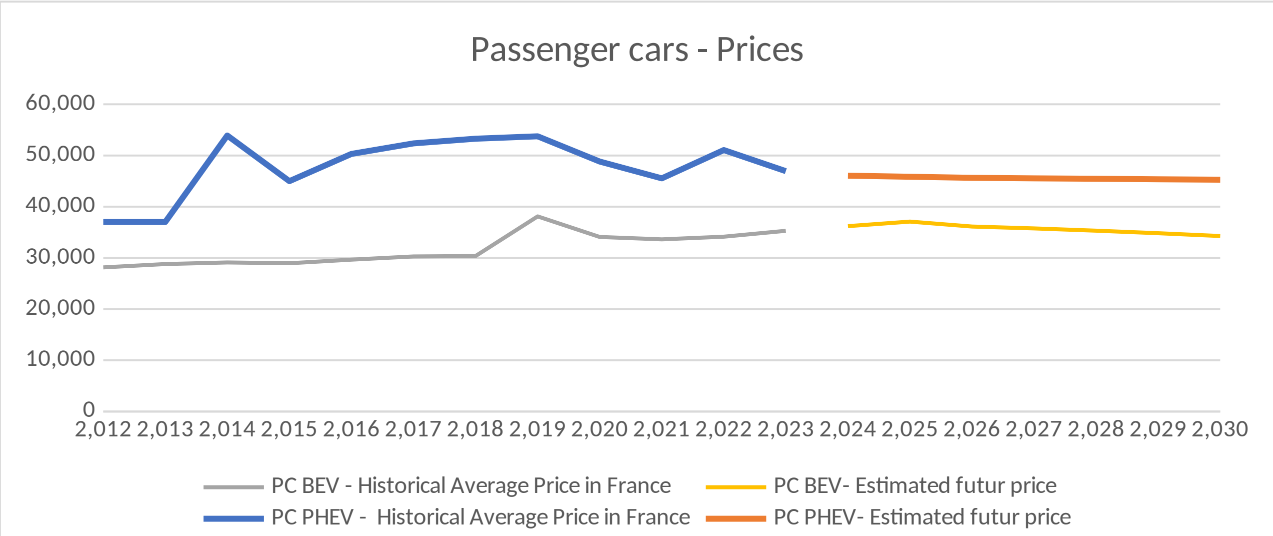


Source: For historical sales (ACEA, 2023). For future sales own modeling.

A4.2. Future prices

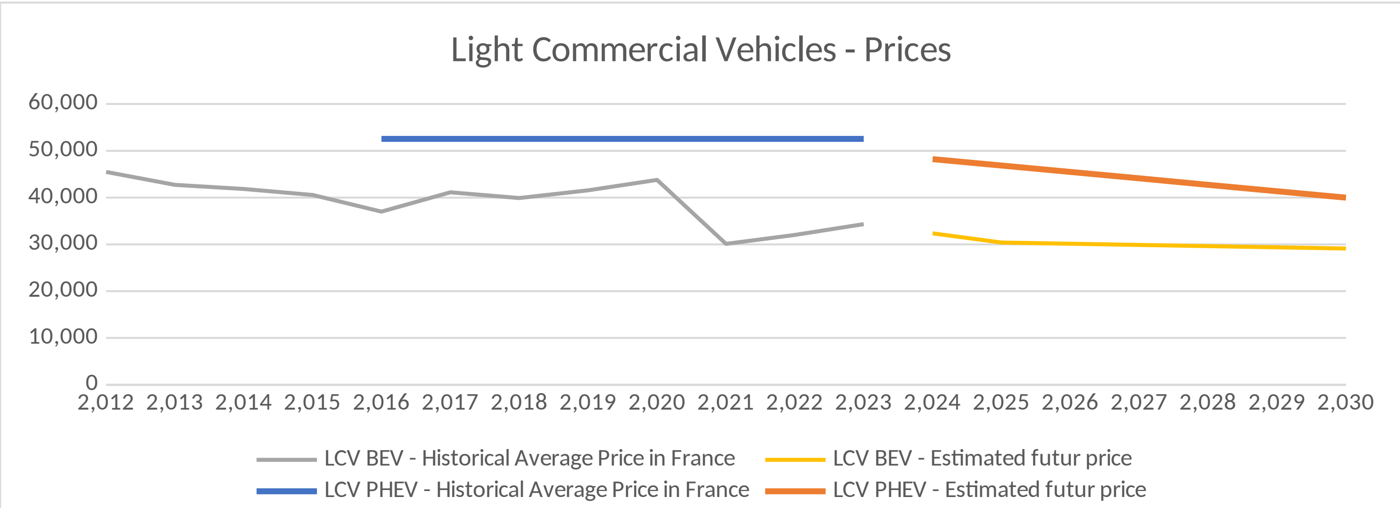
The figure A4.3 and A4.4 show the yearly average price for passenger cars and light-commercial vehicles.

Figure A4.3 – Future prices of passenger cars separated by technology.



Source: I4CE

Figure A4.4 – Future prices of light-commercial vehicles separated by technology.



Source: I4CE, own analysis

Annex 5. Methodology for testing European policies

This annex presents the methods supporting the section 5.2 of the discussion.

A5.1. Technological uptake: S-shaped Curve

The realism of the European target for 2030 has been tested based on the 2035 targets. In 2035, no fossil fuel cars could be sold in the European Union (Regulation (EU) 2019/631, 2019). It means that only zero-emissions battery electric vehicles could be sold. The question then is: are the parameters on track for meeting the 2035 targe.

<u>Equation and parametrisation</u>

The model is assumed to follow a technology diffusion. Every time, someone buys an electric car, the technology spreads. Empirical research shows that the diffusion of technology follows an S-Shape curve (Sarkar, 1998, p. 131). It is assumed that the uptake of BEV vehicles should follow an S-Shape technological deployment on the share in the market. The function giving the share in sales is of the following form (from (Hopeaketo, 2023)).

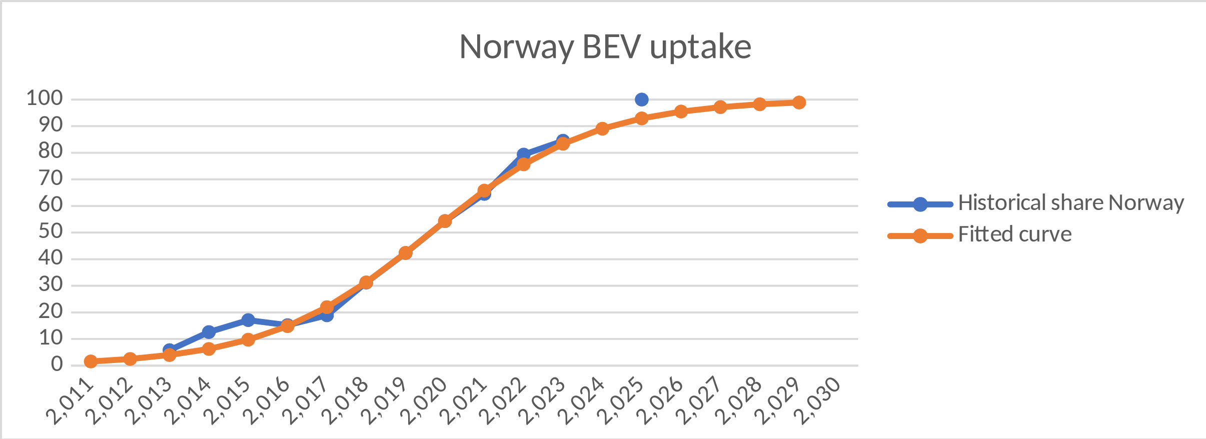
$$y = \frac{K}{1 + e^{-b(t-t_0)}}$$

where	K	asymptote (saturation level)
	b	diffusion rate (steepness)
	t	time
	t_o	inflection point at $K/2$
	Δt	$\ln 81 . b^{-1}$.

This equation describes the uptake of battery-electric vehicles. In 2035, 100% of vehicles should be electric. K was thus set at 100%. The diffusion rate was fitted on the Norwegian case based on data from the ACEA (ACEA, 2023c). To was set at the date when 50% of the Car sold in Norway were battery electric cars (~2019,6). To find the b parameter, an optimisation of the sum-squared distance with Excel was done. The optimum was found for DeltaT = 9,2 years (figure 23).

Knowing this parameter and assuming that the European car market will follow the same technological diffusion, the curve could be fitted to the historical sales in the European Union to find the inflection date. The minimum is reached for t0 = 2026,3 that minimizes the sum-squared error.

<u>Figure A4.1 - Fitting the S-shape diffusion curve to Norway's history</u>

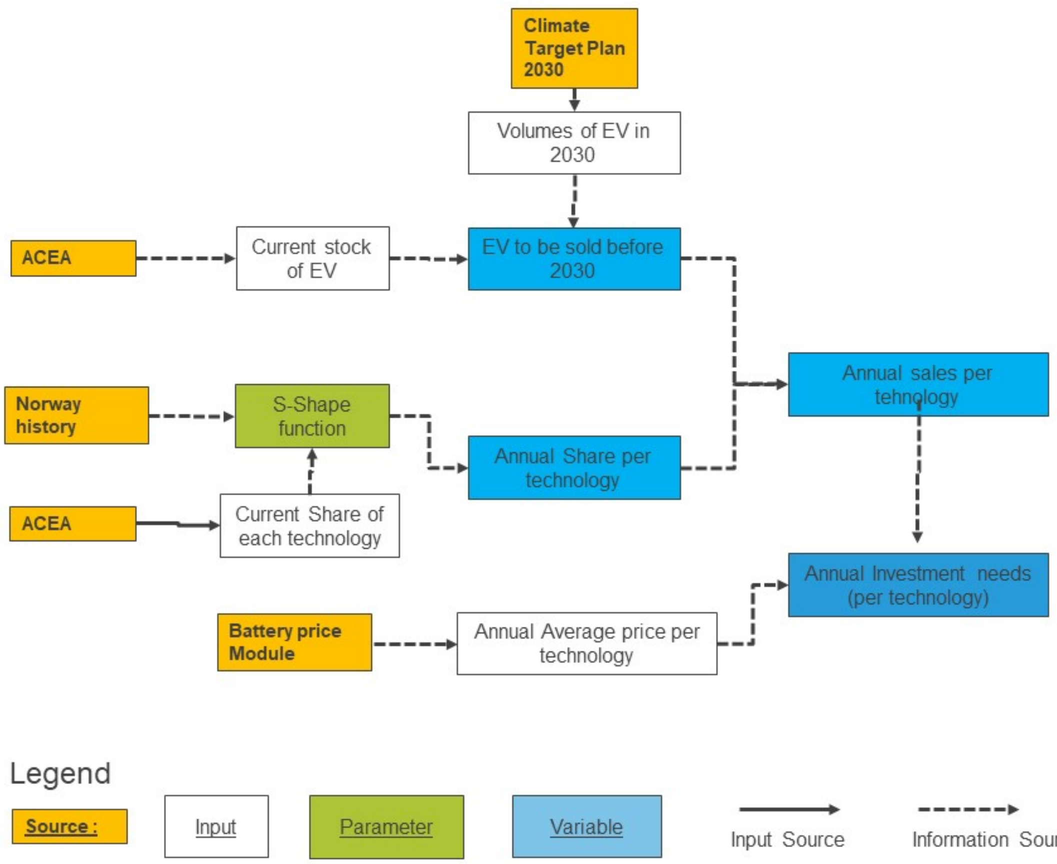


Source: (ICCT, 2023) and (ACEA, 2023) for historical share. The fitted curve is the result of the modeling.

A5.2. Alternative reference regulation

The main input of this scenario is the *Volumes of EVs in 2030* as stated in the *Climate Target Plan 2030* (European Commission, 2021c, p. 76). Assuming a constant growth of the vehicle stock, the number of *EVs to be sold before 2030 can be estimated*. These EVs are sold between now and 2030 based on the *Annual share per technology* that is tuned by an *S-Shape function* defined below.

Figure A5.2 - Alternative Light-vehicles module based on the stock of electric vehicles in 2030



Source: Author

Annex 6. Literature review sources

The following tables provide a comprehensive overview of the literature reviewed. The initial column denotes whether each study was ultimately inlcuded into the review, with inclusion criteria detailed in the Literature review section. The second column outlines the source of each study within the literature review, while the third column provides the corresponding topic. A detailed description of each paper is presented in the fourth column, and the fifth column enumerates the sources extracted from the paper for inclusion in the literature review. The last column is for specific comment. Some papers have been found multiple times but are just shown for one source.

Table A6.1 – Summary table of references found from the first systematic search query used for the literature review

Included in the literature review	Reference	Topic	Description	Snow -Ball	Notes
No	(Clark et al., 2018)	Finance	Propose an overview of finance mechanisms for sustainable development effort by reviewing literature.		
No	(D'Orazio & Popoyan, 2019)	Finance	Review the *"prudential approaches to incentivizing the decarbonization of banks' balance sheets"*		
Yes	(Diaz-Sarachaga et al., 2018)	Sustainable Development Goals	Analyse the suitability of applying a unique sustainable development goal index for assessing the fulfilment of the 2030 objectives		
Yes	(Miola & Schiltz, 2019)	Sustainable Development Goals	*"This paper illustrates the sensitivity of rankings to the choice of indicators and methodological assumptions by comparing the three most prominent methods using the sample of EU28 countries."*.		
No	(Mohsin et al., 2019)	Carbon content of the economy	*"In this study, I develop an aggregated composite index (ACI) of energy security and environmental sustainability for each of the world's highest GHGs and* CO_2 *emitting countries"*		
No	(Raymond et al., 2017)	Evaluation of Nature Based-Solution	Propose a framework to support planning and evaluation of Nature-Based solution		

Yes	(Salvia et al., 2021)	Municipality Targets plan	Review of cities mitigation plan to assess their consistency with global target of emission reduction		
Yes	(Schaffrin et al., 2015)	Evaluation Policy Output	Measure the policy output of a text based on a number of criteria measuring the intensity and the density.		
No	(Warren et al., 2018)	Evaluation of adaptation Plan	Propose a new way to measure risk assessment for UK adaptation plan		

Table A6.2 – Summary table of references found from the second systematic search query used for the literature review

Included in the literature review	Reference	Topic	Description	Snow -Ball	Notes
No	(Reckien et al., 2018)	Local Plan	Review 885 cities plan to assess their alignment with mitigation and adaptation targets		
No	(Olazabal et al., 2019)	Local plan	Propose a "conceptual framework to assess the credibility of climate change adaptation policies"	(Averchenkova & Bassi, 2016)	
Yes	(Huisingh et al., 2015)	Technology Uptake	Investigate "technical innovations and policy interventions for improved energy efficiency and carbon emissions reduction"		
Yes	(Michaelowa, 2018)	Transnational Climate Governance	Evaluate *"109 transnational climate cooperation initiatives based on four design criteria: existence of mitigation targets; incentives for mitigation; definition of a baseline; and existence of a monitoring, reporting, and verification procedure."*		
-	(Edenhofer, 2015)	Climate change mitigation	IPCC report – Working group III on mitigation	(Shukla et al., n.d.)	We preferred the most recent version
Yes	(Shukla et al., n.d.)	Climate change mitigation	IPCC report – Working group III on mitigation		

We preferred the most recent version of the IPCC report.

Table A6 .3 – Summary table of references found from the third systematic search query used for the literature review

Included in the literature review	Reference	Topic	Description	Snow -Ball	Notes
No	(Finger & Serafimova, 2020)	Urban Mobility	Discuss about indicators for Sustainable Urban mobility Plan		
Yes	(Gunnarsdottir et al., 2020)	Sustainable energy	Review "*established indicator sets for sustainable energy development*". Define the characteristics of a comprehensive and robust indicator.		
Yes	(Hák et al., 2016)	Indicators for sustainable development goals	Review Sustainable Development goals indicators		
No	(Herman & Shenk, 2021)	Machine learning	Develop machine Learning methods to find evidence of effects of climate policies		
No	(Kabisch et al., 2016)	Nature-Based solution	Propose a policy strategy to promote Nature-Based solution		
No	(Morgan et al., 2022)	Forest management	Define a framework for assessing landscape planning process.		
Yes	(Salvan et al., 2022)	Environmental policies	Compare indicators following the progress and effect of agricultural policies in the green Deal		
No	(Sheriffdeen et al., 2020)	Investment effectiveness	*"Develops an indicator-based framework to evaluate the institutional effectiveness of the Indonesian Climate Change Trust Fund (ICCTF) as a case study"*		
Yes	(Sridhar et al., 2021)	Climate governance	Analyse the existence of institutions on different aspect of climate policies as an indicator of progress.		
No	(Tavoni et al., 2015)	Regional comparison of carbon budgets	*"Reviews scenario results from model intercomparison projects to explore different possible outcomes of post-2020 climate negotiations"*		

		and announments			
No	(Watts et al., 2017, 2018)	Climate change on human health	Provides indicators for a global overview of health and climate change		

Table A6.4 – Summary table of references found by snow-balling for the literature review on monitoring

Included a	Reference	Topic	Description	Snow -Ball	Notes
Yes	(Vogt-Schilb & Hallegatte, 2017)	National Determined Contribution Policy Design	Review the literature on how policymakers can design climate policies and recommend setting Sectorial Targets and Roadmaps		From IPCC report
Yes	(Shivakumar et al., 2018)	Measuring Progress for Smart Energy Solution	Review methods to develop indicators that can be used to measure the progress of policies on Smart solutions for energy consumers		From IPCC report
Yes	(Rogelj et al., 2016b)	Evaluation of National Plans	Model the effect of current National Determined Contributions on reducing aggregate greenhouse gas emissions, the implications for achieving the temperature objective of the Paris climate agreement, and potential options for overachievement		From IPCC report
Yes	(Roelfsema et al., 2020)	Evaluation of National Plans	Model the emission gap after implementing policies, " *based on a public policy database and a multi-model scenario analysis*"		Also found in request 2 From IPCC
Yes	(Peters et al., 2017)	Track Progress	Propose a framework of indicators to track progress of climate mitigation based on the Kaya equation		Also found in request 2 From IPCC report
No	(Pauw et al., 2018)	National Determined	Recommend the creation of common framework to compare National Determined Contributions		From IPCC report

		Contributions comparison			
No	(Mayer et al., 2019)	Progress towards circular economy	Propose a framework "*that measure the scale and circularity of total material and waste flows and their socioeconomic and ecological loop closing*"		From IPCC report
Yes	(Le Quéré et al., 2018) (Friedlingstein et al., 2023) *	Measuring Carbon budgets	Model and quantify major components of the global carbon budgets and the historical emissions		From IPCC report
Yes	(Iyer et al., 2017b)	Feasibility of US NDC	Asses the coherence of US' NDC to Mid-century targets by modelling the technological development required to met the targets		From IPCC report
No	(Höhne et al., 2018)	Describe ambition of NDC	Propose a review on the different approaches to measure the ambition of NDC		From IPCC report
Yes	(Höhne et al., 2020)	Descriptions of different countries GHG reduction	Review nations' individual pledges and their consistency with their stated collective goals		From IPCC report
Yes	(den Elzen et al., 2019)	Measurement alignment between policies and pledges	Summarize the expected emission reduction for G20 countries and concludes about the progress to meet NDC targets		From IPCC report
Yes	(Averchenkova & Bassi, 2016)	Assessing the credibility of climate NDC	Propose a framework to calculate credibility of plans based on indicators about the policy context		

Table A6.5– Summary table of references recommended by the expert used for the literature review

Used in the literature study	Reference	Topic	Description	References found from this source (Snow -Ball)	Notes

Yes	(Schiemann & et al., 2019)	Corporate emission tracking	Review the literature on how policymakers can design climate policies for corporate actors		
Yes	(Rüdinger, 2018)	Dashboard to monitor the implementation of policies	Propose to summarize indicators of different policies into a dashboards		
Yes	(ECNO, 2023)	Dashboard EU transition	Share an up-to-date dashboard to follow progress of the European Union mitigation policies		
Yes	(Dobrinevski & Jachnik, 2021)	UK building sector	Assess the UK building sector investments consistency with climate objectives		
Yes	(Dobrinevski & Jachnik, 2020)	Norwegian industries	Assess the Norwegian industry sector investments consistency with climate objectives		
Yes	(Sartor, 2016)	Indicators for decarbonisation	Discuss on the indicators to measure progress to 2030 decarbonisation goals		
Yes	(IEA, 2022)	Global energy transition	Overview of the energy transition in the world		Also found in request 2 and by snowballin g
Yes	(IEA, 2023b)	Global Energy investment	Tracking Financial flow for energy transition		
Yes	(Hainaut & Cochran, 2018)	Tracking climate finance flow	Methodology used for tracking finance flow		
Yes	(Fisch-Romito & Guivarch, 2019)	Transport investment gap	Estimating the world transport infrastructure investment deficit	Only used fpr the Methodology review: Carraro et al., 2012; McCollum et al., 2018)	

Table A6.6 – Summary table of references found from the systematic search on Scopus

Used in the literature study	Reference	Topic	Description	References found from this source (Snow -Ball)	Notes
Yes	(Charalampidis et al., 2019)	Effect of transport policies on the Italian economy	Describe with a regional level the effect of European Green Deal transport policies		
Yes	(Tamba et al., 2022)	Socioeconomic assessment of transport policies	Develop a model to understand the socio-economic effect of electrification		
Yes	(Van der Zwaan et al., 2013)	Pathways for decarbonising road transport	Assess two scenarios of decarbonisation for road transport with hydrogen as a dominant technology or EV as the dominant		
Yes	(Klaaßen & Steffen, 2023)	Infrastructure investment needs in Europe	Meta-analysis of the investment needs up to 2035		
Yes	(Ganter et al., 2024)	Hydrogen infrastructure	Investment strategies for deploying hydrogen infrastructures		
Yes	(García-Olivares et al., 2020)	Scenarios for decarbonizing road transport	Define different technology-mix for transport and compare them based on energy consumption and investment needs		
Yes	(Tsiropoulos et al., 2022)	Charging-points investment needs	Factors influencing investment needs for charging points deployment up to 2050		

Annex 7. Press coverage of the European Climate Investment Deficit Report 2024

This master thesis was part of a project from the I4CE measuring the overall investment gap across Energy, buildings and transport. This annex lists some of the press coverage after the publication of the report.

1. **Link to the report**

Clara Calipel, Antoine Bizien, Thomas Pellerin-Carlin, February 2024, European Climate Investment Deficit report: an investment pathway for Europe's future, I4CE (report)

Clara Calipel, Thomas Pellerin-Carlin, February 2024, Launch of the first edition of the EU Climate Investment Deficit report, I4CE (Conference)

2. **News from public institution**

Caisse des dépôts, News, 21 February 2024, I4CE publishes two new studies on climate investment financing

INSP, News, 21 February 2024, European Climate Investment Deficit report An investment pathway for Europe's future

European Commission, ManagEnergy, European Climate Investment Deficit Report: An Investment Pathway for Europe's Future, 27 February 2024

3. **Media with an European/International audience**

Henry Foy, 21 February 2024, Why Poland and the Baltics are jostling for the EU's top security jobs, Financial Times – Europe Express

Federica Di Sario et al., 22 February 2024, Clean Tech Talk Therapy, Politico Pro

Frédéric Simon, 21 February 2024, Extra €406bn needed annually to hit EU's 2030 climate target: report, Euractiv

Frédéric Simon, 21 February 2024, Le Green Brief: la prochaine Commission devra s'attaquer au déficit d'investissements climatiques, Euractiv

Frédéric Simon, 21 February 2024, Climate investment gap looms over next EU mandate, Euractiv

Elise Wu, 221 February 2024, L'UE doit dépenser EUR 122mds/an de plus pour le Pacte vert | Montel News - Français, Montel News

Live Blog, 22 February 2024, Europe must double climate investments to reach 2030 targets, report says, Science Business

Table Climate, 22 February 2024, Climate investments would have to double to meet EU climate targets, Table Media

Knowledge Energy institute, 28 February 2024, $2tn a year needed to triple global renewables by 2030 and ensure 'energy for all', Energy institute

Olalekan Adigun, 21 February 2024, Bridging the Gap: Climate Policy, Finance, and the Future of European Sustainability, BNN Breaking

Weekly News Roundup, 23 February 2024, EFIEES - European Federation of Intelligent Energy Efficiency Services

Knowledge Hub, 21 February 2024, EU's annual climate investment deficit estimated at €406bn, Sustainable views

Mark Evans, 21 February 2024, EU needs to double climate investments to deliver 2030 targets, Better Society Network

Age Bakker, Roel Beetsma, Marco Buti, March/April 2024, Investing in European Public Goods While Maintaining Fiscal Discipline at Home, Intereconomics, Review of European Economic Policy

3. **Media with a French audience :**

Journal de 18 Heures, 21 February 2024, Entrée au Panthéon de Missak Manouchian, France Culture (Starting at 9:20)

Journal de 8 heures, 22 February 2024, L'actrice Micheline Presle, doyenne du cinéma français, est morte à 101 ans, France Culture (Interview, Starting at 8:15)

Briefing Transport, 21 February 2024, UE I4CE chiffre « le déficit d'investissements » climat dans l'UE à 147 milliards d'euros par an pour les transports, Contexte

Briefing Energie Et Pouvoir , 21 February 2024, UE I4CE chiffre « le déficit d'investissements » climat dans l'UE à 406 milliards d'euros par an, Contexte

Anne Feitz, 21 February 2024, Climat: l'Europe doit doubler ses investissements pour atteindre ses objectifs en 2030, Les Echos

Matthieu Goar, 21 February 2024, En France et en Europe, les gouvernements réduisent leurs dépenses « vertes », loin des ambitions écologiques, Le Monde

Agathe Beaujon, 21 February 2024, Investissements pour le climat: l'Europe doit doubler ses efforts - Challenges, Challenges

Guilhem Bernes, 21 February 2024, Les investissements dans les technos vertes en Europe ne sont pas encore à la hauteur des enjeux climatiques (usinenouvelle.com), L'Usine Nouvelle

Emilie Legendre, 21 February 2024, Le déficit d'investissements climat de l'Union européenne atteint 406 Md€ par an, selon I4CE, AEF

Irène Inchauspé, 21 February 2024, Investissements climat en Europe, le lancinant refrain du «toujours plus»! - l'Opinion (lopinion.fr), L'Opinion

N. Gorbatkto, 21 February 2024, Investissements climat : il faut redoubler d'efforts, Actu Environnement

Actualité n°315881, 21 February 2024, Union européenne: le déficit annuel moyen des investissements climatiques estimé à 406 Md€ (I4CE), News Tank Energie.

Doc de Rexecode, 27 February 2024, Climat: l'Europe doit doubler ses investissements pour atteindre ses objectifs 2030 (I4CE), Rexecode

France info, 22 February 2024, Climat: il manque 400 milliards d'euros d'investissements par an dans l'UE pour atteindre nos objectifs climatiques,

Clément Fournier, 23 February 2024, Doubler les financements climatiques, un effort atteignable: les chiffres à retenir dans une infographie, Novethic

Bsmart (TV), 27 March 2024, Financements climat: où en est l'Union européenne ?,

4. Other media with a national audience

Germany:

Table Climate, 22 February 2024, Klimainvestitionen müssten sich für EU-Klimaziele verdoppeln, Table Media

Belgium:

Frédéric Rohart, 21 February 2024, Climat: l'Europe devrait doubler ses investissements pour atteindre ses objectifs | L'Echo (lecho.be), L'Echo

Portugal:

Aline Flor, 22 February 2024, UE tem um "buraco" de 406 mil milhões por ano no investimento climático até 2030, Publico

Executive Digest.com Lusa, 21 February 2024, Investimentos públicos e privados na UE a 50% do necessário para atingir objetivos climáticos em 2030, Executive Digest

Italy:

Flavio Fabbri, 21 February 2024, Energia, trasporti, case: investimenti green cresciuti del 9% nell'Ue, mancano 400 miliardi di euro all'anno, Energia italia

N.A., 22 February 2024, European Climate Investment Deficit Report – An investment pathway for Europe's future, QualEnergia.it

Spain:

N.A., 21 February 2024, La UE debe duplicar las inversiones verdes para alcanzar los objetivos climáticos de 2030, Expansión (also shared in msn.com news)

Netherlands:

N.A, 21 February 2024, The European economy needs to double its level of climate investments to deliver the EU 2030 targets, Duurzaam-ondernemen.nl

Estonia:

Mark Gerassimenko, 21 February 2024, Uuring: EL-i kliimaeesmärkide saavutamine nõuab kulutuste kahekordistamist, ERR.ee

Ирина Догатко, 21 February 2024, Исследование: достижение климатических целей ЕС требует удвоения расходов,ERR.ee (in Russian)

Ukraine:

Halina Yermolenko, 21 February 2024, EU needs an additional €406 billion annually to achieve its climate goal, GMK Center

UK:

Victoria Hatherick, 21 February 2024, Double climate investment to meet EU 2030 goals: I4CE, Argusmedia

Master Thesis

7 June 2024

Antoine Bizien