Delft University of Technology

MSc Sustainable Energy technology

Master Thesis

Pathway and barrier exploration for a 2060 CO2 neutral private transport sector in Java, Indonesia

Yannick Huijsing - MSc SET - 4356586

Supervisors:

Dr. J. A. Annema

Dr. J. Quist

November 23, 2022

Word from the Author

When I started my academic journey a little over 8 years ago now, I didn't expect to end up here. This work in a way reflects that. Although it will likely not be visible in the final version created, this work is a miniature version of my journey up to this point. From a rough idea of what to do to ambitious plans that have to be adjusted last minute due to unforeseen circumstances. Although my journey wasn't perfect, and neither is this work, it represents the steps I had to take and all I had to learn along the way. And I am proud of that.

As with most journeys, one does not travel alone. I would like to extend my thanks to a few individuals here who have helped me along the way during the creation period of this work. I would like to thank my supervisors, Dr. Jan Anne Annema and Dr. Jaco Quist for providing directions, sources and contacts that helped me find my path during the creation of this work. Although I consider myself stubborn in insisting the steps I would take, they guided me in ensuring I wouldn't be here still writing ad infinitum. They spent time with me and on me on this work during times and in places I would not have dared to ask of them, yet they did it anyway.

I would like to thank my parents for providing me with a stable place to live and write my work, even in these turbulent times. I cannot thank them enough for raising me.

I would like to thank those that have treaded this field before me, and paved some of the way to make the construction of this work easier. Specifically, I would like to thank Zejun Ding and Jani Kedar. Although we have never met, I would consider both of you people I have discussed this field of research in-depth with through the works you have written before me. I am truely standing on the shoulders of giants without realising.

I would like to thank the people who have taking the time to take my enquiries in regards to interviews seriously. Although I do not know your names, thank you for taking the time to look through the messages I sent, even though they didn't result in the interviews I hoped for. A part of me wants to think the efforts were fruitless, but another thinks that not getting a result is a result too. In regards to one who did hold an interview with me, I would like to thank Lutfi Prayogi, a PhD candidate who provided me with local viewpoints and information from a different perspective.

Finally, I would like to thank my pet rabbit, Klein, who passed away on 20 September 2022. She provided me with ample moments to take my mind of mind work and kept me sane during the pandemic, during which I probably got more isolated than I would like to admit. I am sorry it had to end the way it did, but I sincerely hope I gave you a good life, because you made mine a lot better. As the toughest pet I have ever had, you taught me to persevere, no matter what.

There are probably many other people I would like to talk about and thank, but despite the length of this work, I am generally a person of few words. I could also take a moment to talk about myself more, but I will refrain from doing so. This work represents the journey I went through over the past 8 years, and with it, contains pieces of me. I will now see where my journey takes me next.

Yannick Huijsing

Written as of 18-11-2022

Executive Summary

Indonesia has ambitious plans to reach CO2 neutrality by 2060. While plans to reach this goal have been made for the energy and forestry sector, no plans have been published for the transport sector specifically. The amount of private vehicles on the road in 2060 has been predicted to increase significantly. As a result of urban sprawl and overall lacking for-profit economic model, public transport is unlikely to be a significant competitor to private transport. Indonesia itself has created scenarios in which biofuel is introduced to the fuel mix to mitigate CO2 emissions from the private transport sector. Current progression however, makes it unlikely the private transport sector will be CO2 neutral by 2060. The overall goal of this report is to serve as an advisory report to create scenarios and pathways as to how Indonesia can reach its CO2 neutral 2060 goals. This objective is illustrated in two topics that will be explored; to allow for the private transport sector in Indonesia to reach CO2 neutrality by 2060 using sustainable transport technologies and what difficulties transition pathways face to reach this goal. To be able to realise these objectives, which forms the main research question, a number of sub-questions have to be answered.

- What characteristics could the island of Java have to cause an apparent pathway dependency for sustainable transport technologies?
  - What are relevant properties and who are the relevant stakeholders?
  - What is the current makeup of the transport sector and how does it trend?
  - What factors influence the development and spread of technology in Java?
- What characteristics do the sustainable transport technologies have? (Limited to electric, biofuels and hydrogen)
- What are potential future scenarios based on the characteristics of Java and the technologies?
- (How) Can these scenarios be realised?
  - What steps need to be taken?
  - What barriers and drivers present themselves?
  - What can be done to resolve these barriers?

By using backcasting, future visions using sustainable transport technologies were created. These sustainable transport technologies were selected through pathway dependencies. A pathway dependency or dependence is defined as *the tendency of institutions or technologies to become committed to develop in certain ways as a result of their structural properties or their beliefs and values* according to Brittanica. By exploring the properties and beliefs and values present, the most suitable technologies could be selected for. Determining a pathway dependency is quantitatively in nature, while backcasting is qualitatively.

In three steps the pathway dependency adapted backcasting method was used to visualise the final goal. First, strategic problem orientation was done based on trends and stakeholder interaction. A number of properties of Indonesia were highlighted to expose pathway dependencies for three selected sustainable transport technologies. Using these properties, future visions were established. Next, based on established trends, a business as usual (BAU) scenario was established to evaluate what would happen if no further actions were to be taken. These future scenarios were created using singular sustainable transport technologies to evaluate the effect a singular sustainable transport technologies could have based on the properties previously highlighted. A combined technologies future scenario is created to properly attempt to reach the goal of 2060 CO2 neutrality for the private transport sector. Finally, using this combined scenario, a pathway was constructed and barriers were highlighted and explored.

Analysis of the problem is the most important step to understanding what needs to be done. First of all, Indonesian properties and stakeholders were discussed and analysed. The relation between different properties were explored. Linkages between different sets of properties were highlighted, and relevant properties for the sustainable transport technologies were explained. The presence of nickel allows for domestic construction of battery electric vehicles (BEVs) while the use of palm oil allows for domestic production of biofuels. Increase in average wealth and knowledge allows for the generation and spread of knowledge to further utilize these

technologies.
Trends were established, and were used to determine a BAU scenario. Increase in average wealth as well as changes in export economy make it likely that the number of private transport vehicles will increase significantly. This is combined with the lack of a unified plan to combat this increase. In the BAU scenario, an increase in private vehicles to between 30 and 156 million is expected, which corresponds to total CO2 emissions ranging from 120 to 616 mega-tons (MT) in 2060.
The mitigation capability of the individual sustainable transport technologies was explored, based properties highlighted. The effect of biofuels, BEVs as well as hydrogen fuel cells was explored. Although biofuels and BEVs due to favourable properties are capable of mitigating a large amount of CO2 individually, they are not capable of reaching the goal on their own. For biofuels, this is due to the large amount of feedstock needed. For BEVs, this is due to the later large scale implementation of this technology. For, hydrogen, it is unlikely that this technology will make significant impact in time.
A combined scenario was then created using biofuel and BEVs. These two technologies both have a number of favourable properties in Indonesia and work complementary. Biofuels are capable of mitigating early CO2 emission but lack feedstock to be able to deal with later larger amounts of CO2 mitigation. BEVs do not mitigate a lot of CO2 early on due to their need for changes in infrastructure but can mitigate larger amounts of CO2 later on. This combined scenario could be capable of reaching the 2060 CO2 neutrality goals.
For this combined scenario, three different phases were identified and goals for each phase were discussed. For each of these stages, goals and barriers that prevent these goals from being reached were discussed using a what-how-why analysis, to form a transition pathway. A number of barriers were explored in-depth to highlight their complexity. Policy packaging is suggested as a tool for dealing with these barriers. The need for interactions between different groups of stakeholders to be able to deal with these complex barriers highlight the need for interaction and discussion between these groups. The use of participative backcasting, and the use of workshops to allow for constructive interaction between stakeholder groups to discuss solutions to these complex barriers, as well as refinement of the scenario presented was suggested. Furthermore, a number of potential starting points for policy packaging were suggested, as well as a number of recommended actions to further discuss the refinement of the proposed scenario.
The main conclusion from this report is that Indonesia lacks a plan to deal with the expected development of the private vehicle sector, but has properties that allow them to deal with this development if the right steps are taken. It is possible to resolve this development using biofuels and BEVs. Scenarios created show that complex barriers are likely to present themselves, which could be resolved through combined efforts from bureaucratic and academic actors using participatory backcasting and policy packaging.

Gained insights from this report include:

- Indonesia lacks a uniformly accepted plan for the expected development of the private vehicle sector
- Emissions from the private transport sector are likely to increase drastically due to increase in average economic level and changes to the export economy of Indonesia
- Biofuels and BEVs are suitable sustainable transport technologies due to present properties in Indonesia allowing for better implementation
- Implementation of hydrogen as a sustainable transport technology is likely not enough to be able to reach the 2060 CO2 neutral goals
- It is realistically possible to reach the 2060 CO2 neutral goals using a combination of biofuels and domestically produced BEVs
- Complex barriers arise in the construction of needed infrastructure, fuelling and market attraction
- From expert interviews, there are likely some conflicts of interests to arise inside stakeholder groups which should be resolved

List of Figures

List of Tables

Contents

1 Introduction

Indonesia is a south-east Asian island nation with a population of about 270 million, making it the fourth most populous country on Earth. Being the only member of the G20 in south-east Asia, Indonesia can be classified as a regional power. As of 2022, Indonesia holds the presidency of the G20, with goals focused on Global Health Architecture, Sustainable Energy Transition and Digital Transformation (G20, 2021). Although Indonesia has stated to be at a net zero emission level by 2060, currently it is not on track to meet this goal (Climateactiontracker, 2021).

According to the IEA, Indonesia has shown an increase in the TES (total energy supply) of fossil fuels, such as coal, oil and gas. The transport sector is the second largest contributor (IEA, 2019). Its reliance on coal and other fossil fuels provide the country with significant challenges to reach its set goal by 2060 (Climateactiontracker, 2021).

Furthermore, its middle class is growing. There are multiple ways the middle class can be defined, using either relative or absolute terms (Easterly, 2001) (Kharas and Gertz, 2010). Here, the middle class is defined in absolute terms. The middle class is by far the fastest growing group and represented at least 20 percent of the population, or around 52 million people in 2016 (World Bank and Australian Government, 2019). Combined with the aspiring middle class, and the upper class, this group is expected to grow to a total of 143 million people by 2050. The growing demand of private vehicles is expected to rise in association with the growth of the middle class (Negara and Hidayat, 2021) (Deng, 2007). Specifically on Java, where the population density of Indonesia is at its highest and a large part of the population lives in large urban sprawls, the demand of private vehicles is expected to increase the most (Handy et al., 2005) (Ewing and Cervero, 2010) (Burchell et al., 2002). With the presence of a so called 'carbon lock-in' in place for the transportation industry as a whole, the growth of the middle class will likely only lead to a further increase of TES of fossil fuels (Unruh, 2000). How can Indonesia reverse the trend of using fossil fuels and turn itself towards its goal of a sustainable energy transition?

While fossil fuels are still the 'locked-in' form of transportation, there are a number of promising sustainable transport technologies that could replace fossil fuels and help Indonesia reach their 2060 goals. These include EVs (electric vehicles), the replacement of fossil fuels by a more sustainable biofuel and the use of hydrogen as a fuel, for instance (Romm, 2006) (Pickrell and The DOT Center for Climate Change Environmental Forecasting, 2003) (Geffen et al., 2004) (Ahmed et al., 2016) (Yue et al., 2014). However, each of these technologies have their own unique characteristics, strong and weak points and a given state of global development (Romm, 2006) (Pickrell and The DOT Center for Climate Change Environmental Forecasting, 2003) (Ahmed et al., 2016) (Yue et al., 2014). How can a given technology be implemented properly given the characteristics of said technology and country of implementation?

Policies are one way to help mitigate the problems, mitigate or help change the difference in characteristics between technology and country. Furthermore, they can help speed up the transition itself. However, the implementation of policies is not that simple(Berg et al., 2017). There are no 'one size fits all' policies for each country. The natural resources, the population and their customs as well as the governing and relevant bodies and their makeup all impact the effectiveness of a given policy. Implementation and adaption of relevant policies would likely result in a set of policies that are most 'fit' for Indonesia's unique situation. How can the most useful policies be selected for, and how can a path towards Indonesia's goals be visualized?

Given the fact that the effectiveness of policies relies on the characteristics of the relevant technology and country, one could expect a 'pathway dependency'. A pathway dependency or dependence is defined as "*the tendency of institutions or technologies to become committed to develop in certain ways as a result of their structural properties or their beliefs and values*", according to Britannica (Britannica, 2022). Here, the technologies in question would be the three forms of RE vehicle technologies mentioned earlier, electric, hydrogen or biofuel-based vehicles, the structural properties are those of the technologies as well as the country in question and the belief and values are the socio-cultural values of the country in question, in this case Indonesia. Indonesia faces the challenge to implement a form or combinations of these technologies in such a way that the pathway dependency can be utilized. Given this issue and relevant definitions, a problem statement can now be made.

1.1 Problem Statement

The problem that will be tackled in this report is twofold. There appears to be an oversight in the approach for Indonesia's 2060 CO2 neutral goals as there are no uniformly accepted plans that can resolve the development of this sector. Sustainable transport technologies could be implemented, but pathways for implementation would have to be found. As a motivation for creation of this report, in Section A.2, it appears there is a knowledge gap when it comes to the use of backcasting on the transport sector in non-western countries. The characteristics of the problem are that the future or normative goal to be reached is radically different from current trends, the goal lies significantly far into the future and multiple paths can be chosen to reach this goal. A method suited for these characteristics is back-casting, a form of transition management (Quist and Vergragt, 2006). By relying on a back-casting approach scenarios of different technologies that can be implemented are created, and suitable sets of policies are then searched for.

Although for some indicators in this report, data for the whole of Indonesia will be used, the focus of this report are policies that can be applied to the island of Java specifically. As will be indicated later in this report, the middle class plays a large role in the development of scenarios created by backcasting. The majority of this middle class is situated on the island of Java. Individual differences across the islands of Indonesia in culture, geography and demographics would result in a wide range of applicable policies per island.

1.2 Research questions

The goal of this report is to serve as an advisory report to illustrate an issue that appears to be overlooked in regards to Indonesia's CO2 neutral 2060 goals. This issue will be researched, and potential technological solutions will be provided in the form of backcasting scenario's. Technological solutions will be selected for using pathway dependencies and scenario pathways will be selected for using backcasting. The research will be divided into several sections based on the questions that need to be answered.

Main research question What difficulties need to be overcome to reach a net zero emission level on the island of Java in Indonesia by 2060 given the apparent pathway dependencies of sustainable transport technologies that can be used?

Sub research questions

- What characteristics could the island of Java have to cause an apparent pathway dependency for sustainable transport technologies?
  - What are relevant properties and who are the relevant stakeholders?
  - What is the current makeup of the transport sector and how does it trend?
  - What factors influence the development and spread of technology in Java?
- What characteristics do the sustainable transport technologies have? (Limited to electric, biofuels and hydrogen)
- What are potential future scenarios based on the characteristics of Java and the technologies?
- (How) Can these scenarios be realised?
  - What steps need to be taken?
  - What barriers and drivers present themselves?
  - What can be done to resolve these barriers?

1.3 Report structure

The report will have the following structure. In Chapter 2 of this report an overview of research methodology, back casting, will be given. A brief historical overview of the development of this policy management technique will be given, as well as the application of the technique on this research. Then in Chapter 3, the structural properties of the island of Java, the geography, available resources, relevant infrastructure, demographics, implemented relevant legislation will be explored. For each of these properties, relevant barriers, drivers and important actors will be highlighted for each. The properties of the sustainable technologies involved, EVs,

biofuel- and hydrogen-based vehicles will also be explored. Based on these properties, trends will be established to form the basis of the future scenarios. Using these trends, in Chapter 4, a baseline BAU (business as usual) scenario will be established for the scenario in which nothing is done.
In Chapter 5, to combat the BAU scenario from happening, three sustainable transport technologies are briefly explored and three scenarios are created to see if these technologies on their own are capable of realizing the 2060 Indonesian goals, influenced by the previously established properties. In Chapter 6, a combination will be made of the most promising technologies to form a combined scenario that makes the best use of the established properties. This scenario will be explored more in-depth, and a number of barriers will be explored in Chapter 7. At the hand of expert interviews, the presence of these barriers will be validated and potential solutions will be discussed. Suggestions are made in regards to potential early steps that could be taken to enact the visualised scenarios and to deal with the presented barriers. Further research will also be suggested.

1.4 Expected outcomes

The expected outcome of this report is that at least one set of possible policy packages that can be implemented to help Indonesia reach their normative goal of emission neutrality in 2060 for the transport sector is created. This research will expand on the use of backcasting in non-western countries. An overview of the trends and problems facing the transport sector in Indonesia will be created. On conclusion of this report, further issues will be discussed and further fields of research will be highlighted. Trends will be established to form a BAU scenario, and steps will be provided that can help the issues that arise from the established trends

2 Method, literature analysis and study

In this chapter, the methodology of research is explained. First, for exploring the future scenarios and their potential, the method that was used to create these scenarios, backcasting, will be briefly explained. How this method will be applied to the methodology in this report is given.

2.1 Back-Casting

In this section, the general process of using the back-casting methodology will be explained. In the simplest sense, backcasting is the opposite of forecasting. It is the creation of a goal and finding the steps necessary for that goal to be reached from the present, instead of arguing the likelihood of a certain future given the present situation. Backcasting as a methodology is very normative in nature, due to being oriented towards policy goals and potential futures, rather than towards likelihood as is the case with forecasting. Furthermore, it reduces the tendency, likened to forecasting, of making the results of analysis invalid by the response of said analysis (Robinson, 1982). For the situation given in this report, backcasting is an ideal method, as the future desired, and its normative goals, do not align with the current trends.
The backcasting approach can be applied to cases for which the following characteristics hold, according to Karl-Hendrik Dreborg (Dreborg, 1996):

- 1. The problem is question is complex and affects multiple sectors and levels of society
- 2. Marginal changes will not solve the situation; there is need for radical changes
- 3. Dominant trends are part of the problem
- 4. The time frame in which changes can be made allows for those changes to be enacted

A number of these characteristics can be identified immediately in the case presented in the introduction; the time-frame extends to 2060, the issue of providing for adequate plans for a CO2 neutral private transport sector affect multiple sectors and levels of society and to solve the issue there is a need for radical changes. Whether or not the dominant trends are part of the problem will be investigated in-depth in Chapter 3.

2.2 Methodological framework of backcasting

Although a number of variations exist on the methodological framework, there exists a generalized basic framework as identified by (Quist and Vergragt, 2006), which involves the following five steps, further illustrated in Figure 1:
1. Strategic problem orientation: The strategic problem orientation, the first step of the framework is determination and specification of the goals and or constraints. A clear indication will have to be given of the normative goal and how this goal is being constrained. In this step is also included the description of the situation as it is currently presented and in which direction it is trending. A systemic overview of these trends and developments, as well as the involved stakeholder should be created.

2. Construction of sustainable future visions: During the second step of this framework, construction of future visions, the end point of the desired trend is determined. There are a number of ways a future scenario can be established. Variation can be made in choosing midpoints of the future scenarios with intermediary goals that will have to be reached, as well as change of perspective (Robinson, 1982). The description of the end point is given by the desired scenario, and provides a goal that is to be bridged to by to-be-chosen methods or policies.

3. Backcasting: The third step, backcasting, is the choosing of policies or methodologies that are necessary to reach the future vision that has been constructed. Changes that need to be made in the framework constructed in the strategic problem orientation will here be explained, and actions that need to be taken by stakeholders will be laid out.

4. Elaboration, analysis and defining follow-up and action agenda: The fourth step, elaboration, is the expansion on the methodologies and policies to include necessary details for implementation, analysis regarding the feasibility of said policies and methodologies and definition of further steps that would have to be taken.

Here, the scenario is finally fully fleshed out into a complete scenario, with steps necessary to reach the goal clearly defined. While these steps up until this point would have appeared very linear, this step can include iteration cycles, where analysis leads to further refinement of steps that would have to be taken to reach the goal (Vergragt and Quist, 2011).

5. Embedding of results and generating follow-up and implementation: The fifth step, embedding of results, generating follow-up and implementation, describes the actual implementation of the steps that would have to be taken to reach the goal, as well as further analysis on the progress of implementation, with further refinement and iteration whenever possible.

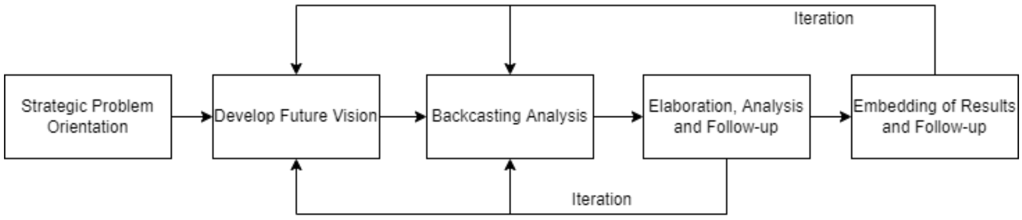


Figure 1: Basic framework for backcasting as stated by Quist and Vergragt (2006). Note that while iteration from the 4th and 5th step to the 2nd and 3rd appears the most intuitive, in reality iteration can occur between any two steps.

2.2.1 Tools and Methods

Aside from these basic five steps which make up the backcasting framework, a number of tools and methods which give indication to the variance of backcasting used have been defined (Quist et al., 2006).
Participatory tools and methods are often included in participatory backcasting studies, and include workshops and tools to support interactions with stakeholders during backcasting more closely (Robinson, 2003) (Robinson et al., 2011). A more complete overview of the various participatory tools and methods has been given by (Mayer, 1999).
Design tools and methods which elaborate on scenario construction and support future system construction, as well as detailing systems (Carmichael et al., 2017) (Quist and Vergragt, 2003).
Analytical tools and methods expand on the backcasting scope by not only assessing the created scenarios and system design, but include process analysis and evaluation, stakeholder identification and analysis, for instance (Quist and Vergragt, 2003). An overview of various forms of stakeholder analysis has been made by (Reed et al., 2009).
Stakeholder and process management tools and methods are tools and methods that are relevant for the overall backcasting approach and process, but are more specific, relevant for managing the project, shaping and maintaining the stakeholder networks and involving stakeholders (Quist and Vergragt, 2003).

2.2.2 Backcasting application on transport

Although the energy sector has always been the main field for backcasting studies, there has been a growing interest in the use of backcasting in the transport sector, mainly in western countries (See Appendix A.2). Backcasting found its use in the transport sector around the 2000s, following the diversification of backcasting as a method for transition management, with focus mainly lying in the Netherlands, Sweden and England (Roth and Kåberger, 2002) (Geurs and Van Wee, 2000) (Åkerman and Höjer, 2006) (Hickman and Banister, 2007) (MCDOWALL and EAMES, 2007). An important reason specifically mentioned by (Geurs and Van Wee, 2000) for using backcasting is that current transport policies were not enough to meet OECD goals. Similar to the energy sector, backcasting can thus be used as a transition management method to develop policies and raise knowledge. While backcasting has been used in a large number of case studies in western countries, it has seen only very limited use in the global south or in developing countries. A reason for this could be the lack of data available to be able to create accurate future scenarios. Only a single paper, by (Feng et al., 2010) has been published which used the city of Jabodetabek as a case study to examine future development of sustainable transportation in developing cities. Backcasting is definitely a suitable method to help assess this problem due to the trends being radically different from the envisioned future.

2.2.3 Variations of backcasting

There are a number of variations of the backcasting methodology developed, of which there are three variants that could be applicable to the research performed in this report.

- 1. Robinson's methodology; Robinson (1986)
- 2. Sustainable Technology Development (STD) methodology; Vergragt (2005)
- 3. Participative Backcasting; Quist (2006)

Robinson's Methodology

The approach proposed by Robinson marked the emergence of backcasting as a policy tool, although he emphasized its purpose was show the feasibility of different energy futures rather than provide proposals. A number of tools were described by Robinson that could be used in backcasting. His method forms the basis of the backcasting methodology used today and is given in the figure below.

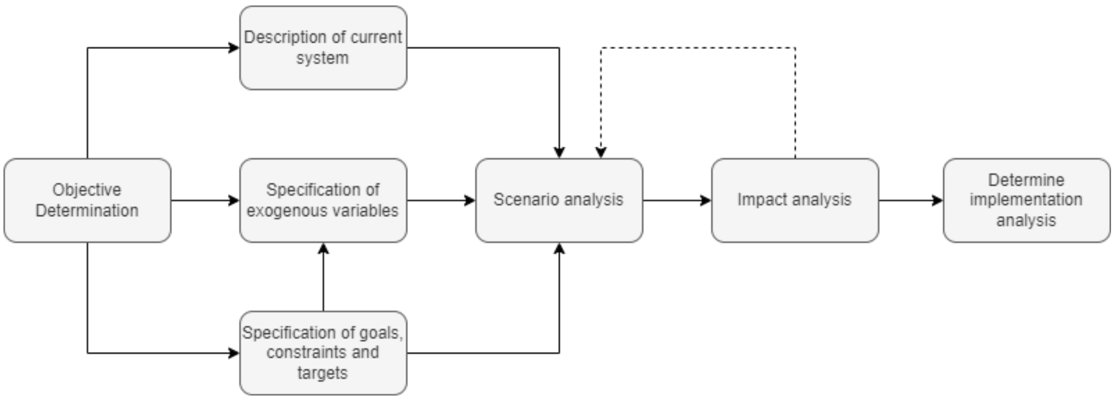


Figure 2: Robinson's methodology framework, adapted from Robinson (1982)

As Robinson originally intended for his approach to be used for backcasting on the energy sector, the approach is quantitative and descriptive. While this methodology could be used in the report, a number of adaptations would have to be made to make it more applicable to the situation presented in the introduction. It is also limited in the sense that it does not specifically involve the imput of actors from different sectors, something that could be important to consider in the situation presented in the introduction.

STD methodology

The STD program was a program used by the Dutch Government for sustainable technology development (Vergragt, 2005). It expands on the basic framework provided above in the manner provided in the figure below.

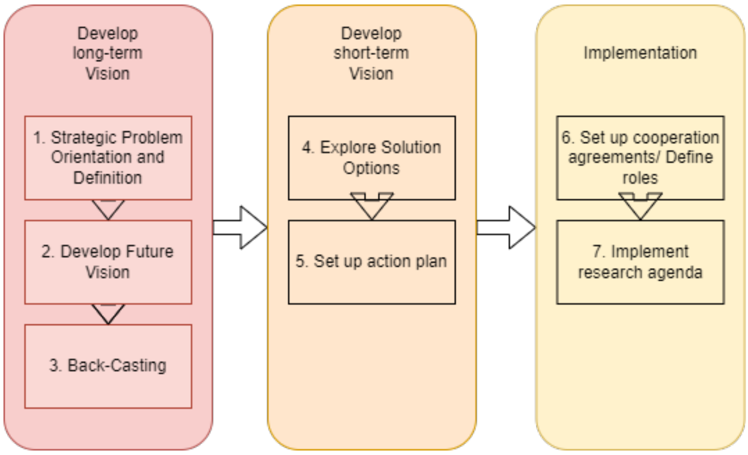


Figure 3: STD methodology framework, adapted from Vergragt, P.J. (2005)

The first three steps are for the formation of a long term vision which is discussed and elaborated on in steps 4 and 5, in which an action plan is established for execution of the vision developed. Finally, steps 6 and 7 are in regards to the implementation of the action plan, in which an agenda is formed and follow ups are planned. This methodology differs from Robinson's methodology in that it has a separate step for backcasting and is more focused on the setting of detailed actions and implementation of said actions. This methodology is more suited for a situation for which the problem is more clearly established and a solution- and implementation-oriented research should be carried out. This is far beyond the scope of this report, mainly due to lack of data, making this variation of backcasting less suitable here.

Participative backcasting
Participative backcasting is a variation of backcasting that places more emphasis on stakeholder interaction, and followed from the STD methodology (Quist and Vergragt, 2006). It involves the use of a number of tools as has been described earlier:

- Participatory tools and methods
- Design tools and methods
- Analytical tools and methods
- Stakeholder and process management tools and methods

Different tools can be used in different stages of the backcasting framework. While the framework in general follows the same lines as the Robinson's methodology, rather than having a future as a goal, the goal of a participative backcasting study can also include:

- Generation of normative options and interest
- Future visions or normative scenarios
- Follow-up agendas for involved stakeholders to reach desired futures
- Inter-stakeholder learning of options, consequences and opinions

As the nature of this report is more in the line of exploring the potential problem of reaching CO2 neutrality for the private transport sector by 2060, this variation is in line with the early steps of the participative backcasting approach. A full description of the methodology is given in the next section and summarized in Figure 5.

2.3 Research methodology used in this report

The participative backcasting structure as stated in the previous section was also the basic structure of the methodology that has been followed in this report. However, there were some changes made. Since the strategic problem orientation is based on the principle of an as previously defined pathway dependency, the strategic problem is not only constrained by natural parameters, but also by a large framework of stakeholders, of whom the acceptance of created policy packages is necessary for the success of the implementation of the sustainable transport technologies and thus achieve the normative goal stated. Expansion of this basic framework was therefore necessary to make sure the stakeholders were properly involved.

Making use of the synergistic nature of pathway dependency as a selector for the sustainable technologies that are being used, there is an emphasis on the properties of Java and Indonesia, the use they have in the future scenario, and the potential barriers that can arise from these properties. For this reason, strategic problem orientation is split into two separate steps, one for elaboration on the relevant properties and one on the direction of trends observed.

Although participatory or stakeholder backcasting would be a possible variation on the framework that could be used in this report, only limited interactions can be held with relevant actors and the scope of this report will be limited to only providing policy packages for implementation of sustainable energy technologies with possibility for a single iteration and implementation of feedback. This report has not included the analysis, implementation and follow-up of the generated policy packages as would be expected from a complete backcasting analysis. Higher stakeholder involvement than has been presented in the basic framework would be necessary in this case though, so the framework this report will follow to involve the stakeholders in the backcasting process was only somewhat participatory in nature.

Due to this report being one of the first in this field on such as scope (see Appendix A.2), and goals of this report was finding a set of sustainable transport technologies to be implemented and finding appropriate policies, this report has laid the groundwork for further research, identifying parameters and stakeholders, and has been mostly analytical in nature. Therefore, the fourth and fifth step of the basic framework for backcasting have been mostly left out.

However, to further elaborate on the to be discovered trends and potential solution, a pathway dependency analysis has been held on the potential technologies to be implemented. Including the exploration of a potential pathway dependency, the research methodology of this report has the following structure.

1. Strategic Problem Orientation based on properties and stakeholder interaction

In this step the problem to be analysed has been explored. First, the problem and its background has been briefly explained. This was explored in Chapter 3, Section 1. Second, the properties of the structure that made up the problem have been examined. This was done using the definition of pathway dependency; a pathway dependency or dependence is defined as "*the tendency of institutions or technologies to become committed to develop in certain ways as a result of their structural properties or their beliefs and values*", according to Britannica (Britannica, 2022). The 'structural properties, beliefs and values' have been used as a base to formulate the problem and Java's current trends. This was split into two parts.

First, the hard and soft parameters were explored, in terms of subjects relevant for the technologies to be implemented. These parameters gave baseline barriers and preliminary insights into the second part, which involves the stakeholders. The parameters that were examined here are the geography of Java, the natural resources available on the island, the demographics of the population of Java and the legislative framework. Although the demographics of the population of Java could only be explored to the degree of data of obtainable from literature/desk research, it should still give valuable insights into Java's trends and potential population barriers.

Second, the stakeholders involved with the transport sector were charted. These stakeholders were separated into 4 different groups, with each holding different stakes in the development and implementation of the technologies. These four groups were; Knowledge Institutions, Governments, Companies, Societal Organisations and Users. The way these parameters affect the development and implementation of the sustainable transport technologies can be seen in Figure 4. The relation between the different parameters and the stakeholders indicates the order in which they were analysed. The reason for these relations was further explored in Chapter 3. These two steps were done by desk research and provided the starting point from which the future visions could be established.

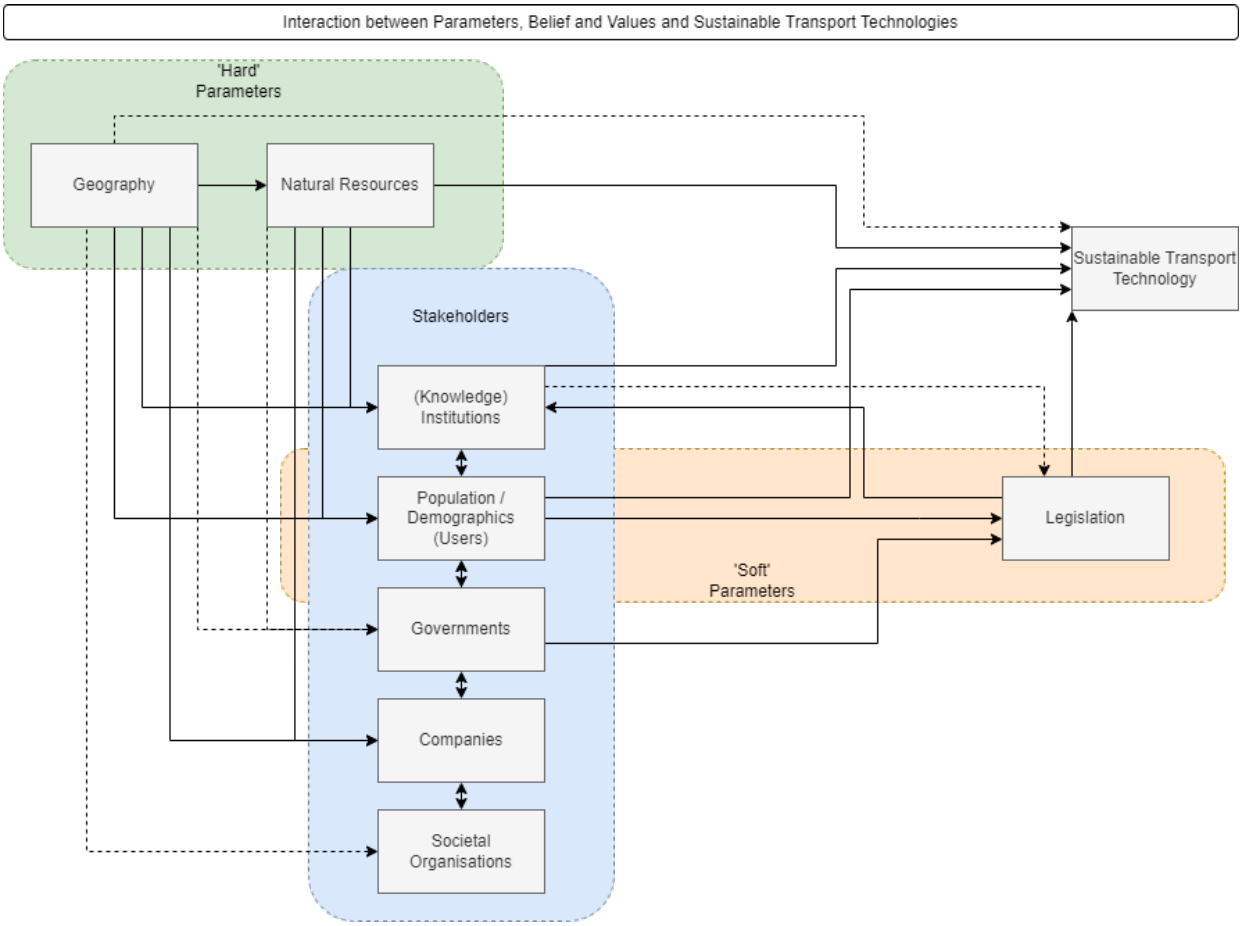


Figure 4: Interactions with the Sustainable Transport Technologies. Dotted lines indicate weaker interactions.

2. Establishing Trends and BAU scenario formation Using the properties found in the previous part, trends could be established which could be used to set a benchmark future in which no further changes were enacted. A BAU (business as usual) scenario was created, based on the trends found in the demographics of Java. This BAU scenario was made to indicate the severity of the problem if no proper solutions were to be provided. Based on the trends found, an indication could be made in regards to the selection of the technologies that could be chosen to help change the trajectory of the BAU scenario to a more favourable future.

3. Developing sustainable Future Visions

With the parameters established and trends highlighted, a number of future visions were established. Since the transport sector is a very complex system, there were some limitations on what can be explored and what not. There were a total of four sustainable different futures explored. First, three scenarios were created that focus solely on the implementation of a single form of sustainable transport technology, so called 'Mono technology scenarios'. These scenarios explored the effectiveness of each individual technology on their own, as well as the degree of difficulty of implementation of said technologies. Second, a single scenario that contains a mix of biofuel and EVs was explored. This final scenario illustrates a 'best guess' scenario of what mix of sustainable transport technologies is likely to succeed given Java's parameters. The technologies enabled in this scenario had been selected for using the path dependency analysis and the results from the previous three scenarios. These three sets of future scenarios gave a clear indication of in what manner the private transport sector should develop in, and whether or not a pathway dependency is present or not. Further research could then be done into qualitative future scenario creation, to determine the proper mix of technologies to be implemented.

4. Pathway construction and barrier exploration

With a number of future visions established, the pathway towards these futures now was created. Here, backcasting was used and a pathway that can reach the desired future was constructed, using the 'best-guess' scenario. A 'what-how-why' analysis was done in regards to fields of interests where actions would have to be taken. This was expressed in terms of 'what needs to be done' for the technology or technologies to be implemented followed by the question how this would be accomplished. This was explained in simple steps that could be further elaborated on. The pathway was split into short, intermediate and long term goals based on the different actions that would have to be taken for each goal.

5. Barrier Exploration
For the actions that had to be taken, potential barriers were considered, given the previously explored properties from the strategic problem orientation. The most pressing of these barriers were explored in-depth to highlight the complexity of the problem at hand. A solution was provided in the form of further steps of the backcasting policy tool, and a number of options will policy packages that can help mitigate the complex barriers presented were suggested.
At the hand of expert interviews, the existence of these barriers were validated and a number of potential solutions were discussed. These solutions formed the basis of further future participative backcasting workshops between different stakeholder groups.

2.4 Information Gathering

As this amount of interaction that could be done with stakeholders was very limited due to the remote nature of this report, information was mostly gathered using desk research. This was done in the following manner.

- For scientific sources, Google scholar was used to search for sources quantitatively and Scopus was used in tandem to qualitatively gauge said sources. Between sources cross referencing was used to find further qualitative information.
- For determination of trends, sites that display relevant statistics were used, such as Statista, GlobalData and WorldMeter.
- For the determination of parameters, such as products of export, sites that display these statistics were used, such as IEA and CIA factbooks.
- For evaluating of policies and steps to be taken, data and policies from organisations such as the World Bank Group, IEA, IAEA, OEC, International Road Federation, EIA and the Asian Development Bank were used.
- For legislation, stipulations, mandates and regulations archives were used, such as legalcentric.com and jdih.com, which archive legislative works.
- For evaluating potential trends that do not show in any other form of source used, news sites or their sources were used. In the case a news site was used as a source, a secondary source was also provided to counter potential bias from said source whenever possible.

Sources used were vetted before being added to this report to ensure a level of quality. In the case of scientific sources, care was taken to ensure up-to-date sources were used in this report. In case a vetted scientific source could not be found directly using methods provided above, regular google searches were used and results were searched for more scientific sources, which were then cited instead. In searching for specific results, or quotes, Boolean search terms were used, while for less specific search general terms were used.

2.5 Overview

A schematic overview of the steps taken in the methodological framework established in the report can be seen in Figure 5. From this point on, a normal backcasting study would go on to establish feedback cycles and perform qualitative analysis on the scenarios created and encourage stakeholders to participate in follow-up workshops. Due to the spread of topic that will be touched in this report, and the 'width' of the study, these steps will not be performed in this study.

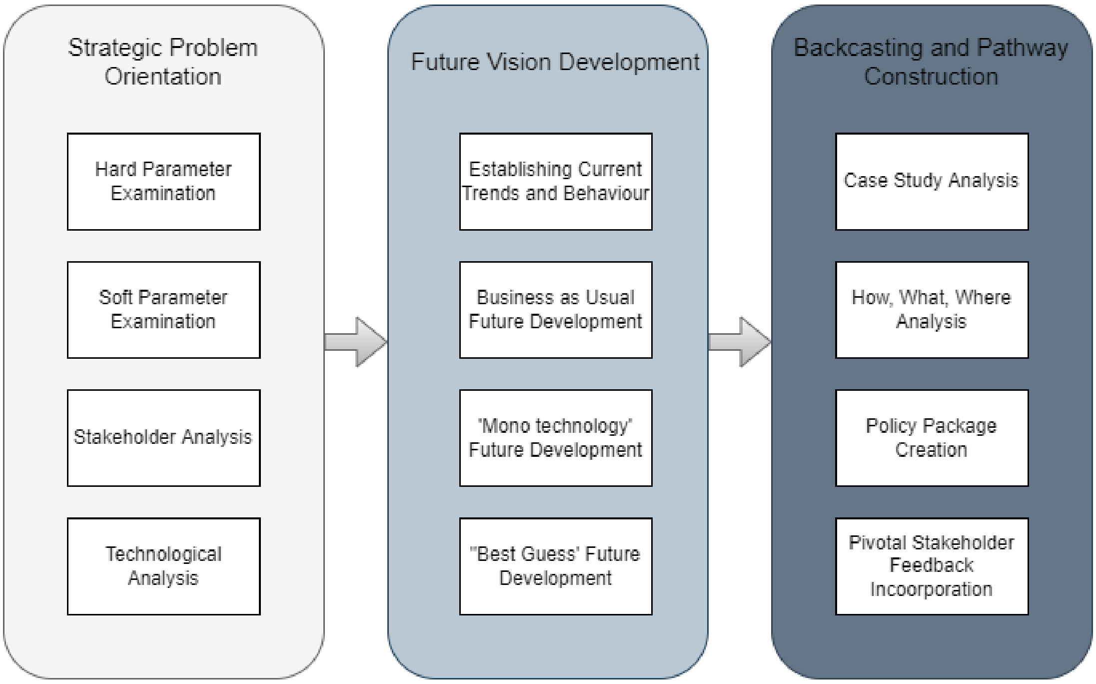


Figure 5: Simple schematic overview of the 3 steps done in this report, as a base for a backcasting study into sustainable transport technology policy packages and the main actions take per step.

3 Strategic Problem Orientation - Properties and Trends

Before backcasting can be used, enough data has to be gathered about the current situation in Indonesia and its trends. To do this, the elements that make up the problem, as well as the elements necessary to create future visions are explored. This is done at the hand of the pathway dependency definition, which has been elaborated on in Appendix A2. First, the various elements that make up the this problem will be hierarchically ordered. This is done to look at the relations between these elements, how they can be affected and how the promotion of certain technologies in favor of others, the pathway dependency, is produced from these relations. Next, to explore the elements of the problem, structural properties that affect the technologies to be implemented will be explored. These structural properties are divided into soft and hard properties, determined as given in Section 2.2. Next, a stakeholder analysis will be done to determine which actors play important roles in solving this problem. Finally, based on the structural properties and relevant stakeholders, an explanation of the current trends can be given, and the problem can properly explained. This will help visualize and explain the trends currently undergoing in Indonesia and set the basis for the creation of a BAU scenario.

3.1 Relation between elements

First, the elements present have to identified. Technology as an element is often defined as one of the factors influencing economic development. Generally, there are four items defined to describe economic development in. These are human resources, or insitutions, physical capital or wealth, natural resources and technology. If a relation between these can be established, it could be rearranged in terms of technology. There are many hypothesised linkages between the economic development of a country and the geography. A number of those are displayed below in Figures 6 and 7 below, described as previously done by McArthur and Sachs, Engerman and Sokoloff, and Acemoglu et al.

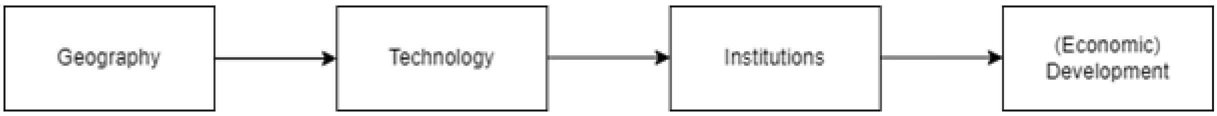


Figure 6: Linear linkage as presented by Engerman and Sokoloff. More rudimentary version provided by Acemoglu et al.

Figure 6 displays the effect of geography on the economic development as a linear linkage. The effect of economic development would then in turn affect the usage rate of private transportation.

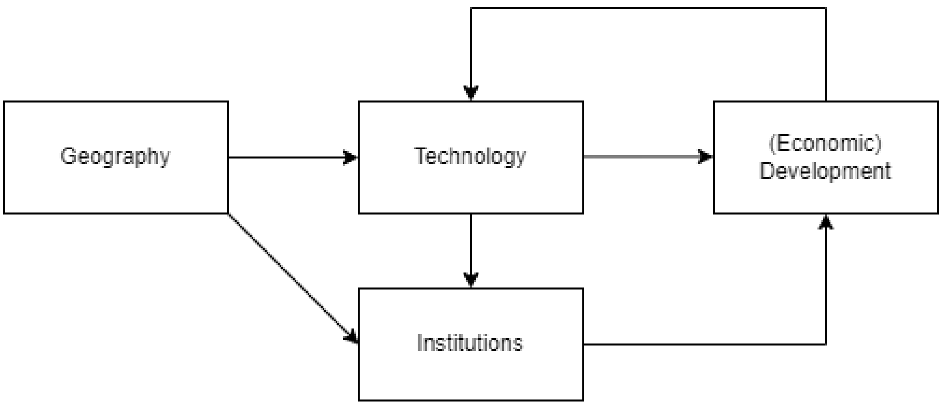


Figure 7: Linkage between Geography and (Economic) development as presented by Sachs (2001). More rudimentary version provided by Gallup et al.

Figure 7 displays the linkages between geography and economic development with internal feedback loops. Sachs and Gallup state that geography influences use and development of technology and institutions independent of each other, rather than linearly, although the development and use of technology does influence the development of institutions. The economic development in turn does affect the growth, development and use of technologies, creating a positive feedback loop. By reframing these linkages the relation in terms of technological development can be found. First, natural resources should exist in the same box as geography and the direct link between geography and technology can be decoupled or the direct influence of geography on technology can be decreased. Second, the institutions can be expanded on in terms of all relevant stakeholders present. Finally, the legislative framework should play an intermediate role between some of the stakeholders and the technological development. The reframed linkages are displayed in Figure 8 below.

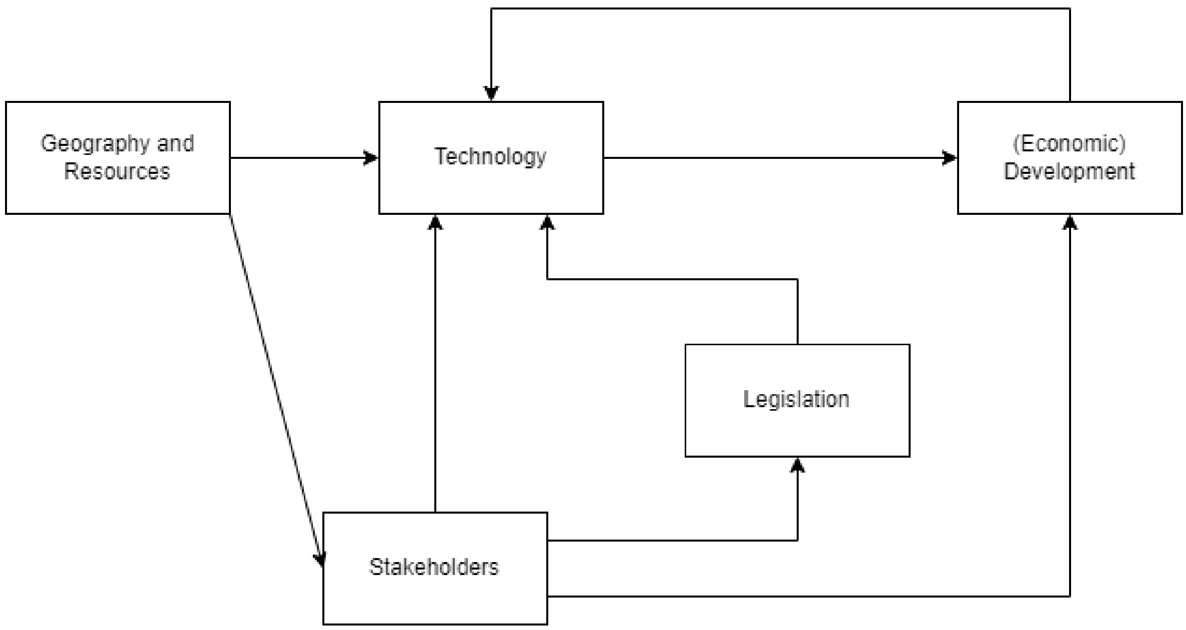


Figure 8: Reframed linkages between economic development, stakeholders geography, resources and technology

Finally, reframing technology in terms of (sustainable) technological development, decoupling the global linkages from stakeholder and legislation by determining individual stakeholders and distancing economical development from these relations allows for the relation to be reframed as has been displayed in Figure 4 in Chapter 2. The elements can then be divided into structural (hard and soft) properties and stakeholders, which will be elaborated on in the next sections. First, the 'hard' properties of the island of Java will be explored. These include the geography, natural resources and relevant infrastructure. Next, the 'soft' properties will be explored. These include the demographics and relevant legislation. For the demographics, their trends to the normative goal of 2060 will be highlighted. Finally, the beliefs and values of the island of Java will be explored in the form of a stakeholder map.

3.2 Hard Properties

As follows from the structure of linkages established in the previous section, Geography and resources form the first element, and will thus be explored first. It is important to get a good view on these properties as they have effect on the institutional basis of knowledge and technologies that have been developed so far and thus provide a base for how sustainable technologies should be implemented. The most basis of the barriers that can be presented to the implementation of renewable technologies, those caused by the environment or lack of materials, can also be highlighted this way. First, an overview will be given on the geography of Java and how this has affected the development of knowledge and the development of institutions. Next, a number of relevant resources to the problem will be explored. The relevancy of these resources is determined by the significance for export by Indonesia as well as their potential application for sustainable transport technologies.

3.2.1 Geography

The geography of a given area has effect on the knowledge being developed and spread as well as the technologies that can be utilized there. It has been repeatedly indicated that geography has a large effect on the economic development of a country due to effects of transportation costs and agricultural productivity to name a few (Gallup et al., 1998; Hall and Jones, 1999; Masters and Wiebe, 2000; Sachs, 2001; Engerman and Sokoloff, 1994; Acemoglu et al., 2001). It can be inferred that it also affects the population that can be sustained, with limiting effect due to the presence of international trade. Geography forms the bottom layer of properties that need to be investigated that have effect on the forms transportation used, as it, combined with the natural resources of a country, affect transportation and infrastructure as a whole. The island of Java is of volcanic origin, with a large number of extinct, sleeping and active volcanoes still present on the island today (Whitten et al., 1997b). This, in combination with its location near the equator results in the island being mostly covered in variations of the tropical climate, with regions of more dry savanna in the east of the island (Whitten et al., 1997a). The island has a tropical wet and dry season, with the wet season lasting from November to April, with the wettest months being January and February. Due to the island being of volcanic origin, there is a large variation in height on the island and the soil has been enriched with minerals due to the weathering of volcanic rock and the presence of volcanic ash (Cawsey and Mellon, 1983; KIMURA and SWINDALE, 1967; Saputro et al., 2022; Ugolini and Dahlgren, 2002). Some more isolated regions, ideal for rice cultivation, are among the richest in the world (Ricklefs, 1993). The effect of such rich soil in combination with a wet and dry seasonal climate could have led to a 'population explosion' between the 1800s and 1900s, instead of a number of different causes stated in previous literature (Peper, 1970). The effect of such rich soil on the infrastructure of the island and thus the development of the transport sector is that due to the population largely being able to provide for themselves, resulting in a limited need for large distance transport of food, thus providing little pressure on the development of infrastructure and transportation technology. The presence of plenty of local food markets or people being fully self-sustained leads to shortened supply chains that are both low cost and transparent to both consumers and producers (Schillhorn van Veen, 2005; Abrahams, 2010). The presence of rich soil and volcanic terrain also helped shape the location of settlements on the island of Java and in turn the development of infrastructure between these settlements. Below in Figure 9 and 10 the height above sea level, as well as the population density is displayed.

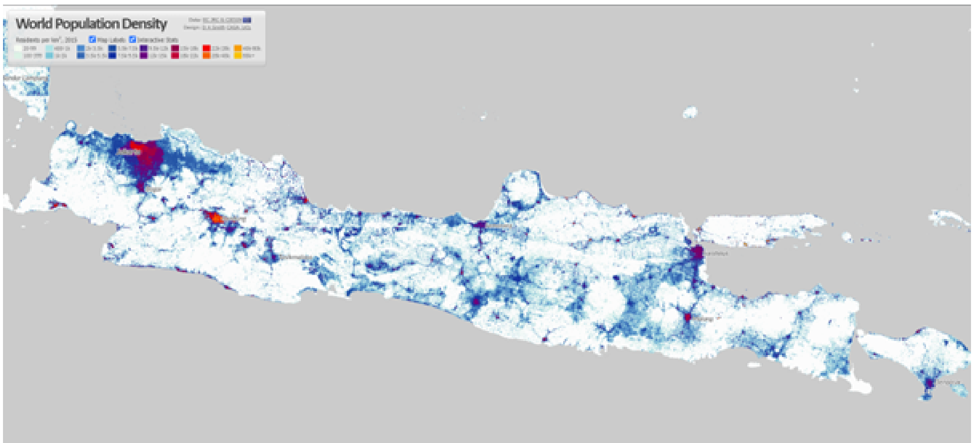


Figure 9: Population density of Java, Reproduced from luminocity3d.org, Data from EC JRC and CIESIN —Leaflet, Copyright by Carto

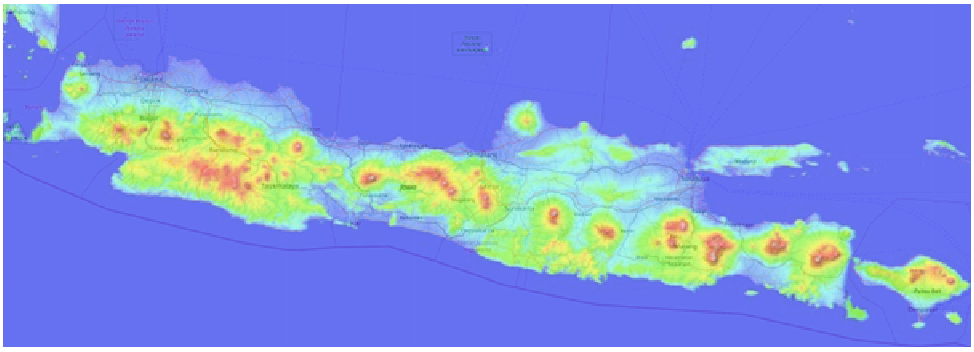


Figure 10: Topographical height map of Java, Reproduced from Topographic-map.com—Leaflet—OpenStreetMap—Merit DEM

With the single exception of the metropolis of Bandung, all the large metropolitan sprawls are located near coastal plains, mostly along the northern coast of the island. This logically follows from where the most rich soil is located, in alluvial valleys mostly near the coast and isolated mountain valleys. The other areas where the population density is large is near roads. This leads to the population mostly being located in large urban sprawls in alluvial valleys, connected by a spiderweb-like network of villages being located near roads. The geography of the island thus significantly impacts where the population of the island is located. More regarding the development of these urban sprawls in Section 3.2.2. Java also has significant solar irradiance, especially along the north-eastern coast east of Surabaya. These coasts receive up to 5.5 kWh/m2 daily, with the rest of the island receiving irradiation significant enough to warrant the use of PV (photovoltaics) to generate electricity. The solar irrandiance received on Java is visible in Figure 11 presented below. In comparison, Java does not have that much potential in the form of wind energy, with less than 10% of windiest areas having a potential over 135 W/m2 (at a height of 50 meters above ground. Most of this energy is either present far off-shore or on volcanic ridges. A map displaying the wind potential on Java is visible in Figure 12.

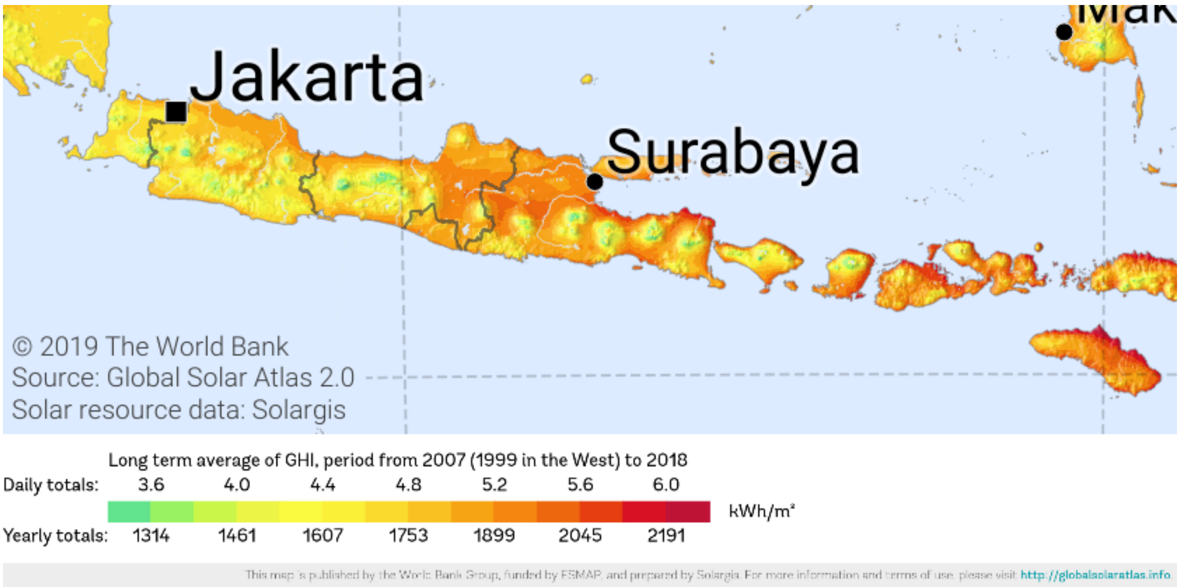


Figure 11: Solar irradiance on the island of Java, data reproduced from Solargis, Global Solar Atlas 2.0 and the World Bank.

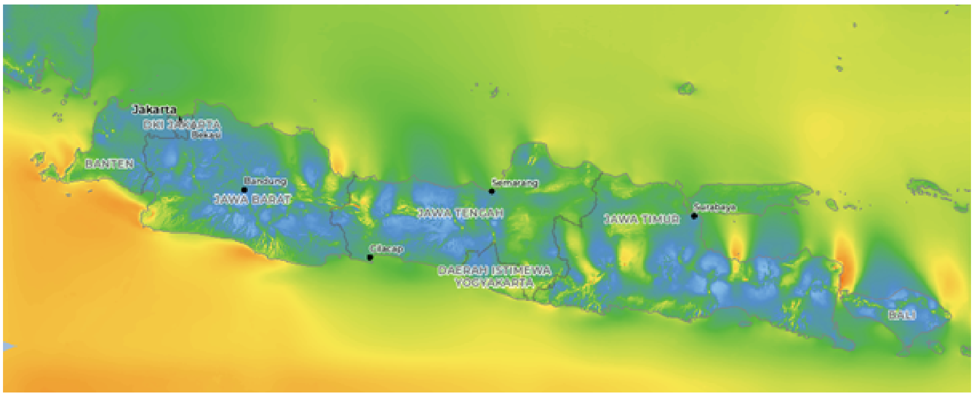


Figure 12: Wind potential of Java, green indicates a wind speed of 3.5-4 m/s or 90 W/m2, reproduced from GlobalWindAtlas 3.0—Leaflet—OpenStreetMap—nazka mapps

3.2.2 Resources

In this section, attention will be paid to the resources and institutions that have spawned from these that can in some way affect the development and use of sustainable private transportation. This includes both resources that can positively and negatively influence the development. There are two categories of resources that will be considered here. These two categories are geological (mineral) resources, which include ores, coal and oil, useable in either the production of private transport vehicles or production of fuel producing infrastructure and biological resources, which in this case refers to the production of crops that could be used in the production of biofuels.

The presence of (natural) resources in a given location will naturally lead to specialization of the local institutions towards those resources to allow proper utilization. While it could be argued that this also leads to increase of economic development, it is hard to judge this in an absolute sense, as the presence of certain natural resources might lead to the underdevelopment of other natural resources, a so-called 'Dutch Disease'. Other reasons why the presence of resources might not lead to an increase in economic development include the lack of relevant education, thus potentially leading to underdevelopment of the necessary institutions (Michaels, 2011; Gylfason, 2001).

According to the Observatory of Economic Complexity (EOC), palm oil (10%), coal briquettes (8.78%), gold (3.54%), petroleum gas (3.21%) and ferroalloys (2.66%) are Indonesia's top five export products by value (OEC, 2020b). This export value totalled at $179 billion in 2020. Gold won't be considered a relevant resource here because although it is used in fabrication of microchips, the amount needed is limited. Furthermore, the amount actually exported is relatively small compared to the other resources due to its high value to weight ratio. Another (set) of export products that can be considered is biomass products, which include plywood, uncoated paper and sulfate chemical woodpulp, which combine to around 3.3% of Indonesia's total exported value (OEC, 2020b).

Although petroleum gas is one of Indonesia's main exports, it does import a large amount of petroleum oils and distillates as well (5.31% of total import value). This is reflected in its natural resources, as Indonesia has more natural gas reserves than it does oil (WorldoMeter, 2017, 2016b). Other large sources of import include machinery and machine parts. The insights that can be gained from this are that while Indonesia consumes oil, it does not have a significant presence of oil-based and harvesting institutions, and is reliant on other countries for production of machinery and parts in a number of sectors (OEC, 2020b). This will be elaborated further on in Section 3.3. The resources that will be highlighted that are being produced in Indonesia are ferroalloys, coal, palm oil and biomass. Although a number of these resources are not located on Java, the presence of the resources in the country positively influence the spread of knowledge and the development of institutions throughout the country.

Geological Resource: Nickel

Nickel is one of the ingredients that will be used in the development of cheaper electric vehicles, as it can be used as layered oxide cathode in lithium-based batteries (Li et al., 2020). Ferronickel, as one of the various ferroalloys Indonesia is the world's largest producer of, is used to make stainless steel and heat resistant steel (OEC, 2020a; Crundwell et al., 2011). Most of the nickel produced in Indonesia comes from the island of

Sulawesi, where large deposits of laterite nickel are present (van der Ent et al., 2013). The use of nickel in cheap lithium-based batteries as well as the use of heat resistant ferronickel make nickel a key component in all three forms of sustainable transport technologies to be considered, in either the battery or engine. Although Indonesia produces a lot of nickel, most of this is either exported raw or exported in the form of one of various ferroalloys (OEC, 2020a; Worldstopexports, 2020). The 5 major mines in Indonesia are operated by Vale, a Brazilian mining company, Indonesia Asahan Aluminium, a state owned mining company, Yiwan Mining, a local mining company and Aquila nickel, under the Solway investment group, which operates on the Asera site (Mining Technology, 2020; GlobalData, 2022b; Inalum, 2022; PT. Yiwan Mining, 2012; Solway, 2017). Recently though, a change in legislation might stop the export of raw nickel products from Indonesia to help increase the value of domestic nickel production and to attract manufacturers to the country. This will be further evaluated in Section 3.2.3.

Geological Resource: Coal
Indonesia is the world's largest producer and exporter of coal by tonnage, although exports of coals have started to fall as of 2019 as production has been scaled back and recently Indonesia banned the export of coal due to shortages in its own supplies (IEA, 2020a; CEICData, 2020; Bloomberg, 2022; Skuld and Katsoula, 2022). Coal, and also more specifically, coke, has historically been used to generate electricity as well as for the creation of steel and various other ferroalloys (Strakhov et al., 1978; Gasik, 2013; Wright et al., 1991). Although it could be therefor considered useful as a product needed for the production of the materials necessary for the fabrication of private vehicles utilizing sustainable transport technologies, coal produces a lot of greenhouse gasses, which in the case of expanded material production would have to be mitigated in a 2060 scenario. There are a number of other technologies available that do not rely on the use of coal to produce ferroalloys, such as arc furnaces, which use electricity, or the use of hydrogen to produce steel from iron (Toulouevski and Zinurov, 2013; Åhman et al., 2018). Both of these serve as renewable fuel or feedstock which should be available in a sustainable scenario. The large availability of coal in Indonesia serves as a barrier to transition to a sustainable future as the cost of use and already developed institutions and infrastructure increase the competitiveness of coal in comparison to other renewables. To be able to reach 100% electrification of the country, it had to rely on coal. Which this might not directly affect the development, production and use of sustainable transport technologies, transport and energy are two very interlinked sectors, meaning that hindered progress in one sector might lead to hindered progress in another. Almost all of the large coal mines are located in the east and south of Kalimantan. The largest mines are operated by Adaro Energy and Indika Energy, two Indonesian energy companies, Banpu, a Thai energy company, Bumi Resources, Bayan Resources and Delta Dunia, three Indonesia mining companies (Statista, 2022a; Carmen, 2021; GlobalData, 2022a; PT. BUMI RESOURCES Tbk., 2022; Banpu, 2022; Adaro, 2022a; Indika Energy, 2022a; Pt. Bayan Resources, 2022; Delta Dunia, 2022). It is important to note that a number of producers of coal are also responsible for the production of electricity and the management of the electricity grid (Indika Energy, 2022b; Adaro, 2022b). This will become relevant in the stakeholder analysis

Biological Resource: Palm Oil
Palm oil is Indonesia's biggest product of export by value (OEC, 2020b). Palm oil is a versatile product as it is both an edible oil and is a potential raw biofuel material. In 2021, Indonesia produced a total of 46.2 million metric tons of palm oil (Statista, 2022d). With the world's total production of 75.5 million metric tons of palm oil, Indonesia is by far the largest producer of palm oil (Statista, 2022c). Production of palm oil mainly takes place on the islands of Kalimantan (both by Indonesia and Malaysia) and Sumatra. Palm oil in comparison to other vegetables has the highest yield per hectare, allowing it to enjoy a significant price advantage (Food and Agriculture Organization of the United Nations, 2020; Ourworldindata, 2018). Palm oil sees use in edible purposes mainly, with fuel and cosmetics as secondary use (Yeong et al., 2012). Indonesia has seen a steady growth in the production of palm oil, which aligns with a global increase in production and use of palm oil as well (Statista, 2022c; United States Department of Agriculture and Foreign Agricultural Service, 2021). Palm oil can provide an alternative to fossil fuels as a bio fuel, due to its good energy density and its chemical and physical properties being close to that of diesel (Ndayishimiye and Tazerout, 2011). However, use of palm oil as a biofuel might be limited due to its widespread use as an edible product. Furthermore, the expansion of palm oil plantations have to be done with care, as the replacing of rainforests with palm oil plantations results in significant decreases in biodiversity (Koh and Wilcove, 2008). Palm oil can be considered as one of the biofuel alternatives in Indonesia. This will be further expanded on in Section 3.4. The planting of palm oil plantations

in areas of pre-existing croplands or on grasslands also helps further carbon mitigation as replacing grasslands with palm oil trees increases that land's carbon fixation (Germer and Sauerborn, 2008). The palm oil market is a very splintered market with many actors. The production of palm oil is in the hands of three groups, private producers, large plantations and governmental related producers. The three largest producers of palm oil are PT. SMART Tbk., PT. Salim Ivomas Pratama Tbk. And PT. Astra Agro Lestari Tbk., all three Indonesian plantation and processing owners (ScienceAgri, 2022; Devex, 2022; Astra Agro Lestari, 2022; Pt. Salim Ivomas Pratama Tbk., 2022).

Biological Resource: Biomass

Raw biomass can be used to produce biofuels, biomass energy or produce value added products for use in industry (Famoso et al., 2020; Saha and Basak, 2020). In Indonesia specifically, due to exporting a number of biomass-related products, including plywood and uncoated paper, as well as producing a lot of agricultural products such as palm oil and rice, raw biomass is relatively easily obtainable (Anitha et al., 2015; Nukman and Sipahutar, 2015; Rahayu et al., 2018; Prastowo, 2015). Biofuels can be produced from biomass in a number of ways including gasification, pyrolysis and fermentation (Sikarwar et al., 2017; Jahirul et al., 2012; Rodionova et al., 2017; Sarkar et al., 2012). Difficulties in implementation of biofuel production from biomass remain mainly in the high processing costs required (Sarkar et al., 2012; Pradhan et al., 2018). The production of biofuels from biomass is one of the alternative fuels that will be considered as a technical alternative to fossil fuels. This will be further elaborated on in Section 3.4. APROBI (Asosiasi Produsen Biofuel Indonesia, Indonesia Biofuel Producer Association) is an Indonesian association of biofuel producers located in Jakarta. It has the goal to gather all biofuel companies in the industry, unite the business actors in the biofuel industry and be a partner to the Indonesian government, both local and national, to help develop policies to increase competitiveness of biofuels on the national and international market (APROBI, 2022; Climate Action, 2022).

3.3 Soft Properties

The second group of elements that will have to be explored is the soft properties which are the demographics, infrastructure and legislation of Java. These properties differ from the hard properties because they in part depend on the underlying hard properties for their development and interact with policies and technology on a much shorter timescale. First, the demographics on Java will be explored to help further explain the trends that will be explained in Section 3.5 and give a basic idea of the position the population of Java, as a user stakeholder would have in regards to the sustainable technology. Next, the infrastructure that is currently in use for the transport sector will be explored. This will give further insights in the relation between private vehicles, public transport and other forms of transport that make use of the infrastructure in place.

3.3.1 Demographics

The change in demographics, the increase in the middle class and the growing population of Java, is the main driver behind the increase in personal vehicles. In this section, more attention will be given to this middle class to observe trends and barriers. To do this, the income, type of work, and education will be looked at.

The middle class is defined by the World Bank as those who enjoy economic security, which means they are able to turn their disposable income toward other things than subsistence. This middle class comprises one in five of all Indonesians currently, and is growing still. It is expected that there are 143 million individuals in this middle class in 2050 (World Population Review, 2022; World Bank and Australian Government, 2019). Those that have security of income reach a threshold where risk-taking is more of an option and are able to explore other options of employment, like entrepreneurship (Banerjee and Newman, 1993). This makes the middle class a major driver for diversification of jobs and a driver for economic diversification, stability and growth (World Bank and Australian Government, 2019). In relation to the increase of the middle class, and the increase of the wealth of a majority of the population of Indonesia, the labour force is rapidly becoming more educated, with over 30 million secondary senior graduates and 10 million tertiary graduates. With government policies to provide universal access to senior secondary education through a compulsory 12 years of education, this amount is likely to increase (World Bank, 2014). However, this does not mean that the skilled labour gap in Indonesia is being filled. When surveyed, a large number of employers still finds it difficult to fill professional level positions, while lower-wage jobs, like sales, production and unskilled workers are relatively easy to find (di Gropello et al., 2011). [1] Those from the middle class and above are also capable of spending an increasingly larger share of their income on entertainment and durables, with car ownership being one of the key dividing factors between the upper-middle and lower classes (World Bank and Australian Government, 2019). The government revenues from taxes is significantly lower compared to other middle income and east Asian countries (World Bank and Australian Government, 2019). Increases in taxes would increase the government's ability to fund investments in infrastructure and education, although the majority of these taxes would be paid for by the middle class. The majority of the middle class is also situated in the urban agglomerations, with around two-thirds of that on Java. While the population density of this middle class as a result of its urbanization can lead to boosts in productivity and promote economic growth, it can also result in congestion, pollution and other negative externalities when not properly managed (World Bank and Australian Government, 2019). In reality, the latter outcomes are currently being realized, as will be discussed in the next section.

3.3.2 Infrastructure

With regards to nfrastructure, there are two parts that will be paid attention to, which can be further subdivided into two parts. These two parts are the fuelling infrastructure and the road infrastructure. The road infrastructure can be further divided into the actual roads vehicles can travel on and the rails. The fuelling infrastructure is divided into fuelling stations and production based on the sustainable technology that will be used. These are electric charging stations, biofuel stations and hydrogen stations.

[1] While this is a significant barrier: the mismatch between skilled workers and work, and could affect the development of institutions that are capable of handling sustainable transport technologies, in-depth policies for fixing this problem will not be provided in this report. The educational system, while having effect on the development of institutions, is too far away from the problem that is being solved here. This mismatch would however, make for a good subject for further research.

Roads

The roads on Java can be divided into three groups, tollways, paved highways and unpaved highways. Of the paved highways the national roads of Indonesia make up roughly 9% of the total length, but carry up to 40% of all traffic. Although public spending has increased over the years, this goes mostly to more expensive road development and preservation costs. The improvement of the national roads when held to an international standard and quality and speed of implementation of national road projects has been hampered by the highly decentralized nature of the Directorate General of Highways (DGH), the responsible managing body. An overview of the structure of governance of the national roads and expressways can be seen below in Figure 13.

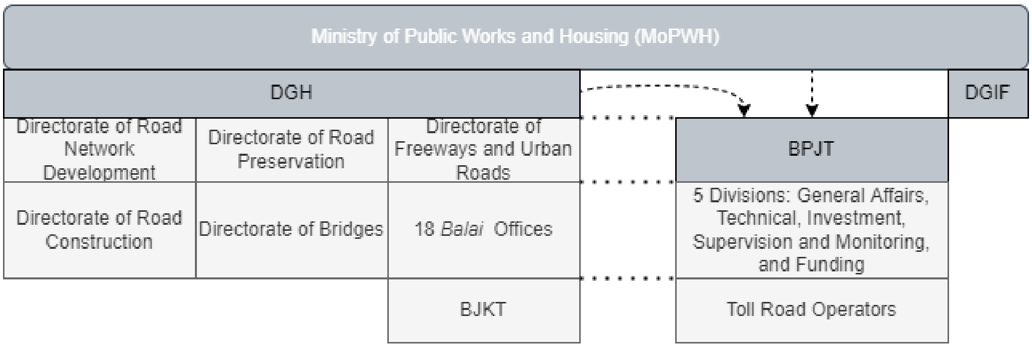


Figure 13: Institutional arrangement for the national road and expressways sectors, adapted from Chesheva, E. et al.

Furthermore, nearly two-thirds of all the kms travelled on the national roads is in slow or congested traffic (Chesheva et al., 2020). Data from the International Road Federation (IRF) from 2010-2015 shows that demand for road transport in Indonesia has been outpacing economic growth (International Road Federation, 2017). While the national roads are often judged to be in fairly good condition, this is often not the case for provincial and district roads, which on average are for 70% paved, and up to two-fifths are to be considered in bad or poor quality (Chesheva et al., 2020). The same goes for the urban roads, where traffic congestion is an issue due to the rapid urbanization of large agglomerations like the Jabodetabek (Jakarta, metropolitan area, which has been rated as having some of the world's worst traffic congestions (HumanCities, 2017). The districts and municipal governments themselves are responsible for the management of these roads, clarified in government regulation PP 25/2000 on responsibilities of central and regional governments (FAOLEX, 2000; Soesastro et al., 2003). The highly decentralized nature of governance here might lead to significant discrepancies between districts and municipalities. The sprawl of the larger urban conglomerates themselves also play a significant role here. Spatial growth in the largest cities on Java took place in the form of organic growth (densification), linear growth along roads and leapfrog growth, where built-up land emerged further away from the administrative boundary (Marwasta, 2019). Further effects from emergence of urban sprawl is the decrease of road planning, and with it efficiency and competitiveness of public transport (Camagni et al., 2002). Controversially, it also seems to have limited effect on the travel time of automobiles, increasing their competitiveness in comparison to public transport. The use of automobiles and other forms of motorized transport appears to be the preferred method of travel (Camagni et al., 2002; Burchell et al., 1998a,b). Finally, the tollways or expressways make up the smallest percentage of all the roads, totalling at 0.2% of the total length of all roads. These roads are generally the best managed roads, and are all paved (Chesheva et al., 2020). Under road law 13/1980, the ownership and management of the toll roads is the responsibility of the Indonesian central government. Although this responsibility was handed over to the Highway Corporation, under the road law 38/2004, which replaced 13/1980, the authorization was handed back to the government (Djohari and Australian Road Federation, 1992; PT. Jasa Marga, 2019). This Highway Corporation, PT. Jasa Marga, operates under a concession license from the government as a toll road operator and developer (PT. Jasa Marga, 2019). (Discuss BRT (rapid Bus transport)?)

Rails

The original railway network on Java was constructed by the Dutch during the colonial period, but was left in relatively poor condition after the Japanese occupation and the Indonesian War of Independence, with a number of railways being abandoned due to their poor state. A number of these railways are now the location of informal settlements (Rahmawati et al., 2020). After the war, while a number private railway companies existed, the railways were maintained by the government. The railways were officially nationalized fully in 1971, under the sole state-owned PT. Kereta Api (Persero) (Krishnamurti, 2004b). An overview of the structure of governance of the railway system can be seen below in Figure 14.

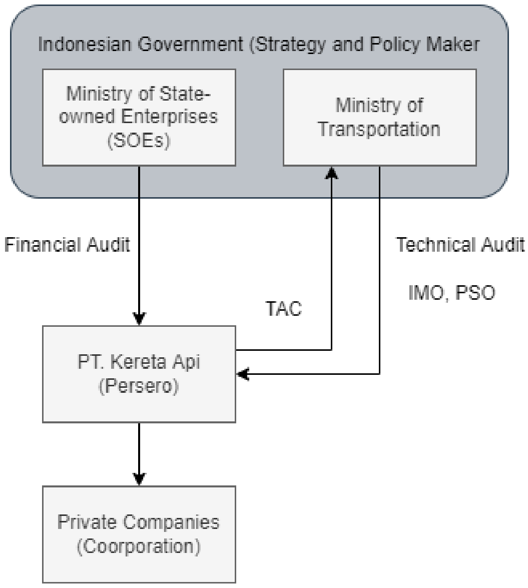


Figure 14: Governance Structure of the Railway system, adapted from Lubis, H.

This structure indicated how the state-owned railways responsibilities were shared, in accordance with the 13/1992 law on railways (Widyanto and Malkhama, 2013). Both the ministry of SOEs and the ministry held a responsibility on PT. Kereta Api (Persero), a financial and technical one respectively (Lubis and Nurullah, 2007). PT. Kereta Api (Persero) had a basis in funding in the form of the TAC, IMO and PSO, which stood for track access charge, infrastructure maintenance and operation cost and public service obligation respectively. However, in reality, this system of funding provided was not enough to maintain PT. Kereta Api (Persero), and additional funds were required (Lubis and Nurullah, 2007). The railways have since been slowly expanding onto previously abandoned railways. Electrification of the railways is a process that is still going underway, with almost 9% of all railways being electrified according to 2017 data from the International Union of Railways (UIC and International Union of Railways, 2019). Approximately 2700 kilometres of railways is still closed due to significant competition with road transportation (Lubis and Nurullah, 2007). Rail is a significant competitor to transport by road, although this is more so on the transport of goods rather than personal transport. On the front of personal transport, rail occupies the largest percentage of individuals transported, although from an absolute level, the amount of individuals transported is far smaller than those transported by road (Lubis et al., 2005). In regards to the transport of individuals, rail and road are mutually exclusive. Rails is therefore a direct competitor with road transport, and improvement of rail might lead to an increase in use of rail and thus a decrease in use of road (Lubis et al., 2005). Giving however that significant sections of the railway system in Indonesia are not yet electrified, this would result in increased use of heavy duty oils like diesel as a fuel for trains, thus an increase in greenhouse gas emissions (Krishnamurti, 2004a). Freight transport by trains is however the most cost efficient method of travel, meaning the railway system that is currently in place cannot be neglected in favour of a pure system of travel by roads (Forkenbrock, 2001).

Fuelling Stations and Production

Originally, the state-company PT. Pertamina had a monopoly on the retail oil and gas market, until the Indonesian government liberalized the market in 2004 (Goverment of Indonesia, 2004). PT. Pertamina still has by far the largest share of fuel stations in Indonesia, at over 5500 stations, with other significant vendors being AKR and Shell who own 133 and 111 stations respectively as of 2018, out of a total of little over 5800 stations (PT. Pertamina, 2019a; AKR Corporindo Retail, 2018; Shell Indonesia, 2020). PT. Pertamina is a state owned company that is responsible for a number of processing and handling steps of petrochemicals. An incomplete overview of the company and its subsidiaries can be found in Figure 15 below.

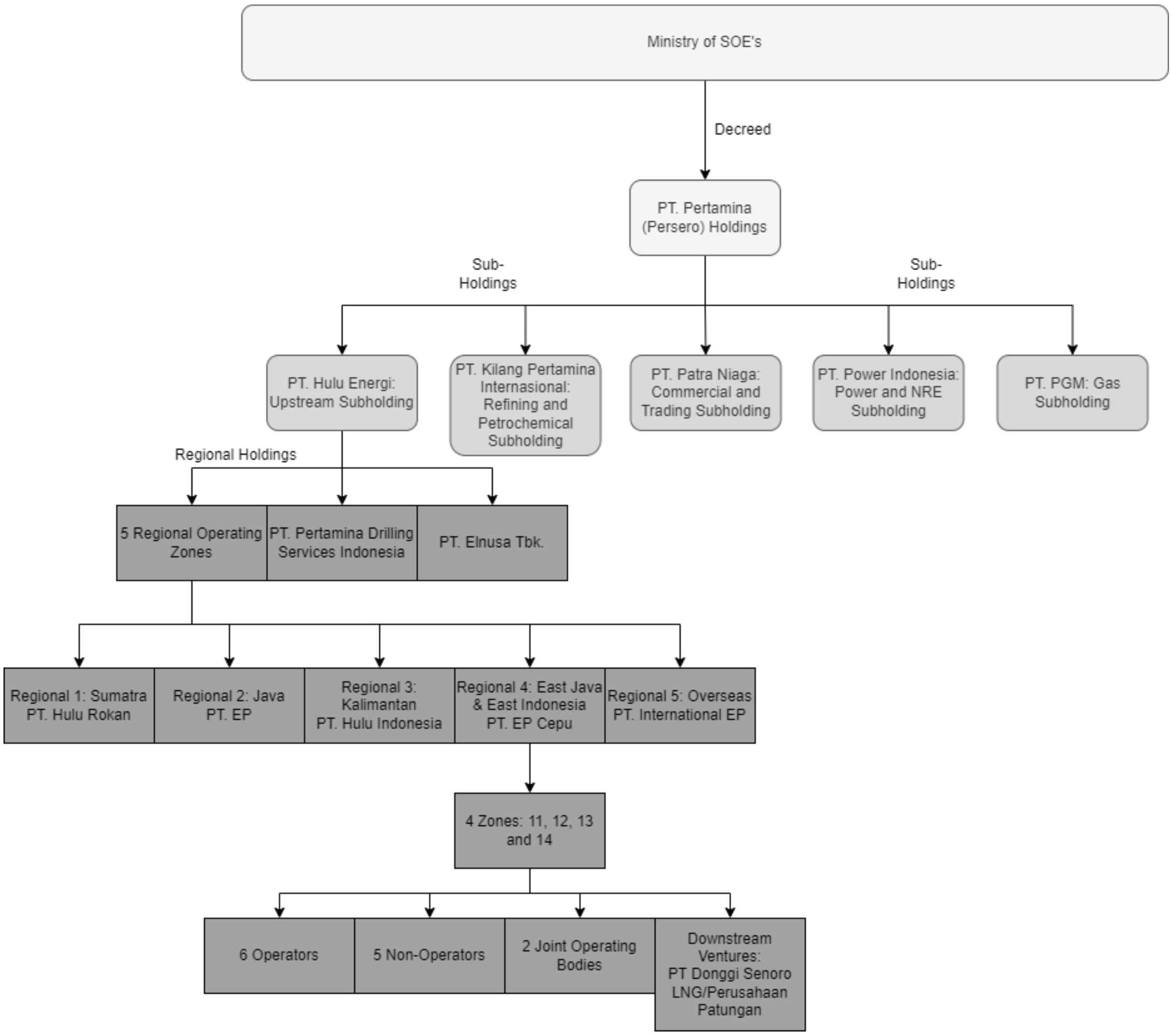


Figure 15: Simplified Governance Structure of Pertamina and its subsidiaries

PT. Hulu Energi is the main sub holding with its regional holdings responsible for exploration and production of gas and oil. PT. Elnusa Tbk. is responsible for processing and sale of oil and gas products. PT. Patra Niaga is responsible for trading services and industrial activities. PT. Power Indonesia is responsible for electricity services, maintenance, management and operation of power plants, either through a number of subsidiaries or joint ventures (PT. Pertamina Power Indonesia, 2022a) PT. PGM (Gas Negara) is responsible for oil and gas trading, gas transportation, processing, distribution and storage (PT. Pertamina, 2019b). PT. Pertamina sub holding Kilang Pertamina Internasional is the operator of the refineries in Indonesia, with 5 major refineries with a capacity of more than 100.000 barrels per day. Even so, a supply gap between domestic supply and demand has existed every year from 2014 to 2018 onwards, leading to significant fuel imports (Xie and Harjono, 2020). To fix the supply gap, PT. Pertamina has launched two initiatives, the Refinery Development Master Plan (RDMP) and the Grass Root Refinery initiative (GRR), which are aimed at revitalization of older and construction of new refineries respectively, with the government also stimulating private investment in refineries (PT. Pertamina, 2019c, 2017). However, with Indonesia's limited domestic limited oil reserves expected to be depleted as early as 2030, and current technology only being able to extract up to 40-50% of the total oil reserves, Indonesia will very quickly become reliant on oil imports unless it is able to shift away from its dependency on oil (The Jakarta post, 2018). One of the alternatives to oil is the use of biofuels, specifically palm oil biodiesel. Data from APROBI showed that biodiesel production significantly increased from 2013 to 2018. Government policy to substitute a part of the demand with biodiesel seems to have stabilized the deficit and lowered oil imports (Xie and Harjono, 2020). The government is subsidizing the higher cost of palm oil biodiesel using levies on the export of palm oil and palm oil products. As of 2018, the government mandated all diesel fuel at the pump to contain at least 20% (B20) biofuels and has a timeline to raise this to 30% (B30) in 2021 and 40% by 2022 (Christina, 2019; CNBC Indonesia, 2020). PT. Pertamina has said it would pilot 100% (B100) biodiesel production at its Cilacap converted biorefinery (Reuters, 2020).

EV Infrastructure

Compared to the amount of fossil fuelling stations available in Indonesia, EVCS (electric vehicle charging stations) are still in their infancy. A total of 219 units have been built, spread over 189 locations, as of the end of 2021 (AHK Indonesien, 2021). However, Indonesia plans to scale this to have 2500 charging stations built every year until by the end of 2030, to reach their goal of 25.000 EVCS nationwide, in line with their National Grand Energy Strategy (IDN Financials, 2021). More units are to be added by Indonesia's state-owned electricity company PT. Perusahaan Listrik Negara (PLN). Similarly, PT. Pertamina, the state-owned oil and gas company, has started to operate battery swapping stations at seven green public fuelling stations (Ramadhani, 2022). Furthermore, their subsidiary PT. Patra Niaga is preparing similar battery swapping services for electric motor vehicles (Pers, 2021). When it comes to production of EVs themselves, the government of Indonesia in collaboration with Hyundai Indonesia under the Hyundai Motor Group and LG Energy Solution ltd. has started construction on an EV battery cell plant in Kawarang, near Jakarta. The facility is expected to begin operation early 2024, and should produce up to 10-GWh worth of battery cells each year, enough to provide for 150.000 battery EVs (IDN Financials, 2021; Hyundai, 2021). The batteries being produced are new NMCA lithium-ion cells, which contain up to 90% nickel, and is considered a superior product compared to current, conventional NCA and NMC cells, boasting longer cycle life without deterioration and faster charge capability (Ramanathan, 2021; Kim et al., 2019). The nickel needed for the production of these cells can be sourced locally, as Indonesia is already a significant producer and exporter of nickel and nickel-based ferrometals, as stated in Section 3.2.2.

Hydrogen Infrastructure

Hydrogen has a number of uses not only as a transport fuel, but also as an energy carrier, feedstock and fuel in the industry. This makes hydrogen a more central product in an energy transition (Saputra and Jati, 2021). This will be further discussed in Section **??**. Currently, there exists no major hydrogen infrastructure on Java, however, there are a number of grassroot projects in development. PT. Pertamina, or rather, its holding company PT. Pertanima Power and New Renewable Energy (PNRE) is looking to invest up to 12 billion dollars in green and blue hydrogen investments (Nathan, 2021). Another company, the Marubeni Corporation, is looking to produce and transport hydrogen in metal hydrides from South Australia to be used as power or heat supply in industry on Java (Marubeni, 2021). Further cooperation between Australia and Indonesia to develop infrastructure and transport technologies for green and blue hydrogen are undergoing (FuelCellsWorks, 2021). Other than these projects, the hydrogen infrastructure in general, let alone the infrastructure for hydrogen use in the transport sector has yet to be developed to the degree the EV or biofuel sector has.

3.4 Stakeholder Analysis

The last element that will be inspected are the stakeholders. For any given project, there are a number of groups that have interests in that project. These are the stakeholders, and a number of them have already been identified in the last section. In this section, the relations of the stakeholder will be displayed, and the remaining stakeholders will be identified. These stakeholders can grouped into four different groups. These are the governments and government-related bodies, the companies and their subsidiaries, knowledge institutes and societal organisations and users. In Figure 16 below, the general interaction between the four groups is given.

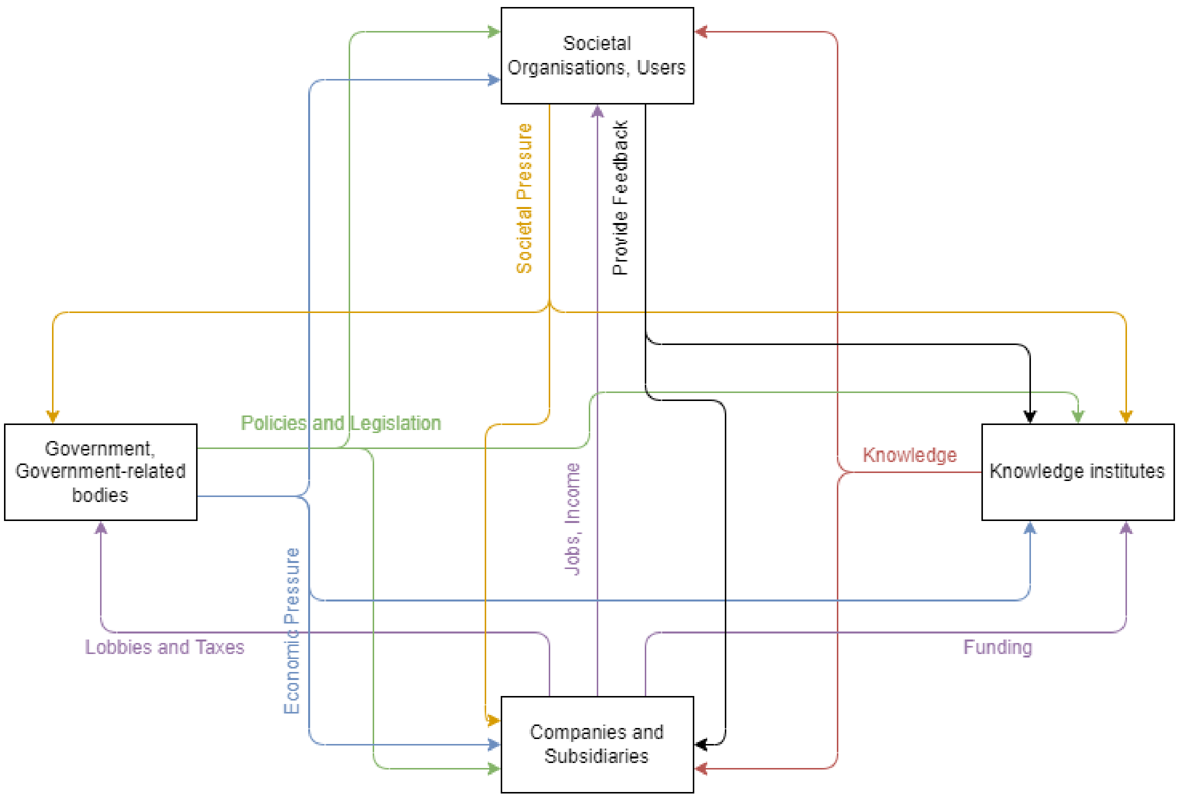


Figure 16: Expected relations and interactions between stakeholder groups

3.4.1 Government and Government-related Bodies

The governmental stakeholders are responsible for providing policies and legislation to the other groups, as well as provide economic pressure or leverage on the other groups in the form of funds provided. Local and municipal offices are also related to the government-related bodies, as the transport sector is a complex and large system. However, due to their sheer number only the larger, relevant overarching bodies will be mentioned.

The **Ministry of Environment and Forestry** (MOEF) is the governmental office in Indonesia responsible for the protection, preservation and utilization of the forests and forestry matters, as well as the national environmental policy and planning. It can be divided into the Ministry of Forestry (MOF) and the Ministry of the Environment (MOE). The MOE coordinates the policy construction, guidance and implementation, provides technical guidance and supervises environmental management. It also holds direct regulatory authority over hazardous waste disposal and management facilities (Sia-Toolbox, 2022).

The **Ministry of Energy and Mineral Resources** (MEMR) is the governmental office in Indonesia that manages the supply and production of energy and mineral resources. It is responsible for the formulation, technical guidance, supervision and provision of policies with regards to energy and mineral resources, as well as administrative and support and research and development. The MEMR has a wide range of responsibilities which are handed to a number of smaller bodies responsible for individual tasks. There are four main directorates under the MEMR that have such responsibilities. These are the directorate general of Mineral and Coal, Oil and Gas, Electricity and New Renewable Energy and Energy Conservation (Ministry of Energy and Mineral

Resources of Indonesia, 2022).

The **Ministry of State-Owned Enterprises** (MSOES) is the governmental office that regulates the state owned enterprises, which include the state owned oil and gas company, PT. Pertamina, the state owned electricity company, PT. PLN and state owned coal and mineral mining companies. The MSOES is responsible for formulating and determining policies as well as coordination and synchronisation of the implementation of said policies, in the field of sustainable growth of businesses and business development and infrastructure (Ministry of State-Owned Enterprises of Indonesia, 2022).

The **Ministry of Transportation** (MOT) Is the governmental office that is responsible for the governance and regulation of transportation in Indonesia. Its functions include the development, execution and supervision of execution of transportation policies and provision of support and supervision on a regional and national level. It also handles licensing of transportation businesses (Ministry of Transportation of Indonesia, 2022).

Other indirectly related governmental bodies include the **Ministry of Public Works**, under which the department of Electricity and Power and the department of Highways are organized, which are responsible for the management and development of electricity and roadway infrastructure (Indonesia Water Portal, 2022).

3.4.2 Companies and Subsidiaries

The companies and their subsidiaries are responsible for providing funds to knowledge institutes, provide jobs, income and goods to societal organisations and users and are source of income and influence on the government in the form of taxes and lobbies. A number of governmental owned companies, due to nationalisation of certain sectors like oil and gas and the rails are being closely tied between the company and government stakeholder groups, and will be mentioned in this group.

PT. Pertamina is Indonesia's state owned oil and gas company. It falls under the coordination of the MSOES, and holds a cooperation contract with the directorate general of Oil and Gas under the MEMR. Pertamina holds a number of petrochemical refineries and is the largest owner of petrol fuelling stations in Indonesia (PT. Pertamina Power Indonesia, 2022b; PT. Pertamina, 2019a). It has a large number of subsidiary companies that manage specific parts of the oil and gas exploitation, development and trade that Pertamina does (PT. Pertamina, 2019b). An overview of these subsidiaries was given in Section 3.3.2. Although it mainly handles fossil fuel related products, its cooperation is required in a sustainable energy transition, as a number of its subsidiaries control important relevant infrastructure.

APROBI is an Indonesian association of biofuel producers and sellers in Indonesia. The association includes two of the three biggest palm oil producers, PT. Smart and PT. Astra Agro Lestari via PT. Tanjung Sarana Lestari (APROBI, 2022). As a result of a decision mandated in decree 252.K/10/MEM/2020 by the MEMR, only the members of APROBI were allowed to distribute biofuels (Ministry of Energy and Mineral Resources of Indonesia, 2020a,b). If a biofuel based future were to be realized, APROBI would likely become a significant player. Further smaller producers of biofuels should also play a role, however.

Although the production and use of hydrogen is still rare, companies like **Marubeni** from Australia have started production and shipments of hydrogen for use in local industries in Indonesia (Marubeni, 2021). If hydrogen were to become more prevalent however, local production companies would still have to be set up.

A number of car manufacturers are present in Indonesia, and could play a role in the production of various types of battery or hydrogen-fuelled vehicles. Most of the car manufacturers present in Indonesia are of Japanese origin (**Daihatsu, Honda, Mitsubishi, Suzuki and Toyota**) and operate on a joint venture. **Hyundai** has already committed together with the Indonesian government and fellow Korean business **LG Energy Solutions** to the construction of a new battery production plant in Indonesia (Hyundai, 2021).

Further supporting industry in Indonesia is also present, providing raw materials for manufacture, as well as components and small parts. The shift from trading raw materials and their direct products to a more manufacture-based economy was presented in Indonesia's development plan 2015-2035 RIPIN, and will likely promote the supporting industry (Ministry of Industry of Indonesia, 2015).

A number of competing transportation companies are also relevant. **PT. Kereta Api** or PT. KAI, is Indonesia state owned railway company and is a direct competitor to road transport. The fares are directly paid to the government, in a scheme that can be seen in Section 3.3.2. Due to the limited development of the rails and the low electrification rate of the rails, increase in use of the rails would require significant changes to be made. Plans for this are in the making, however (BIRO KOMUNIKASI DAN INFORMASI PUBLIK, 2010). PT. operates under the MSOES, with evaluation of assets done by the MOT and financial audits under the Ministry of Finance (MOF) Alternatives are BRT or rapid bus transit, for instance the TransJakarta owned by **PT. Transportasi Jakarta**, which is a municipally owned company or taxi, motorcycle taxi, tuk-tuk and Bajaj operators (TransJakarta, 2022). These forms of transport fill the niches between public and private transport and could also play a significant role during a transition to more sustainable vehicle technologies. Finally, start-ups from local or international origin might be able to fill other niches or reach different aspects of the market. This includes start-ups like **SWAP**, an emerging company that handles electric motorcycles and has a battery-as-a-service model for handling them.

3.4.3 Knowledge Institutions

Knowledge institutions include universities as well as public and private research institutes and provide knowledge and technologies. They are also capable of providing the population with skills and knowledge, making them the primary knowledge spreaders. They require funds from either companies or governments to operate, and in return lend their knowledge and skills for these groups to use or develop technologies.

Universities make up a large section of this group. As Java is the wealthiest and most populated island in Indonesia, there are a large number of universities situated here. As of 2022, there are a total of 125 state universities in Indonesia, hosting 3.2 million students (Statista, 2022b). Notable technical universities on Java include the **Sepuluh Nopember Tech, Surabaya Electronic, Madura Polytechnic College, Gadjah Mada University and Bandung Institute of Technology**.

Local institutions include the **Indonesian Transporation Society** (MTI), which acts as a mediator. Its functions include advocacy services to transport decision makers, encouraging interactions between stakeholders to further quality of transport services and developing the professionalism of actors (Masyarakat Transportasi Indonesia (MTI), 2022). A number of these institutions are bound to universities, like the **Center of Transportation and Logistics Studies** (PUSTRAL), which is a research institution that operates under the Gadja Mada University (Center for Transportation and Logistics Studies, 2022).

A number of international developmental organisations and institutions can be included as well. Ones that have previously provided work done on Indonesia and their energy transition are mentioned here. **The World Bank** is an international organisation that provides funding and knowledge for developing countries. It provides policies, policy review and country analysis of various topics in Indonesia including demographics, infrastructure and economics (World Bank, 2022). **The International Institute for Sustainable Development** (IISD) is an international think tank focussed on development and informing of international policies on sustainable development governance, to promote human development and environmental sustainability (International Institute for Sustainable Development, 2022). Other institutions include the **Institute for Transportation and Development Policy** (ITDP), a non-profit organisation focused on development of BRT systems and promotion of walking or cycling and the **International Road Federation** (IRF), which develops knowledge resources, delivers advocacy services and education programs for the road and transport industry (Institute for Transportation and Development Policy, 2022; International Road Federation, 2022).

3.4.4 Societal Organisations and Users

Societal Organisations and Users include civil society organisations, non-government organisations (NGOs) and the general public, the users of the technology. They are capable of influencing the other groups through public opinion as well as their needs, expressed in broad terms as societal pressure. They can deliver feedback to companies and knowledge institutes on goods and services provided, and are in turn influenced by the policies provided by the government, knowledge generate and spread by the knowledge institutions and jobs and income generated by companies.

There is some overlap between societal organisations and knowledge institutions. A number of local institutions, like the MTI, although providing knowledge through advocacy services, can also act as a platform for the local community to mediate to larger stakeholders. Users are capable of influencing the other stakeholder groups by voicing their opinion in regards with their experience of the transport sector. In contrast, the users are often very reliant on the care of the knowledge institutes and governments in their belief of what is and is not good for them, as they lack the knowledge or ability to generate knowledge themselves. However, concerning the government in particular, it appears that the population, the users, only have limited influence on the decision making of the government. The government is often in control of nationalized companies which both, in turn fund the knowledge institutes. In this way, the government has in a very vertical structure significant control over the direction the development of the transport sector progresses in. Although awareness is raised and increasingly brought to light in regards to the effects of greenhouse gas emission on the climate and local and global environment, the population has limited paths to express their needs and concerns. There is a need for collaboration between stakeholders from different groups. As stated by Agus Taufik Mulyono (2019), *there is a need for a national transportation research forum institute, where stakeholders can discuss their needs and opinions on an equal level*.

3.5 Trends

From the exploration of the elements in the previous three sections, trends emerge. The increase in vehicles, and the lack of current options for mitigation of resulting increased greenhouse gas emissions can be explained at the hand of these trends. The most relevant trends are those in infrastructure and the development thereof, the demographics and economic development and the policies that are being implemented.

Infrastructure

The current trends are towards significant increases in the emission level of fossil fuels due to increasing amounts of private vehicle ownership, with only limited sustainable technological alternatives. Lack of alternatives in transportation options, like BRT or train, is hindered by the decisions made by the Indonesian government in transportation development, geography and demographics. Urban sprawl has led to decreased efficiency in travel time, cost and routing of BRT (Camagni et al., 2002; Burchell et al., 1998a). The rail network, which has originally been maintained by the Colonial Dutch regime, had to be sized down, with new expansions only occurring recently. Due to the overwhelming majority of transport being done by road, rails have a hard time competing (Lubis and Nurullah, 2007). Furthermore, new infrastructure that is being created is often done by the government or government-related bodies, and not designed and operated with profitability as a primary goal. This not only leads these projects to become stuck in a so-called 'subsidy trap', but also disincentivises the private sector from investing (Leung, 2016). The railways are a prime example of this.

Demographics

The amount of fossil fuels emitted by private vehicles can be correlated with the size of the middle and upper class, which have the wealth to be able to afford private vehicles. If it is assumed the size of this middle and upper class stay the same in relation to the total population, the amount of emissions can then be correlated to the population growth in Indonesia. As Indonesia shifts from an exporter of raw goods to one of produced goods, its industry will intensify and the average income will increase. This in combination with a growing population will shift a large section of the population to the middle class and will enable them to be able to purchase vehicles for private transport. The lack of infrastructure and competitiveness of sustainable alternatives will lead to a significant increase in the amount of vehicles burning fossil fuels on the road. This situation will to an increase in the amount of greenhouse gasses emitted in the future, and forms the basis of the BAU scenario. This scenario is explored in Section 4, and the calculations are done in Appendix B.1.

Policies

While trends may suggest that nothing is being done to prevent the increase in fossil fuel emissions, Indonesia has created a number of their own future scenarios and policies to be implemented to help further a renewable transition. There are three approaches that can be taken to that lead to a more sustainable transport sector. These are reducing impact of motor vehicles on the environment through improvements in efficiency and incorporating new technologies and low emission fuels, such as biofuels, enhance the transition to more sustainable motor vehicles use through a combination of restrictions on motor vehicle use and stimulations of sustainable transport activities, like walking, biking, car sharing and the use of public transport and reducing the need to travel via urban planning, use of communication technologies like work-at-home and mobility management (Xenias and Whitmarsh, 2013). Indonesia intends to stimulate at least two of these three approaches, in promoting public transport and incorporating biofuel into the fuel mix. These approaches have been outlined in the Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050) report (Ministry of Environment and Forestry of Indonesia, 2021a). In this report, a total of three strategies are outlined. A current policy scenario (CPOS), a transition scenario (TRNS) and a low carbon scenario that is compatible with the Paris Agreement (LCCP). All three scenarios consider only two sectors to include in the modelling of fossil fuel emissions: Agriculture, Forestry and Other Land Uses (AFOLU) and Energy. The Transport sector is not modelled in the scenarios considered by the Ministry of Environment and Forestry (KLHK) of Indonesia, who wrote the report. Furthermore, only the LCCP scenario succeeds in reducing the amount of net emissions of fossil fuels, mainly by reducing the use of coal in the energy sector, and by providing mitigation of emissions in the Forestry and Other Land Uses (FOLU) sectors. The potential effects of these three scenarios can be seen in Figure 17 below:

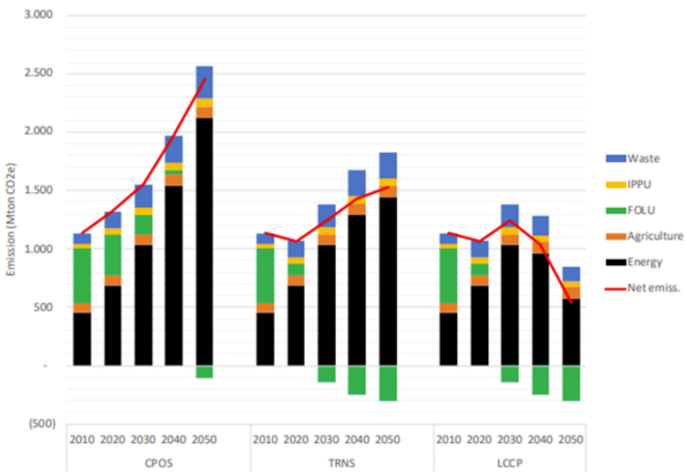


Figure 17: Fossil fuel emission trends according to the scenarios provided by the Ministry of Environment and Forestry of Indonesia

Previously implemented plans that did include the transport sector were plans like the NAMA sustainable transport plan (Presidential Regulation for a National Action Plan For Reducing Greenhouse Gas Emissions, in Bahasa Indonesia: 'Rencana Nasional Penurunan Emisi Gas Rumah Kaca' or "RAN-GRK"). The RAN-GRK was expected to be implemented between 2010 and 2020, and should have resulted in a 26% below BAU scenario greenhouse gas emission level or even 41% below BAU if adequate international support were to be provided. The objectives of this plan were to design plans and activities to reduce greenhouse gas emissions in a number of sectors, including the forestry, energy, transportation and industry sectors, as well as serve as a guidance on investment related to coordinated greenhouse gas emission reduction both at national and regional levels (Thamrin, 2011; Situmeang et al., 2012). Further policies that resulted from this plan, as well as the stakeholders involved, will be discussed in the respective Sections. The part of the RAN-GRK that was created for the transport sector, was the Sustainable Urban Transport Programme in Indonesia (SUTRI NAMA) plan. This NAMA Support Plan (NSP) aimed to prepare a large number of funding proposals for low-carbon transport projects. Furthermore, the NSP promised a number of quality of life improvements, such as better public transport services, reduced travel times and improved air quality (NAMA Facility, 2017; Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2014).
However, the success of the plan as of 2022 is hard to determine. One of the to be implemented policies was increase blending of diesel and gasoline with a mixture of biofuels. As almost all of the biofuels come from palm oil, the increase land use needed for this policy could have actually resulted in an increase of greenhouse gases (Kharina and Searle, 2016; Wijaya et al., 2017). Since Indonesia has since developed a new set of future scenarios to further decrease greenhouse gas emissions in the form of the Indonesia Intended Nationally Determined Contribution (INDC) in 2017, which outlined a plan to reduce greenhouse gas emissions to 29% below a 2030 BAU scenario, which in turn was later updated to a 2021 version to fall in line with the LTS-LCCR 2050, it can be argued that the effect the RAN-GRK plans had was limited (Wijaya et al., 2017; Ministry of Environment and Forestry of Indonesia, 2017, 2021b).
Indonesia therefor seems to be aware of the problem and creating plans and allocate funding to help solve the problem, but fails to reach their desired goals due to either difficulties in dealing with the carbon lock-in or not having significantly developed capable endemic institutions. The involvement of multiple ministries in the creation, development and management of policies and their implementation also leads to significant reduction in efficiency (Leung, 2016). As stated by Fabby Tumiwa, representing Indonesia in the Berlin Energy Transition Dialogue 2021, "*Indonesia still does not have a long-term strategy towards net-zero by 2050 yet. Even in 2050, it is projected that fossil energy will still dominate the national energy mix by 70%. Indonesia's current energy fulfilment strategy has not yet reflected an energy transition approach*" (Saputra and Jati, 2021).

3.6 The Problem

The trends help establish the problem as a whole. The problem that is present here is one that is shared worldwide. Global warming is an issue that is relevant to every person on Earth, although some countries and individuals would suffer more from the consequences than others. Indonesia is in the situation where it is both a significant contributor to current fossil fuel emissions, being one of the top ten emitters worldwide, and one of the countries that would suffer significantly from the consequences of global warming, due to its location near the equator and most of its population being coastal (WorldoMeter, 2019; IEA, 2021a; Eckstein et al., 2021; Buchholz, 2020; Envirotech, 2015). Although Indonesia has made claims of being able to reach emission neutrality by 2060, it appears to be struggling to create plans to reach this goal (ANDRIYANTO, 2021; Zheng, 2021; Climateactiontracker, 2021). Furthermore, Indonesia has a growing middle class, which is expected to reach 143 million in 2050, and is expected to peak somewhere around the 2060s (World Population Review, 2022). The growing demand of private vehicles is expected to rise in association with the growth of the middle class (Negara and Hidayat, 2021; Deng, 2007). This is because private vehicles are luxury goods, the use of which increases as the income increases. The transport sector is already the second largest contributor to the rise in TES of fossil fuels in Indonesia, and thus forms a significant sector that needs to undergo change for Indonesia to be able to reach its goals (Climate Transparency et al., 2020). Sustainable and renewable vehicle technologies could offer solutions to Indonesia to help mitigate the emission of fossil fuels from this growing sector. However, present economical and institutional systems make the implementation of these technologies, even if they offer economic advantages, nearly impossible. The presence of these systems has been described by Unruh (2000) as the 'carbon lock-in' (Unruh, 2000).
Stated in terms of the properties mentioned, Indonesia sees a significant increase in wealth and population, making larger combustion engine vehicles affordable for a larger group of people. This increase in the fleet of private vehicles will, due to the presence of economic and institutional systems, lead to an increase in fossil fuel emissions, as fossil fuels are still favoured. Transport alternatives are unlikely to offer solutions due to Indonesia's geography and infrastructure, as well as its handling of state owned companies. While Indonesia has created plans for a sustainable energy transition to 2060, transport does not appear to play an important role in this transition. Due to the structuring of Indonesia's stakeholders, it is the government that has to plan and act on its actions. However, Indonesia, unlike a number of other countries facing the same difficulties in achieving its goals, has its own endemic resources to be able to resolve its problems. Resolving these problems lies mostly in breaking the systems that keep the current situation in order. To be able to break these systems, and enable the spread of these technologies, policies are needed. Since the future that is desired is radically different from current trends, backcasting, a transition management tool, is used to create potential futures and the pathways to those futures. To be able to reach those futures in an efficiency manner while creating minimal negatives, policy packages are created.

There are a number of barriers and drivers to potential solutions, which will be explicitly stated here to sum up the results of the previous sections.

3.6.1 Barriers to solutions:

Developmental barriers

Economic development in Indonesia will likely accelerate when its economy shifts, worsening the already present development problems. These in turn could lead to significant barriers for the implementation of sustainable transport technologies.

- **Urban Sprawl** as a result of the growing population hinders efficient placement of infrastructure needed for sustainable transport technologies like hydrogen and EVs to function properly. It also decreases efficiency of (complimentary) public transport, can lead to increased travel time and increased pollution.
- **Road Maintenance** is already a problem which could become worse when the trend of maintaining and creating systems not based on the generation of profits results in warding off private investors. Tollways are already the best maintained type of roads, despite them comprising the least amount of road.

- **Transport Infrastructure Development**, like roads, is mostly not done with making a profit as a key point of interest. Warding away private investors and decreasing overall investment will slow down development of transport infrastructure, which already is being outpaced by economic growth.
- **Learning curves and electricity grid intensification** are likely to occur when EVs or hydrogen vehicles become part of a more sustainable and intermittent grid, based on renewable energy generation. Unlike coal, this system will be more intermittent, and require large loads as the overall electricity demand increases as the EVs fleet increases. Indonesia's system operators will need to learn how to handle the changes in the system.

Legislative and governmental barriers
A number of governmental and legislative issues could also lead to significant barriers for the implementation of sustainable transport technologies.

- **Planning and implementation** of current, but also potential sustainable transport technology infrastructure is hindered by the involvement of a large number of ministries and sometimes company subsidiaries. The lack of a streamlined body for the planning and implementation of infrastructure further adds to the slow infrastrucutural development.
- **The lack of a unified plan for transport** potentially explains the limited success of previously implemented plans. There seems to be multiple ministries that take some responsibility in creating plans for reducing CO2 emissions in the private transport sector. While this seems to be a good thing, there appears to be limited communication between these groups, resulting in limited implementation or reduced efficiency of the plans.
- **Differences between local, municipal and national administrations** and their financial situation further adds to the discrepancy of the development of infrastructure. Differences between ownership of infrastructure on local and municipal levels leads to different amounts of funds allocated and different development speeds. Financing of local projects is often still very dependent on allocation of funds from a national level.

Economic barriers
From an economic perspective, there are a couple of points that form barriers to the implementation of sustainable transport technologies as well.

- **The price of EVs and hydrogen-based vehicles** is currently often higher than that of conventional combustion vehicles. This is due to the manufacturing costs of the more expensive parts in the battery and fuel cell. The higher price of said vehicles de-incentivises their purchase, giving combustion vehicles an economic advantage. To compete with this, EVs and hydrogen-based vehicles would have to be produced locally.
- **The price of diesel** in Indonesia is currently much lower than in most of its south-east Asian neighbours. Although a large part of this is imported, the lower price of diesel propagates the use of combustion vehicles. This lower price is due to fuel subsidies in Indonesia to stimulate economic growth.
- **The widespread use of coal** to allow Indonesia to reach 100% electrification in the country means that current electric vehicles present in the country are likely not sustainable. The coal is locally sourced, making coal a much cheaper option for electricity generation than solar PV or wind.
- **Food vs feedstock** for palm oil is still a serious issue in Indonesia. Although palm oil trees have one of the highest oil per surface area yields, there is much more use in palm oil in the culinary sector. Palm oil is Indonesia's largest export by value.
- **Imports of refined petroleum** to supplement Indonesia small amount of local natural oil reserves makes it very reliant on other countries for its petroleum. This trade generates a trade deficit to other countries in times of high petroleum prices. Indonesia will have to stabilize its international trade as its economy transitions to be able to balance out the petroleum trade.

Geographic barriers

Finally, the inherent geography of Indonesia leads to some properties that also can form barriers to implementation.

- **The tropical environment** leads to increased costs of infrastructure maintenance during the monsoon season. With implementation of new sustainable technologies and infrastructure, a learning curve will have to be overcome to be able to maintain this infrastructure under these conditions.
- **Rainforests and peatland** are some of the terrains on which new palm oil plantations or PV electricity generation can't be placed, as the change in land use will lead to an increase of CO2 emissions in the short term.

3.6.2 Drivers to solutions:

Developmental barriers

- **Growth of average level of knowledge** is both a barrier and driver to solutions. While on one hand it raises the economic level of wealth of Indonesia, thus potentially increasing the number of private transport vehicles, it also helps with the generation of knowledge. For a number of technologies to be implemented, it is likely a level of knowledge will be required. The growth of knowledge among the population is therefor a driver for the implementation of these technologies.
- **Producing infrastructure for sustainable transport technologies** is already being constructed to some degree or is already in place, although not to the extent necessary to realize the 2060. There are already producing entities of biofuel to be used in the fuel mix and infrastructure for the production of batteries based on local material is already being set up.

Legislative and governmental barriers

- **The 2060 goals** set by Indonesia are in of themselves a driver for Indonesia to reach CO2 neutrality. Even if no concrete plans are in place, these goals give a clear indication of the will of the Indonesian government to strive towards CO2 neutrality in 2060.
- **A number of laws** already in place could help smooth the further progress of development and implementation of sustainable transport technologies. The Indonesian government has already mandated a minimum percentage of biofuel in the fuel mix. While this might not directly stimulate reductions in CO2 emissions, as the production of said biofuels might still be CO2 intensive, further mandates could enforce this. Further laws which indicate what or what cannot be defined as an BEV might help promote the production and introduction of BEVs to the greater Indonesian market.

Economic barriers

- **Changes in export economy** from the export of raw goods to one of manufactured goods is both a barrier and driver. On the one hand, this change will bring about longer local supply change, as it forces more specialisation. It will also increase the average level of wealth. These two factors will likely stimulate an increase in private transport vehicles. On the other hand, the changes in export economy might also given rise to the introduction of more stakeholders that will allow for the further development of sustainable transport technologies, either through knowledge sharing or through the availability of funds.
- **The price of diesel** is also a driver to shift away from the use of fossil fuels. Due to the reliance of importing fossil fuels in Indonesia, in the case of high international fuel prices, the total import cost rises dramatically.

Geographic barriers

- **The geographic location of Indonesia** along the equator makes it a suitable location for the generation of solar energy, which could drive the transition to more sustainable forms of energy, including in the transport sector. Furthermore, Indonesia is located along the Ring of Fire, which also gives it access to a more exotic form of renewable energy generation in the form of geothermal energy.

It should be noted that while there are significant barriers to the implementation of sustainable transport technologies, there exist drivers as well. However, the effect of these drivers is often a double-edged blade, and if not stimulated properly could further exacerbate the problem.
Using the established trends, a BAU scenario can now be created to help visualise the 2060 scenario in the case nothing is done to stop the current trends.

4 Strategic Problem Orientation - BAU Scenario

A BAU scenario can be established following the trends established in the previous chapter. The BAU scenario does not involve the use and implementation of any of the sustainable transport technologies. In this scenario, there is no effort made to mitigate the amount of greenhouse gasses produced by private vehicles, specifically cars. For the other scenarios, a range of expected increase in greenhouse gas emissions will have to be determined, to provide mitigation goals. Secondary effects of the trends that arise from the business as usual scenario will be highlighted. The calculations made to come to the results obtained here can be found in the next section. Two sets of calculations are made and are based on the projected growth of energy intensity of non-OECD countries the increased use of private automobiles as a result of the increase in population and shift from lower income classes to higher income classes. Assumptions per method are given and the results are briefly discussed. Using these calculations, a range on BAU emissions in 2060 can be established and a BAU scenario can be created.

4.1 BAU Scenario Calculations

The BAU scenario is based already established mandates by the Indonesian government currently in place, but does not implement any further measures. For further simplicity, it is assumed that the CO2 that is mitigated by biofuels can be canceled out by the CO2 generated from land change to produce the necessary palm oil and CO2 emitted from coal burning to produce the energy required to produce the biofuel. To figure out how much greenhouse gases will have to be mitigated in the other scenarios, this amount as a result of increases in private transport will have to be figured out. This is calculated in two ways.

First, the total amount of greenhouse gases projected to be emitted by the transport sector in 2060 can be determined from data from sources such as the IEA and EIA. Then, by determining the percentage of transport the private sector makes up, one can determine the amount of greenhouse gases emitted in 2060.

Second, the amount can be determined from the increase in population up to 2060, combined with the increase in the middle class. Estimates for the makeup of the population as well as the population growth are available via sources like the World Bank. As stated previously, it is mostly the middle class that reaches the monetary security capable of purchasing private vehicles. By multiplying the percentage increase of the population and the increase of the middle class with the amount of greenhouse gases emitted by the private transport sector currently, one can determine the amount of greenhouse gases emitted by the private transport sector in 2060.

First, the first method will be used to come to a rough estimate of the amount of greenhouse gases emitted in 2060, then the second method will be used to gauge the accuracy. After this has been done, the BAU scenario can be evaluated, to see if it is truly capable of mitigating this amount of greenhouse gases. It should be noted that this scenario is based on data for the whole of Indonesia, as there is no data available for specific locations only.

Fully elaboration, assumptions and calculations of the method used is given in Appendix

4.1.1 First Method:

Using data from the IEA a total of 150 MT of CO2 was emitted by Indonesia's transport sector in 2019 (IEA, 2019). Of this 150 MT of CO2, 45.1% is attributed to transport of individuals, which is given in the table 1 below (IEA, 2022).

Table 1: Emission distribution per transport form

Form of Transport	Road (passengers)	Road (freight)	Aviation	Shipping	Rail	Other
Percentage of emissions attributed	45.1%	29.4%	11.6%	10.6%	1%	2.2%

The road transport of passengers still includes the use of public transport, such as buses, but the per passenger CO2 emission efficiency of buses is much higher than that of private vehicles. Furthermore, the relatively high cost of taxis and lower popularity of public transport skew the proportion of public transport emissions to private transport emissions in favour of the private transport emissions. Therefor, the conservative assumption is made that 42% of land transport emissions are from private transport. Over 90% of all transport of individuals and freight in Indonesia happens by road currently, and due to limited investment into transport diversification it is assumed this will stay the same in 2060. This gives a total of 50.75% of emissions attributed to private land transport in 2060.

According to the EIA, non-OECD countries are expected to increase in carbon dioxide emissions from 23 billion MT (metric tons) in 2020 to about 32 billion MT in 2050. This estimation was based on a business-as-usual trend estimate, given known technology and technological and demographic trends, and indicates a roughly 1.1% increase in emissions per year (EIA, 2021). Applying this increase to the transport sector in Indonesia and extending the trend to 2060 will give 234.9 MT of CO2 emitted. This will give us the first estimate of the amount of CO2 that will have to be mitigated, based on expected emission increases from non-OECD countries, which is roughly 120 MT of CO2.

4.1.2 Second Method:

Economic wealth can also be used as an indication of the amount of vehicles present, and thus the amount of CO2 that would have to be mitigated. The World Bank divides the population into 5 different groups, based on their monthly per capita consumption. These five groups are poor (P), vulnerable (V), aspiring middle class (AM), middle class (which in itself is subdivided into lower (MC1) and upper middle class (MC2)) and upper class (U) (World Bank and Australian Government, 2019). The distribution is given in the table below. Data is given for 2016. The upper middle and upper class are in part defined by their level of car ownership. As the average economic level of Indonesia increases, more individuals are expected to enter these classes, thus increasing the number of private vehicles. The number of vehicles in 2060 can be represented by number of vehicles per 1000 individuals. The amount of cars and motorcycles owned in Indonesia are 60 and 450 per 1000 individuals in 2018 respectively (Adiatma et al., 2020). [2].

The average economic level in Indonesia is expected to increase as a result in change in export economy. By comparing current car ownership in Indonesia with countries which have the desired export economy, mainly western countries an estimation of the number of vehicles in Indonesia in 2060 can be made. This can be further reinforced by shifting the economic classes in Indonesia to ratio's observed in western countries.

Compared to China, which underwent an economic transformation sometimes called nothing short of a miracle, the private car ownership percentage went from less than 2.5% in 1985 to over 60% in 2005 (Deng, 2007). Although it is unlikely that this percentage will be reached in Indonesia, this percentage is similar to the car ownership percentage of the upper middle class. It is very likely that the income of all the classes will increase as Indonesia transitions its economy to a goods producing one. It is therefore assumed that the car ownership in Indonesia stays at an insignificant level for the poor and vulnerable groups, but increases to 10% for the aspiring middle class, 30% for the lower middle class, and remains at 60% for the upper middle class and 80% for the upper class, to be in line with more western car ownership. A comparison to car ownership is given in the table below.

Table 2: Car ownership in 2016 and 2060

Year/Class	P	V	AM	MC1	MC2	U
2016	<1%	1-2%	4-6%	22%	60%	80%
2060	<1%	4-6%	10%	30%	60%	80%

To determine the percentage of the population in each group, again a comparison is made to other, more developed countries. China in comparison has about 0.33% of the population in the poor class, over 50% in the upper class and the rest spread over the remaining classes according to the World Bank classification used above. Comparing Indonesia to western countries (including Japan, Malaysia and Singapore) would result in a upper class that makes up at least 60% of the total population, according to this classification (ChinaPower, 2022). Most western countries also have a car ownership rate of somewhere between 350 and 700 cars per 1000

[2]Adiatma's data is based mainly on the previously mentioned 14.8 million, which is data obtained from Indonesia's State Police, published on Badan Pusat Statistik, Adiatma likely correctly assumes that the actual number of privately owned vehicles is higher, with some not being accounted for by the ISP, thus resulting in a total of 16 million privately owned vehicles, this number will be used as a baseline in the calculations in the rest of this report

individuals (Eurostat, 2019). Shifting the population classes to be more in line with China in a potential 2060 scenario for Indonesia, the population distribution is given in the table below.

Table 3: Economic Class distribution and car ownership in 2060

Class	P	V	AM	M (MC1 + MC2)	U
Percentage of population (%)	<0%	1-2%	13%	60% (34% + 26%)	24%
Number of individuals (milion)	3	7	44	202 (114.6 + 87.4)	81
Number of cars (million)	0.03	0.28-0.42	4.4	86.82	64.8

The total amount of cars in 2060 using this population distribution is roughly 156.5 million cars in 2060. This increases the amount of cars per 1000 individuals in 2060 to 464, putting Indonesia in line with developed eastern countries like Malaysia, Bahrain and Qatar. Compared to the amount of cars in use in 2018, it is almost a tenfold increase in cars. If there is no increases made in efficiency of combustion, this would also result in a tenfold increase in greenhouse gas emissions. Using data obtained using the first method, the 16 million cars in 2018 are responsible for a total of 63 MT of CO2 emitted. In 2060, this amount would then increase to roughly 616 MT of CO2.

Table 4: Emissions based on number of cars in 2060

Year	Amount of cars (millions)	CO2 emitted (MT)
2018	16	63
2060	156.47	616.1

Assumptions of the first method:
To reach an amount of 120 MT of CO2 a large number of assumptions have to be made. First, it is assumed in a conservative estimate that the distribution of emission in the transport sector in Indonesia is equal to the distribution of individuals transported. This likely does not hold up to reality. Rails for instance, although a large share in Indonesia is not electrified, is likely more efficient in number of passengers transported per distance per amount of CO2 emitted. There is a significant change that the amount of transport emissions by land transport is a percentage larger than 90%, especially on Java.
Second, it is assumed that this share will continue to be the same in 2060. This claim is likely to hold due to the state of the rails and the infrastructure of the cities, making travel by rails or buses less favoured. Significant improvements would have to be made to both road planning in cities and rail infrastructure would rail or bus increase their share of passengers transported.
Third, the IEA attributed emission percentage of 45.1% for road transport of individuals. This is a global aggregate and is hard to extrapolate from since it also includes international freight, which is hard to attribute to a given country. The relation between the percentages can also widely vary on a country by country basis, based on the development of modes of transportation in a given country. The relation of 45.1% emission by passenger transport of the 74.5% total emission by road transport (or 60.5% of all road based transport emissions), is hard to evaluate especially. This is since in Indonesia the use of more efficient methods of transportation of freight specifically, rail and sea, are very underutilized. It might be that the amount of emissions attributed to transport of individuals based on the relation given is an overestimate.
Fourth, there is no reason for the emission attributed percentages as given by the IEA to be very different in 2060. However, given that is a business-as-usual scenario, it has been assumed that these percentages stay the same in 2060.
Fifth, the increase of emissions of non-OECD countries are also an aggregate number of all non-OECD countries, and the case for Indonesia is likely different. The increase in emissions is likely a conservative increase as Indonesia is in an ongoing transition towards a developed economy, resulting in increased energy intensification in both the industry and transportation sector, meaning that the actual increase in Indonesia in reality is likely higher.

Combined, the assumptions here have been made in such a way that the amount of CO2 emitted by the private transport sector is likely lower than in the actual BAU scenario.

Assumptions of the second method:

There are a number of assumptions that have to be made to reach 616 MT of CO2. First, the change in car ownership between 2016 and 2060 is a complete estimate. There is a large gap in data, where for car ownership for developing countries like Indonesia there is extremely little data, while developed (western countries) have plenty of data. There is also a disparity between development and car ownership. While a broad relation can be stated between increase of wealth of the population and increase in car ownership of the population, this relation is dependent on a far larger number of factors. It is unclear whether this assumption is fair to make based on other countries' data, but it helps provide a ballpark figure.

Second, the comparison of different wealth classes makes comparing countries very difficult. Here, compared to other countries, only the poor class and upper class are well defined. The spread of population in the middle classes is an aggregate estimation. The wealth classes selected by the World Bank give a good distribution of the population, and there are clear indicators present, such as car ownership, that separate these classes. However, these classes cannot be compared to western countries, or even most other Asian countries. The spread of wealth in these classes would put a far larger part of the population in the upper class than would be the case for Indonesia. However, of the people in the classes aspiring middle class and middle class, the income translates to $3.3 to $38 daily. This would put most of this group below the upper middle income poverty income line (World Bank Group, 2020). It can be expected that a significant portion would raise above this standard however, to become more in line with more 'western' east-asian countries. The degree to which this occurs is very hard to estimate, however.

Third, the vehicle ownership is scaled to become largely in line to what is expected of a current western country. It is unknown whether or not this will actually be the case. Although countries that have similar climate and culture (Singapore, Malaysia and Brunei) have a car ownership rate that is around or even above this 2060 number, their economic and demographic development has still been very different from that of Indonesia.

Fourth, this scenario does not assume changes in vehicle efficiency or changes in fuel composition. This results in a nearly tenfold increase of CO2 emissions. In reality, further improvements in vehicle efficiency, improvements in infrastructure, travel time optimization and phasing out of older vehicles would likely result in significant reductions of the estimated 2060 CO2 emissions. Changes in fuel composition, to lower the overall carbon content of the fuel would also have this result. However, gauging what this reduction would be is nearly impossible.

4.2 BAU Scenario

Based on the final 2060 values calculated in the previous section an over time development of the CO2 emissions from 2018 to 2060 can be established. The likely shape of such a development is likely to be a S curve, where initial and final growth is slow, with the most significant growth taking place somewhere in the middle. Although the curve could follow a different shape, the S curve is the more likely scenario as it better illustrates the adaptation of the growth market that is the middle class to private vehicles, which would reach saturation near 2060 as most individuals that are economically capable of purchasing a vehicle would have done so at this point. This growth is modelled after the expected growth predicted by the National Council on Climate Change of Indonesia for the period 2010-2025 and the NAMA prediction of vehicle growth for the period 2009-2030 (National Council on Climate Change of Indonesia, 2010; Situmeang et al., 2012). This would also follow the same historical precedent as the growth of motorcycles between 1980 and 2015 (IESR et al., 2020). These two predictions are graphed below. Note that these graphs include other forms of road transport as well, even though the main contribution to CO2 emissions is expected to come from cars.

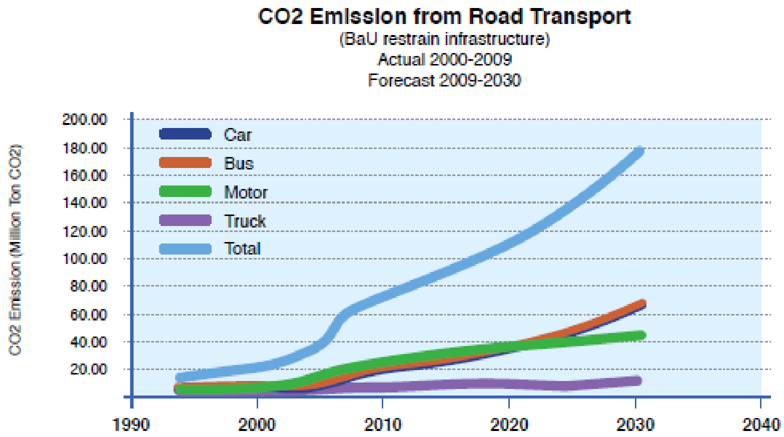


Figure 18: CO2 Growth, NAMA estimation for 2000 to 2030, adapted from Situmeang et al. (2012)

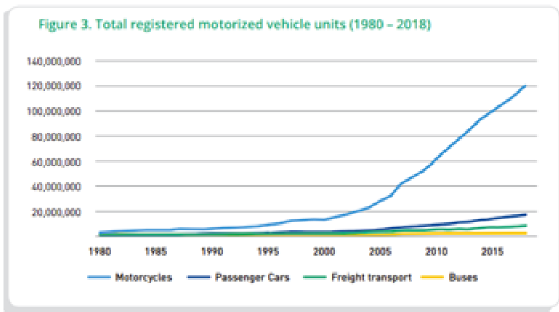


Figure 19: Historical motorcycle growth compared to other forms of private transport from 1980 to 2015, based on data from Badan Pusat Statistik, adapted from Adiatma for IESR, 2020

The predicted growth for the BAU scenario calculated using the two methods previously discussed is given below.

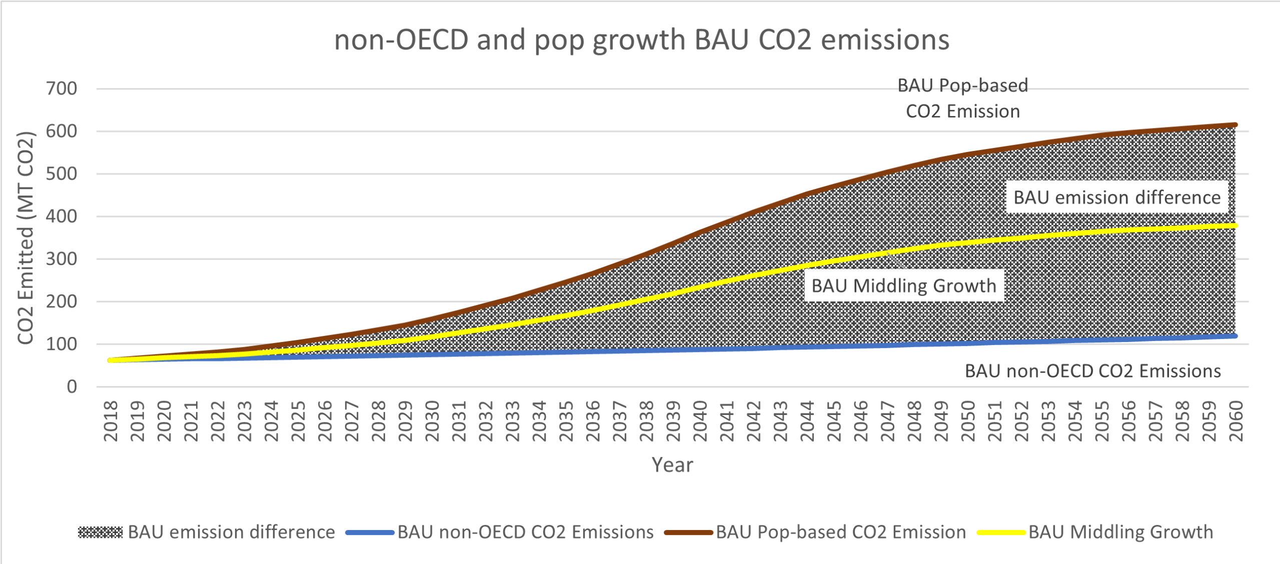


Figure 20: CO2 Growth estimations in a potential BAU scenario

The expected growth is divided into a spread between a low estimate (in blue) and a high estimate (in brown). The low estimate is based on projected growth of energy intensity of non-OECD countries and the high estimate is based on the increase in population and income shift. The highest estimate is modelled in both an exponential and s curve. A middling scenario is given (in yellow) which would represent a likely growth scenario if it is assumed that the low and high estimates are in reality actually low and high. The spread between the scenarios is indicated by the dotted area. There is significant spread between the population based growth and the non-OECD based growth. This spread indicates the uncertainty of the actual future use of cars, which would be the main producer of private transport CO2 emissions. The population based growth will be treated as a worst case BAU scenario and will be used to model the effectiveness of the sustainable transport technologies chosen.

It should be noted however, that the shape of the graph does not accurately match reality, and that the exact shape of the graph does not matter much for this study. The only relevant portions of the graph are the starting and ending values. The values are given explicitly in the table below. The CO2 emissions are purely based of the number of cars in this case. It should be noted that there are more types of vehicles that attribute to private vehicle CO2 emissions, such as motorcycles. However, the simplification is made to only include cars as the makeup of the private vehicle sector by vehicle type can also widely influence the total amount of CO2 being emitted. This point is further elaborated on in the Discussion.

Table 5: BAU Scenario Data

	Situation in 2018	2060 scenario non-OECD based growth (blue)	2060 scenario population based growth (brown)	2060 scenario middling estimate (yellow)
CO2 Emissions by private vehicles (MT CO2)	63	119.17	616.09	379.05
Amount of cars as private vehicles (million)	16	30.27	156.47	96.27
Amount of cars as private vehicles (per 1000 individuals)	60	90	464	286

The total amount of cars used for private transport are given as well, in millions of cars and in per 1000 individuals. The amount of cars per 1000 individuals gives a good comparison compared to other countries.

Even the upper bound scenario gives an amount of vehicles that is well within the range for modern western countries, of which the amount of cars per 1000 individuals ranges from 350 to 700 (Eurostat, 2019). The number of cars, in the population driven scenario does also somewhat reflect order of magnitude of current motorcycles present.

Scenario Drivers:
There are a number of factors that drive this scenario. The main driver behind this scenario is the carbon lock-in. There are a large number of technologies that are currently operating on fossil fuels, and switching them to another form of energy would be very expensive. Indonesia enjoys very cheap fossil fuel prices in comparison to other countries, making the switch to more renewable sources of fuel more difficult. This is exacerbated by the nation's ongoing fuel subsidies in an attempt to stimulate industrialisation and help the lower class.

Scenario Barriers:
There are significant barriers to the continuation of this scenario however. Indonesia as a country lacks large reserves of oil that can be used to make fuel. A significant portion of its fuel for vehicles is imported from abroad. Refined petroleum is Indonesia's biggest product of import by value (OEC, 2020b). This dependency on imported oil, combined with high prices of oil and lack of diversified products that can be exported in return, has led to significant trade deficits previously (CEICData, 2022; Statistics Indonesia and Badan Pusat Statistik, 2022). Indonesia is somewhat reliant on the export of coal and palm oil, its two largest export products, to make up for these trade deficits (Indonesia-Investments, 2022). While in the short term these deficits are sustainable, long term deficits are not sustainable and may have adverse consequences for the economy of Indonesia, including decreased domestic worker wages and currency depreciation (Tiwari, 2012; Harberger, 1950; Cooper, 1992). A diversification of fuel sources would therefore also be preferred to lower Indonesia's dependency on imports, and the potential effects of not having a sustainable trading environment. In a 2060 BAU scenario, these fuel imports would have to increase to a potentially unsustainable level.
The main barriers are the pledges made by the country to ensure decreases of greenhouse gas emissions. With the self-imposed goal of Indonesia being reaching carbon neutrality in 2060. While the main goal would be carbon neutrality in of itself, the harmful side-effects of fossil fuels are also adressed as a reason. Knock-on effects of carbon emissions include increased soot emissions, air pollution and effects on the public health in Indonesia's large cities.
These barriers in this future scenario will therefore mean that there is enough reason to make significant changes to the transport sector besides the environment. These changes are presented in the next scenarios, where the implementation of renewable technologies should help eliminate or mitigate the emission of the private transport sector to help Indonesia reach their 2060 goals.

5 Developing Future Visions

With the problem explained, trends evaluated and a BAU scenario created, the solution to the problem can now be orientated for. This solution comes in the form of multiple potential sustainable transport technologies. With these technologies, future scenarios can be established, and policy packages can be created to reach these futures. First, a brief technical overview will be given of the three sustainable transport technologies that will be considered for the future scenarios, biofuels, EVs and hydrogen. The strong points and weak points of each of these technologies will be briefly discussed, to highlight potential barriers and drivers inherent to the technologies.

5.1 Technical Overview

In the technical overview the strong and weak points of each sustainable transport technology will be given to highlight barriers inherent to the technologies. Attention will be paid to a number of factors that are important for the implementation of the technologies. These include intrinsic parameters such as cost, safety, reliability, lifetime, energy density, fuel source, range of operation and operational conditions and extrinsic parameters like needed infrastructure and required operational knowledge.
The three technologies are linked through the structure given in Figure 21 below.

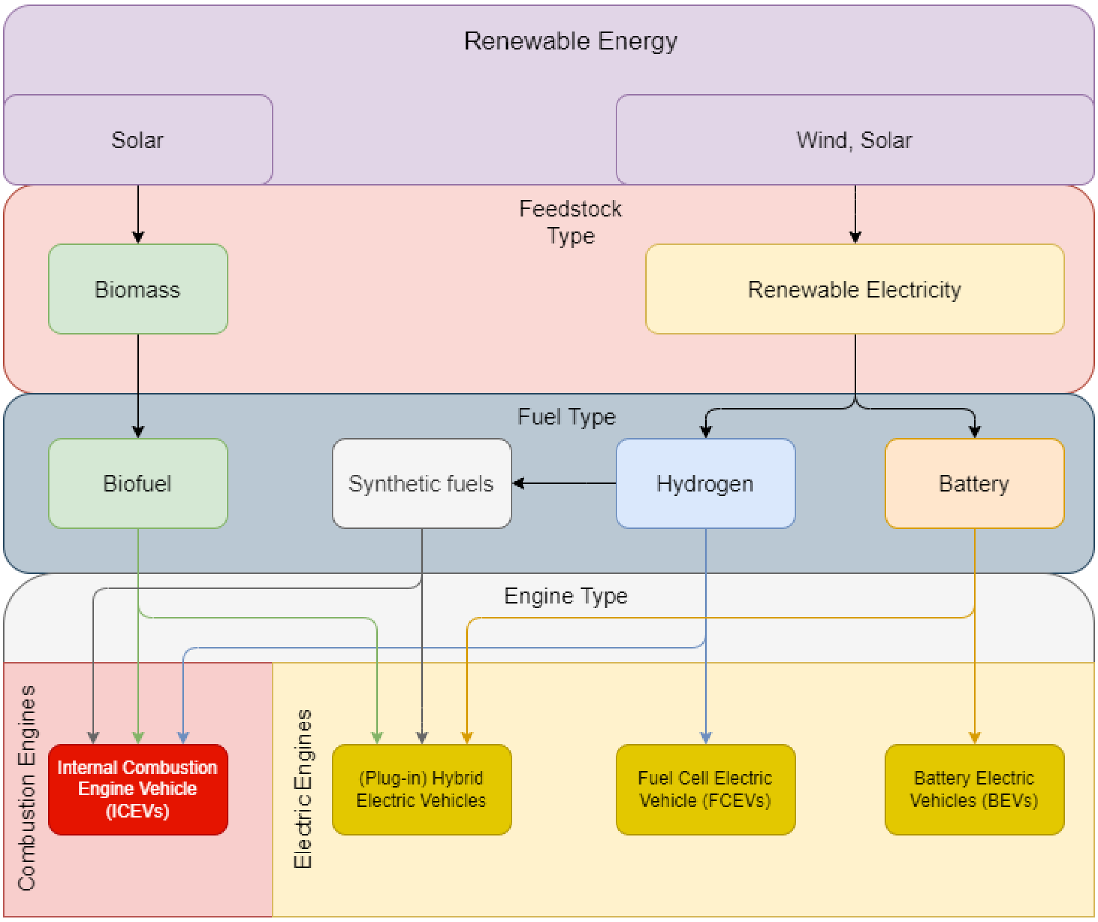


Figure 21: Relations between different fuel sources and engine types

5.1.1 Biofuels

Biofuels are arguably the most mature sustainable transport technology that has been developed thus far. Biofuels can be divided into three generations. These generations are defined by the feedstock that is used to produce the biofuel. For the first generation, this feedstock generally also sees use as food, or use in the culinary industry (Hirani et al., 2018; Havlík et al., 2011). Examples of this feedstock are corn and palm oil, for instance. For the second generation, the feedstock are materials that generally compete with food for land, but see no direct use as food or in the culinary industry (Hirani et al., 2018; Havlík et al., 2011). Examples of this feedstock are wood or wood waste, organic waste, food waste and biomass-specific produced crops (Karmee, 2016; Cesprini et al., 2020; de Jesus Martínez-Roldán and Ibarra-Berumen, 2019). For the third generation, the feedstock comes from sources that do not interfere with the production of food crops (Peng et al., 2020). Examples of this feedstock include algae. There are a number of barriers that are specific to each generation of biofuel.

Broadly, there are two types of biofuel that can be produced from biomass that are very suitable for use in vehicles. These are bio-ethanol and bio-diesel. However, the production of biofuels is not limited to these two forms (Demirbas, 2008). Bio-ethanol production is the more mature of the two and is produced using older more mature production methods like fermentation and distillation of biomass that has a high sugar or starch content (Mojovic et al., 2009; Mohd Azhar et al., 2017). Bio-diesel is produced from fatty acids in plant oils or animal fats using transesterification (Fukuda et al., 2001).

Pros:

Biofuels generally burn cleaner than fossil fuels and produce less greenhouse gasses and particulate matter, lowering the pollution in large urban sprawls like those present on Java (Tran et al., 2012; Altarazi et al., 2022). Biofuels, particulary biodiesel is chemically and physically similar to regular diesel, which means that for the vehicles the same transportation infrastructure and vehicle can be used. Apart from the production of biofuels, this means the same safety standards, lifetime, range of operation, reliability and operational knowledge can be assumed. Biofuels, particularly second and third generation biofuels can be produced using feedstocks which otherwise would have been considered waste, like food and agricultural waste (Hirani et al., 2018). Third generation biofuels can be produced on terrain that is unsuitable for the production of other agricultural products, as it does not rely on the soil quality (Peng et al., 2020). Third generation biofuels also promise significantly higher yields per area than conventional first and second generation biofuels (Kröger and Müller-Langer, 2012). There are a large number of production methods and feedstocks available for the production of biofuels, meaning that production of biofuels can more easily be adapted to local conditions. Finally the cost competitiveness of production of biodiesel compared to regular diesel. In a future sustainable energy scenario, the energy needed to produce biodiesel is renewable, and around 85% of the cost of biodiesel comes from the cost of feedstock (Meira et al., 2015). In comparison, the cost of diesel is a composite of the cost of raw oil, manufacturing costs and various taxes and revenue streams for producers, distributors and sellers (EIA, 2022). Given that raw oil is a finite resource, scarcity will drive up prices eventually, while the cost competitiveness of biodiesel can be increased by decreasing costs by for instance making use of integrated biorefineries (Harahap et al., 2019).

Cons:

First generation biofuels compete with food and cash crops for land. This is especially a problem when Indonesia is reliant on the export of palm oil for a significant part of its export value. The land needed for the large scale production of first and second generation biofuels is also high, as the yield is only between 500-5000 litres per hectare (FAO, 2008) [3]. Estimates of the total land use for biofuel production in future scenarios is given in Appendix B.2. For third generation biofuels barriers lie in the cost of production and the lack of proven results on large scales. While third generation biofuels could solve most of the problems of the first and second generation biofuels they are still very much unproven out of lab situations (Lam and Lee, 2012; Peng et al., 2020). Large scale production of third generation biofuels also still subject to scaling problems in providing enough nutrients for instance (Pate, 2013). The production of bio-diesel is done via transesterification of fatty acids in the feedstock. This process requires a secondary reagent, an alcohol and a catalyst to be preformed efficiently. The secondary reagent would need to be present in large amounts. For efficient conversion of palm oil for instance a ratio of 5:1 methanol to palm oil would be needed (Satya et al., 2019). For large scale production of bio-diesel a source of this reagent would also need to be found. Bio-ethanol has a significantly lower energy density than diesel, at 23-26 MJ/kg compared to 45.5 MJ/kg. One last issue with complete replacement of regular fossil fuels with biofuels is the higher oxygen content of biofuels, which results in a lower energy content and faster deterioration of fuel quality. Removal of the oxygen content is possible, but this is a costly process (Ko et al., 2012).

[3] Note that the numbers used here are both for bio-ethanol and bio-diesel, using different crops and the production method of biofuels is not disclosed.

5.1.2 EVs

After biofuels, battery electric vehicles (BEVs), here generalized to EVs are probably the most mature technology. Production and sale of EVs has increased significantly in western countries, and is likely to replace a large part of fossil fuel private vehicles. BEVs make use of an internal battery to store their fuel source, electricity, and use electric torque to propel themselves, instead of internal combustion. The use of electricity instead of other forms of fuel diverts most of the relevant properties away from the fuel and to the fuel infrastructure and construction of the vehicle. The battery plays a large role in determining the cost, reliability, lifetime, operational conditional and energy density. While there is a large number of battery variations available, each with their own set of parameters and corresponding pros and cons, in this case a battery that can be produced in Indonesia with local materials will be considered. As discussed in Chapter 3, Indonesia is rich in nickel, which can be used to produce cheap but reliable nickel-lithium batteries (van der Ent et al., 2013; Li et al., 2020). It is these batteries that will be considered to be used in the production of BEVs. In a sustainable future scenario, the electricity needed to fuel the vehicles will be produced entirely through renewable, carbon-free methods, such as solar PV and wind.

Pros:
Electricity is a very versatile fuel. It can be expected that in a sustainable energy future, electricity will be one of the main forms of energy carriers. Compared to internal combustion engine vehicles (ICEVs) using conventional fuels, electricity, especially generated from renewable resources, costs significantly less (Mitropoulos et al., 2017). (Levelized) Cost of electricity is almost purely determined by the variable cost of the generation method, which in the case of renewable energy from solar PV and wind is effectively zero (OEE Project, 2022). This allows for policymakers to set the price of electricity to a price competitive level or even a superior price level compared to conventional fuels. This price competitiveness extends to the vehicle as well. BEVs also provide mitigation for a intermittent energy generation system that is likely to be present in a sustainable energy future, providing storage in cases of excess energy produced. As BEVs use a different engine compared to ICEVs, the purchase of a different vehicle is needed for transitioning. While costs of purchase for ICEVs is currently lower, due to higher price of batteries and economies of scale, the operational costs of BEVs is lower. This is due to lower fuel costs as well as lower maintenance costs, which allow even BEVs with a lower operation radius to achieve cost parity with ICEVs in 5-8 years (Liu et al., 2021). The fuel source of BEVs, electricity, does not have any form of exhaust apart from generated heat. This means no greenhouse gasses, particulate matter or soot is produced. Specifically for the high nickel-lithium batteries that will be used, higher energy content while maintaining low costs of production are pursued (Li et al., 2020). Trends show an increase in gravimetric and volumetric energy density and decrease in battery pack costs over the years which is expected to continue at least in the near future (König et al., 2021). Finally, Indonesia's location near the equator in a tropical, sub-tropical environment leads to stable temperature ranges, which in turn could help the lifetimes of the batteries (Yuksel and Michalek, 2015).

Cons:
In terms of reliability and safety, while individual aspects of Li-ion batteries have been tested, no real concepts of reliability and safety exist yet for batteries, and a number of potential degradation mechanisms have yet to be tested for (Gandoman et al., 2019). The range of operation and energy density of batteries in BEVs is also lower than those of ICEVs. This makes BEVs currently more cost effective for short to medium range drivers (Hao et al., 2020). There are a number of cost barriers still present in enabling the widespread use of BEVs. The battery of a BEV determines a significant section of the cost of a vehicle, currently driving the cost of a BEV above that of a ICEV (König et al., 2021). The cost of providing enough EV infrastructure and intensification of the electric grid are also not insignificant. A similar barriers is present in the lack of experience in handling BEVs and maintaining the relevant infrastructure. This may result in a period of higher replacement costs of parts, vehicles and infrastructure.

5.1.3 Hydrogen

Vehicles running on hydrogen, like BEVs, use a fuel source produced purely from renewable energy and in theory are completely greenhouse gas free [4]. While there are broadly speaking two forms of hydrogen based vehicles, combustion vehicles and fuel cell vehicles, only fuel cell vehicles will be taken into account here due to superior efficiency. See Appendix B.4 for the discussion regarding this. Fuel cell vehicles operate an engine that uses the fuel, hydrogen and an oxidizer, oxygen, to produce electricity and water. Like with EVs, this electricity is then used to generate electric torque to propel the vehicle. There are a number of variations on fuel cells, but the two forms that will be considered here are alkaline fuel cells (AFCs) and proton exchange membrane fuel cells (PEMFCs). In general a fuel cell is composed of an anode, cathode and an electrolyte. A fuel cell works by allowing carrier ions to transport charge from the one to the other through the electrolyte, allowing for current to flow through an external circuit in the other direction. AFCs work by allowing the exchange of ions through an alkaline electrolyte to oxidized hydrogen to water, and produce electricity. AFCs operate at temperatures ranging from 60 to 90 degrees celsius and have an electrical efficiency of around 60%. PEMFCs work by formation of hydrogen ions from elemental hydrogen by the catalyst and transporting these ions through the cell to form water, generating an electric current (Mekhilef et al., 2012). PEMFCs have a higher electrical efficiency of 80% while operating at lower temperatures, ranging from 20 to 80 degrees Celsius (Shiva Kumar and Himabindu, 2019).

Pros:

Like electricity, hydrogen is a versatile fuel source. In a potential sustainable future, hydrogen will be a widespread feedstock and fuel in a number of processes, including cement, iron and steel, ammonia and a number of other chemicals and refining of hydrocarbon products (Nhuchhen et al., 2022; Vogl et al., 2018; Nicita et al., 2020). Hydrogen shows promise in large scale storage for longer times compared to other conventional storage methods, like electricity, due to its low costs (Kharel and Shabani, 2018). Variation in storage methods allow for a wide range of uses for hydrogen as an energy carrier as well (Wijayanta et al., 2019). Hydrogen can generally also be refuelled faster than can be done with electricity, and its energy density allows for a larger operational radius (Murugan et al., 2019).

Cons:

There are a number of significant downsides to the use of hydrogen. Hydrogen has no precedent widespread use in a national economy, meaning there are significant holes in the knowledge necessary to be able to properly handle it. Hydrogen is inherently a dangerous substance. It is colourless and odourless and burns in a near transparent flame. It has a wide range of mixtures with air in which it can burn or explode, is very easy to ignite and auto-ignites at temperatures between 500 and 571 degrees Celsius (Airgas, 2020). Hydrogen is also harder to store than other similar gasses. There are three methods of storage that can be considered feasible for vehicles (Alazemi and Andrews, 2015; Lototskyy et al., 2017). There are a number of cons to using compressed hydrogen in tanks. Due to the small size of the hydrogen molecules, hydrogen is capable of passing through microscopic cracks in the metal structure, or permeating through the metal lattice structure itself. It can also react with the metal itself, weakening the metal lattice structure. This is known as hydrogen embrittlement (HydrogenTools, 2022). This allows for leaking of hydrogen over time in small amounts and decreases the lifetime of metal storage tanks. The weight of the metal storage tanks also significantly reduces the overall energy density of the storage system. The compressing and decompressing of hydrogen also releases and adsorbs a lot of latent heat, limiting the speed at which hydrogen can be stored or released from metallic containers. Although the hydrogen embrittlement of compressed hydrogen containers can be avoided by using materials such as carbon fibre, this increases the cost of storage. The second method is hydrogen liquefaction. The boiling point of hydrogen is about 20 K at standard pressure, and the Carnot efficiency is about 0.073, meaning that liquefaction of hydrogen is a very energy intensive process (Yanxing et al., 2019). Furthermore, the ratio of ortho and para hydrogen determines the time the hydrogen stays liquid, even when properly insulated. Ortho and para hydrogen refer to the spin state of the hydrogen atoms in hydrogen molecules. Ortho molecules have both atoms spin in the same direction while para molecules have spins in opposite directions. Ortho molecules have a slightly higher energy state, meaning that they can change to para molecules, and when they do, energy

[4] If production and replacement of parts is done purely on renewable energy as well or not taken into account.

is released. This released energy per changed molecule is enough to gasify one other hydrogen molecule. This means that liquefied hydrogen will have to be converted to mostly para molecules to prevent it from returning to a gaseous state, which makes the process more energy intensive and costly (Milenko et al., 1997). The third method is hydrogen storage in solid metal hydrides. While metal hydrides have the potential to provide superior energy densities at manageable conditions, there are significant problems in long term stability of the metal hydrides, expansion of the material making it less suitable for storage in vehicles and thermal decomposition of some materials (SAKINTUNA et al., 2007). It is likely a significant amount of research still has to be done before metal hydrides find commercial application as storage methods in vehicles. In regards to the production method, fuel cells are also limited in their lifetime and costly. PEMFCs are estimated to cost $50/kW in mass production, which is well above the expected targets needed to become competitive with ICEVs (Chen et al., 2015). The lifetime of a PEMFCs is expected to be shorter in vehicles than in a constant generation setup due to the differences in its load profile during different stages of drivers, increasing degradation (Zhang et al., 2017). Furthermore, PEMFCs, use increasingly rare materials, such as platinum, as catalysts. Increased use and production of PEMFCs in hydrogen fuelled vehicles is likely to increase the scarcity and in turn drive up the price of production.

Table 6: Pros and Cons of selected technologies

Pros	**Cons**
Biofuels	
Large variety of feedstock available,	Many forms of feedstock compete with other industries (1st and 2nd gen),
Biofuels burn cleaner and emit less matter and soot,	Biofuel energy density degrades over time
Biofuel availability is higher than oil	Production scaling of 3rd gen biofuel is still costly
BEVs	
Electricity is versatile,	Limited knowledge on reliability, safety and degradation,
Fuel costs are very low,	Lower range of operation compared to ICEVs,
BEVs provide a form of storage for intermittent energy generation,	BEVs are currently more expensive than ICEVs,
BEVs are emission free	ICEVs use a higher gravimetric and volumetric energy carrier
Hydrogen	
Hydrogen is versatile, Hydrogen shows promise for large scale storage, There are a large number of storage methods	Hydrogen has limited use currently, Hydrogen is a dangerous substance, Hydrogen production is expensive, Each storage methods has substantial downsides

5.2 Future Scenarios

With the trends in Indonesia clarified and the stakeholders and their relations highlighted, scenarios and the policy packages that would have to be implemented during the duration of these scenarios can be envisioned. And with the characteristics of the technologies to be used explained, future scenarios can then be created. In this section, there will be three different scenarios explained. These three scenarios focus on using a single technology to mitigate the greenhouse gas emissions. With these scenarios, the feasibility of a single technology to mitigate the problem can be tested. The pathway dependency of each of these technologies can also be analysed.

There are three individual goals that can be set for the three mono-technology futures. These futures are constrained by the characteristics of each individual technology. By finding out where these constrains are the pathway dependencies of each technology can be checked, and it can be determined whether or not a single technology is realistically capable of reaching the set goals. These three goals are indicated on the expected growth scenarios, which were found in the BAU scenario. The low estimate, the non-OECD growth represents the minimum amount of CO2 that is expected to be mitigated by each technology. The middling scenario represents the amount of CO2 that would have to mitigated for a likely net neutral future scenario. The population development based scenario represents the worst case scenario and the largest amount of CO2 that would have to be mitigated. The future and the policies that will have to be developed will be done on three timescales. These timescales are short, intermediate and long. Although no exact times will be given for these timescales, they are there to give an indication when certain policies will have to be implemented and how long they will last.

5.2.1 Assumptions

For the sake of simplicity, a number of things will be assumed for the ease of scenario creation. For EVs, the range of plug-in hybrid electric vehicles will not be taken into account here, as a barrier to sales. For the biofuels, ICEVs will be considered, for hydrogen FCEVs and for battery BEVs. The reason combustion engines aren't considered for hydrogen fuelled vehicles is a matter of lower energy efficiency, and the proof this is given in Appendix B.4, where combustion engines are compared to fuel cells. Also, considering this scenario is purely in regards to the transport sector and not energy production sector, it is assumed that the whole cycle, from well to wheel, is done in a CO2 neutral manner. Delays in implementation to allow for the infrastructure for BEVs in particular to be realized are taken into account.

5.2.2 Mono-technology: Biofuels

In the biofuel based scenario, only biofuels are used to mitigate the CO2 emissions of the private transport sector. This includes all forms of biofuels that can be produced, although lifetime CO2 emissions will have to be taken into account. Current production of palm oil would be able to supplant the use of fossil fuels in private vehicles if it was completely processed to biodiesels. Other forms of biodiesel, produced from algal biomass, could be able to support even the worst case scenario of CO2 emissions predicted. The land needed as well as the amount of biofuels produced are displayed in the table below. Calculations made to reach these numbers as well as discussion regarding them can be found in Appendix A5. These scenarios assume that a renewable energy transition is taking place in the other fields at the same time this scenario evolves, such as that as time goes on, more and more renewable energy becomes available, and does not have to be taken into account for this scenario explicitly.

Table 7: Biofuel Scenario Data

	Situation in 2018	2060 scenario non-OECD based growth	2060 scenario population based growth	2060 scenario middling estimate
CO2 Emissions by private vehicles (MT CO2)	63	119.17	616.09	379.05
Diesel Consumed (Million L)	22900	43330	224000	137800
Biofuels Consumed (Million L)	25440	48140	248800	153100
Palm Oil needed (Million L)	27660	52330	270400	166400
Sq. km needed for Palm Oil production	146000	276300	1427900	878600
Sq. km needed for Algae production	10020	18960	97970	60290

Potential Progression:
In this future scenario the progression could be as is laid out in the following section. In the short term, an increase in palm oil production on suitable land would help increase the biofuel percentage in the diesel blend. During this short term increase, feasibility studies have to be made to increase local knowledge into biofuel production from algae. This is needed due to the limited amount of arable land palm oil can be produced on. This will likely take some cooperation between knowledge institutes, governments and company spin-offs that form from the knowledge institutes. Further feasibility studies will have to be done to ensure the production of the other main reagent for biofuel production, methanol, can be scaled accordingly to increases in biofuel production. Indonesia contains vast reserves of coal, which after a renewable energy transition would not be able to be used for the goals they are used for now, which is generation of electricity. The coal could be used to produce methanol via coal gasification and methanol synthesis. Small projects utilizing coal in such a way are already being planned (China Dialogue, 2022). The government would have to provide mandates and guidelines in such a way that these projects are successful, potential by establishing an independent controlling stakeholder.

In the intermediate term the palm oil production fo biofuel production would have to be stabilized and eventually scaled down as suitable locations on which palm oil can be produced with lifetime CO2 neutral emissions. The studies done and knowledge generated for the methanol and algae production would lead to the creation of early pilot plants and small scale production facilities. A new group of actors would arise here, the algae producers. Enough renewable energy can be produced to sustain these new facilities to allow for CO2 neutral biofuel production. At this time, the biofuel forms the majority of the diesel blend, mandated by the government. This would allow the government to scale back imports of refined petroleum and diesel significantly.

In the long term knowledge generated regarding algae biofuel production and methanol production from coal reaches maturity. Palm oil production can be scaled back to supply only for culinary and export needs. The biofuels are exclusively produced using algal biomass. Coal mining is limited only to the new forms of intermediate reagents and new renewable products that can be made from it. The government will be able to scale back imports of refined petroleum and diesel to needs outside of use in transportation. Biofuels comprise the entirety of the fuel mix. Knowledge institutes have gathered enough information to ensure the biofuel mix burns cleaner than diesel, resulting in significantly less pollution, and that the difference in energy content between diesel and biofuel is minimal. A graphical overview of the potential course of this scenario (green) from present day to 2060, compared to the worst-case BAU scenario (brown) is given in Figure 22 and 23 below, each bump in production of biofuel clearly representing an increase in biofuel percentage in the fuel mix.

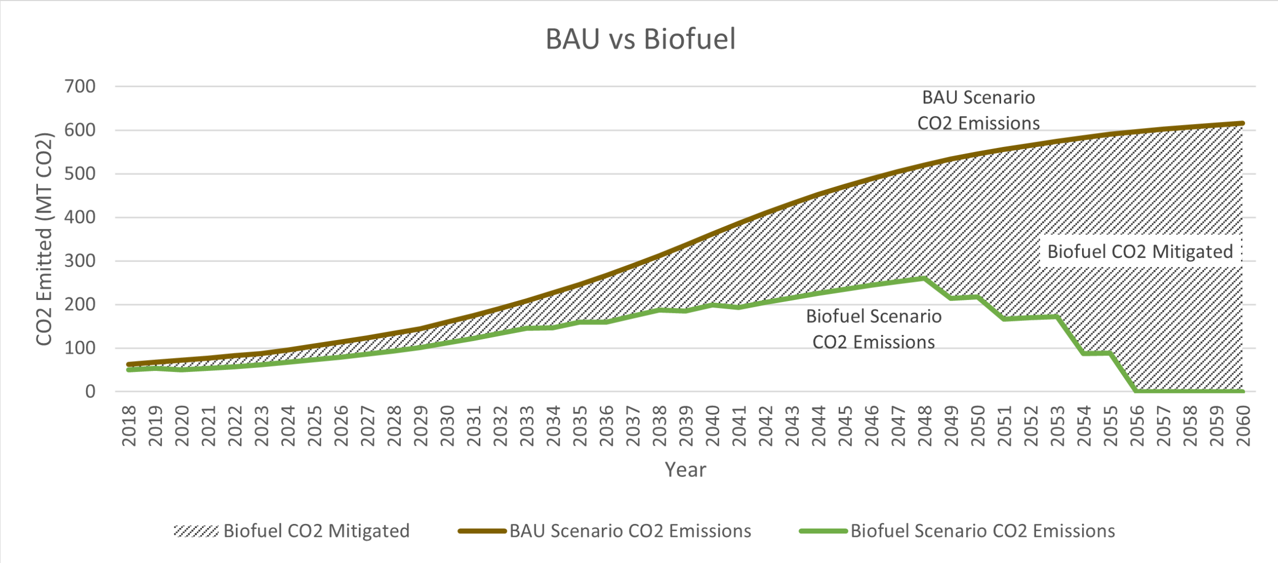


Figure 22: CO2 Growth estimation in a potential BAU scenario compared to CO2 growth in a potential biofuel scenario

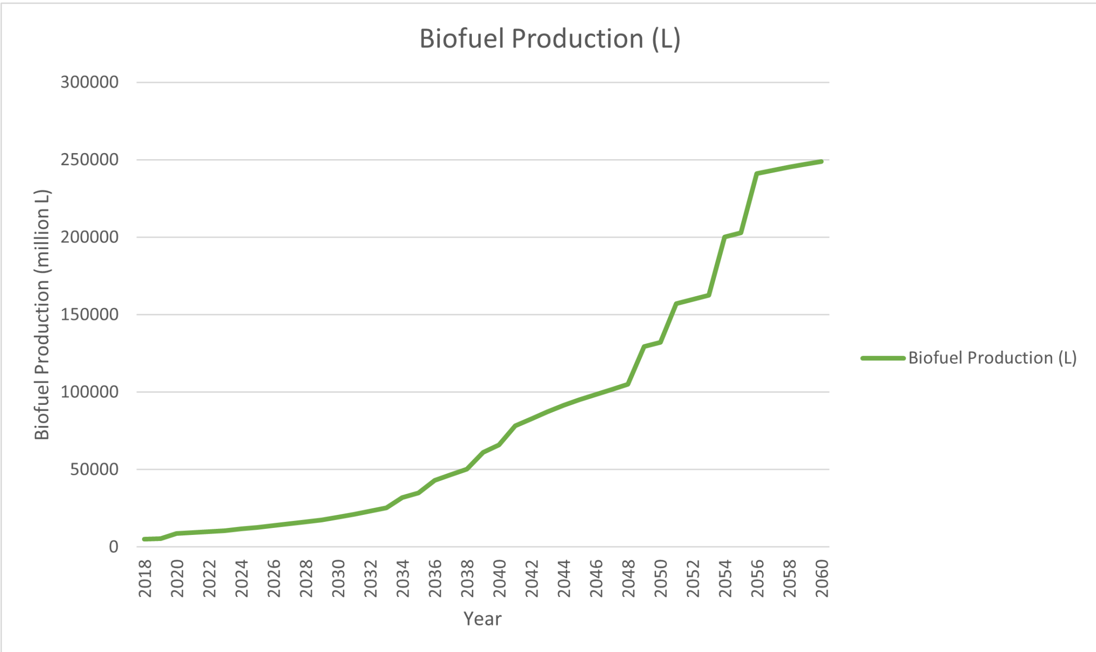


Figure 23: A potential biofuel production overview

However, as will be explained in more detail in the barriers section, there is a limit on how much biofuel can be produced based on land availability. The most rich arable land is already in use, either for food production or palm oil production. Setting a cap on the total palm oil being produced using the production numbers from 2021 gives a yearly production of 46.2 million metric tons of palm oil. This is equivalent to 51.11 billion litres of palm oil (Statista, 2022d). This is plotted below as a baseline, with increasing biofuel percentages in the fuel mix in Figure 24.

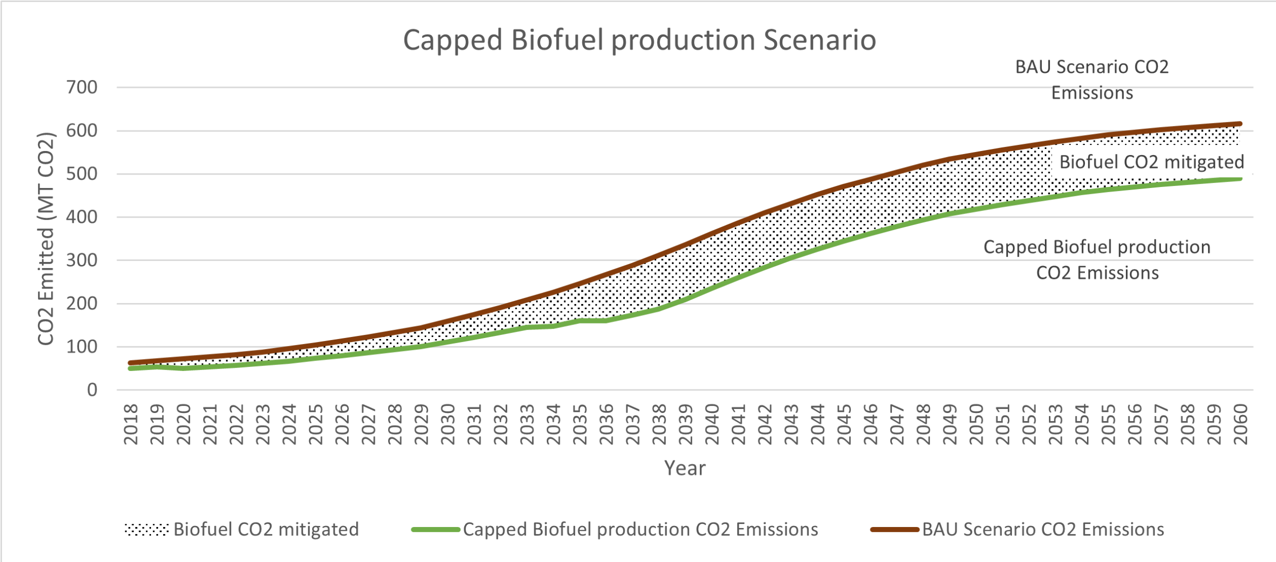


Figure 24: CO2 Growth estimation in a potential BAU scenario compared to CO2 growth in a potential capped biofuel scenario

Compared to the earlier presented biofuel production overview, it can be seen that as soon as the needed biofuel production crosses the 51 billion litres mark, there is no more addition CO2 being mitigated, as all produced palm oil is used to produce biofuels. This is a clear limit on this scenario and means that diversification and expansion of the production of biofuel will have to take place if this scenario is to succeed.

There are a number of actors that are important in this scenario. The government is important to help mandate legislation and fund knowledge institutes. The knowledge institutions are important to develop knowledge in regards to the use of new forms of biomass and methanol production from coal. There are a number of steps that will need to be taken by a number of actors on all three timescales for this future to be reached, as has been laid out in the above progression.

Barriers:

One of the main barriers to ensure the production of the biomass, be it in the form of palm oil or algae, is that has to be done CO2 neutral. The change in land use may have significant impact on the CO2 retained in said land. Peat wetlands can emit significant CO2 emissions is dried and used for palm oil plantations, for instance. This is one of the main barriers to the large-scale introduction of biofuels. Another barrier is food vs feedstock. Palm oil has both use in the culinary sector as well as feedstock for biofuels. Indonesia is the largest producer and exporter of palm oil worldwide. Repurposing palm oil from value export to feedstock for biofuels may have significant effects on their trade balance. Another barrier is the oligopolistic market for the sale of biofuels. Currently, the Indonesia government has limited sale of biofuels to a small number of producers, effectively turning the market into an oligopoly. This risks the formation of cartels, which in turn might raise prices, providing barriers for the sale of biofuels to the general public. The government in turn would have to closely monitor these groups so that such a situation does not occur. One last barrier is present in the costs of algal biomass production. Currently, large scale production of algal biomass is expensive. Extensive research will likely still have to be done to make sure biofuel based on algal biomass is produced at a price-competitive level. Finally, there is a barrier in the form of land availability. In the worst case scenario, there is a need for a total surface area of 1.427.900 square km. For reference, the surface area of the island of Java is 128.297 square km, meaning that over ten times the total surface area of Java is needed in rich arable land to be able to produce enough biofuels from palm oil. For algae this is less of an issue, although the land required in the worst case is still almost 75% of the total surface area of Java. Since the amount of arable land is limited, and is also needed for the production of food in the case of palm oil biofuel production, land availability sets a hard limit on the total amount that can be produced.

Drivers:

This scenario has a number of drivers that stimulate the development towards this future as well. For one, it provides a use for the otherwise useless coal, which after the renewable energy transition cannot be used for the generation of energy anymore. Second is Indonesia's already present infrastructure and knowledge in the production, processing and distribution of palm oil and biofuels. Processing of palm oil already takes place in the country, even if it is not on a scale large enough to provide enough fuel for the entire private vehicle sector. Compared to a lot of other countries, Indonesia is already actively increasing the percentage of biofuels in their fuel blend and observing the effects of it, leading to further development of knowledge which can be used in this scenario. Third is Indonesia location close to the equator, which allows for production of forms of energy that require significant amounts of solar radiation, which include PV and algal biomass. This algal biomass can be produced in a significantly smaller area as well. Specifically for algal biomass, rich soil is not necessarily required as algae can be grown in ponds which can be constructed on otherwise poor farming soils. Finally, the use of biofuels as renewable fuel technology means limited changes will have to be made the infrastructure that is already in place, as biofuels are made to behave physically and chemically similar to diesel.

5.2.3 Mono-technology: EVs

In the EV scenario, EV technology is used to mitigate the CO2 emissions of the private transport sector. Battery vehicles are used to supply electricity as a fuel source to replace diesel. This is done in line with increased production of electricity in the greater renewable energy transition where most of the energy generated and consumed in produced in the form of electricity from solar and wind. Intermittency of the production of this energy will result in the need for storage, to which the large fleet of electric vehicles can serve as a basis for. In the table below, relevant numbers can be found, including yearly energy consumed and available total storage per growth scenario. Electric vehicles have a number of benefits over normal combustion engines, including higher energy efficiency, leading to less overall energy consumed.

Table 8: EVS Scenario Data

	Situation in 2018	2060 scenario non-OECD based growth	2060 scenario population based growth	2060 scenario middling estimate
Total yearly energy consumed combustion engine (EJ)	0.7145	1.352	6.989	4.299
Total yearly energy consumed EVs (EJ)	0.262	0.4957	2.563	1.575
Surface Area PVs needed (Sq. km)	175.8	332.6	1718.7	1056.7
Total storage capacity (MWh)	984000	1861000	9622000	5921000

Potential Progression:

The progression towards this scenario once again can be done in three terms, short, intermediate and long. The future progression could be as it is laid out here. It should be noted that unlike the biofuel scenario, the EV scenario is much more integrated in the renewable energy transition as a whole and thus interdependencies between different sectors might arise. In the short term, it is important for the Indonesia government to lay out plans and form relationships with manufacturers of infrastructure and EVs. There need to be plans for the transition towards more electricity generation on renewable basis, and plans for a large scale electric infrastructure capable of handling EVs. This can be done by inviting foreign companies, as is currently already being done with Hyundai and LG solutions. These companies are to help provide initial knowledge and infrastructure for the production of EVs and expansion of the electricity grid. Initial pilot plants for the production of EVs should be made. Basic infrastructure for EVs should come into place in major locations, where first clients are established. Plans should be created to incentivise the population to choose EVs over regular combustion engines. Potential societal organisations could be founded or expanded on to promote the use of EVs. Locations would have to be chosen for the renewable electricity generation to meet the demand of the private vehicle sector.

In the intermediate term, the cooperation between foreign companies and the Indonesian government should lead to exchange and generation of knowledge. Knowledge institutes that specialise in the handling of knowledge regarding the RD of electric vehicles, managing the emerging intermittency of the electric grid and EV related infrastructure. Infrastructure should be expanded accordingly with the ongoing renewable energy transition. This includes building large solar PV farms. Production of EVs should be ramped up and competition should be incentivised to promote optimized designs and ideas and to promote the use of EVs in more niche conditions. Further ramped up production could also help Indonesia become a market player in the export of electric vehicles, a position that is favourable due to their natural resources. Further incentives should be provided for the consumer to favour EVs over combustion engines.

In the long term, Indonesia should have a complex, well-functioning EV producing industry. This industry should be regulated by either a government backed or independently operating body. Complete EV infrastructure should be in place to accommodate for the large number of EVs present in the country, and the electricity companies should have the knowledge generated to handle the intermittency of energy generation present in their system and handle the storage provided by the fleet of EVs accordingly. An area large enough to meet the demands of the private vehicle sector should be covered with PVs. A number of different EV producers should be present in the country allowing for Indonesia to export internationally competing EVs. Fossil fuel based vehicles should be phased out. A potential course of this scenario is graphically displayed in Figure 25 and 26 below.

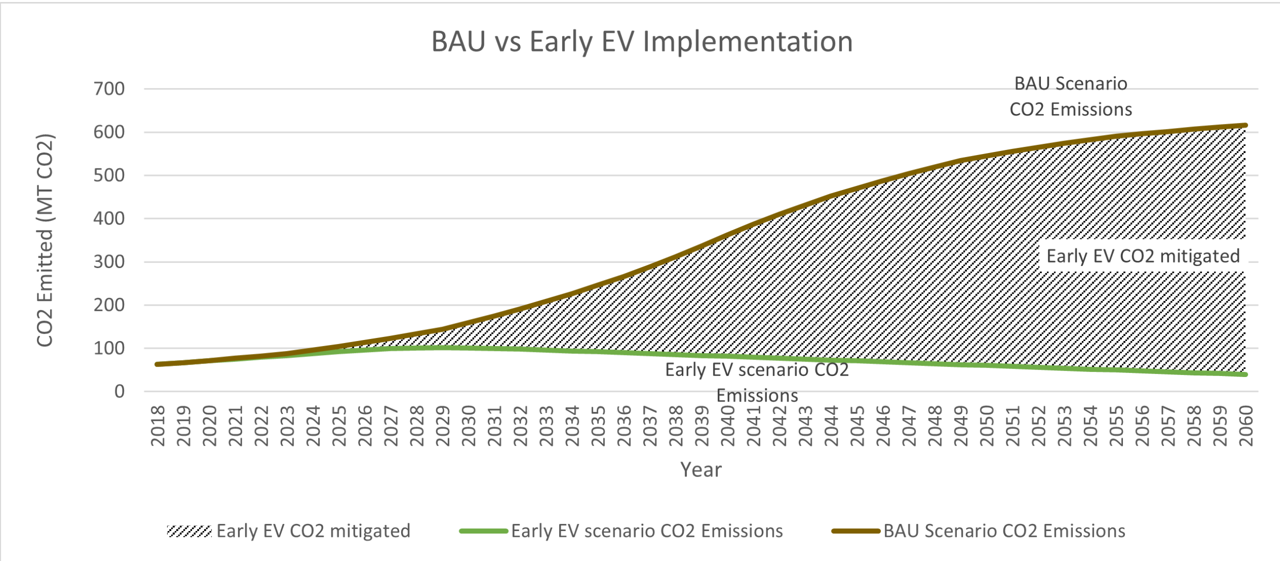


Figure 25: CO2 Growth estimation in a BAU scenario compared to CO2 growth scenario for a potential early implementation of EVs

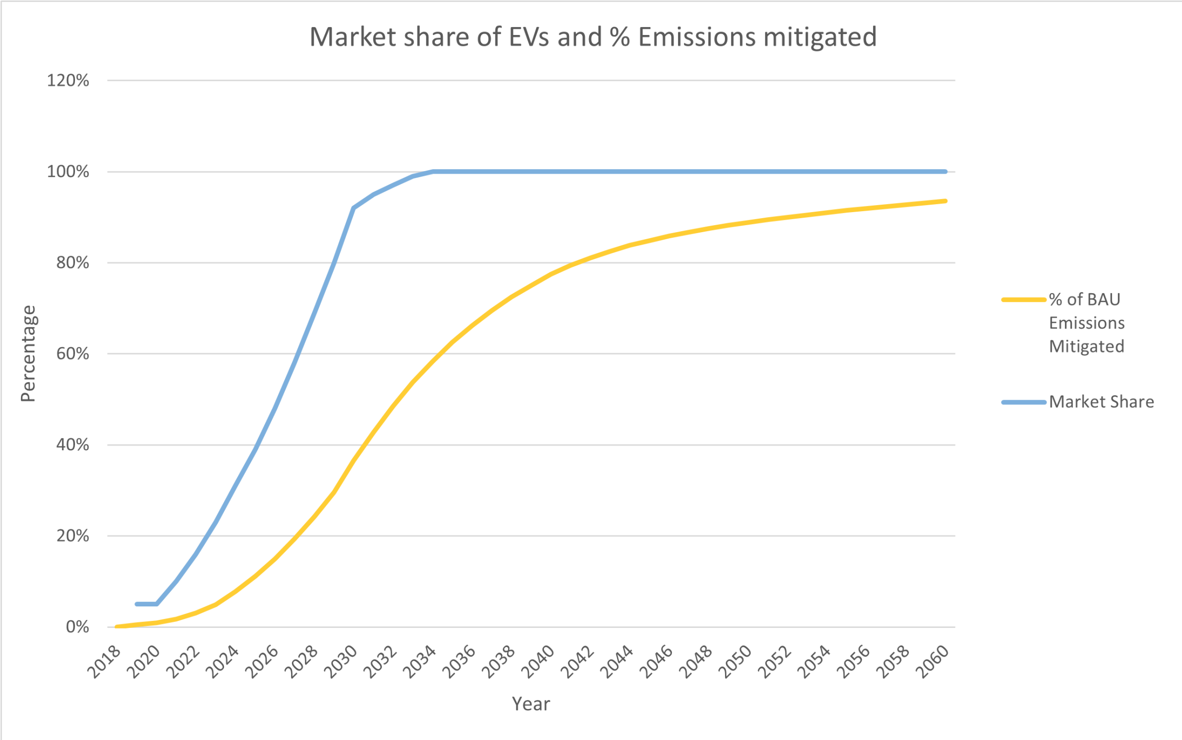


Figure 26: Early implemented EV market share and total CO2 mitigation

It should be clear that this scenario, unlike the biofuel one, also depends on the sale and market share of the EVs. If there isn't a significant share of the market converted to the sale of EVs, a fleet of already present fossil fuel emitting vehicles will continue to exist until 2060. This can already be seen in the above Figures, as 100% mitigation of CO2 emitted by the private transport sector by 2060 is not achieved, even when the market share of EVs is above 80% before 2030. There is however a real chance that EVs never reach a significant market share, or do so way too late. Such a scenario is graphically displayed in Figure 27 and 28 below. Only very draconic measures, such as a ban on possession or sale of fossil fuel emitting vehicles can prevent this.

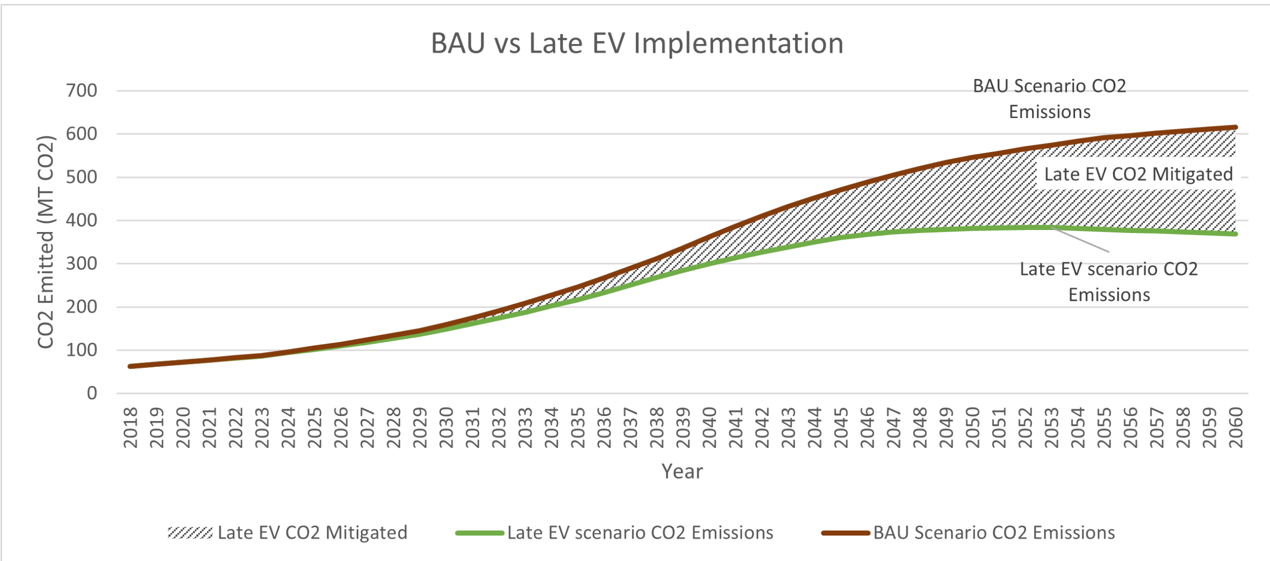


Figure 27: CO2 Growth estimation in a BAU scenario compared to CO2 growth scenario for a potential late/slow implementation of EVs

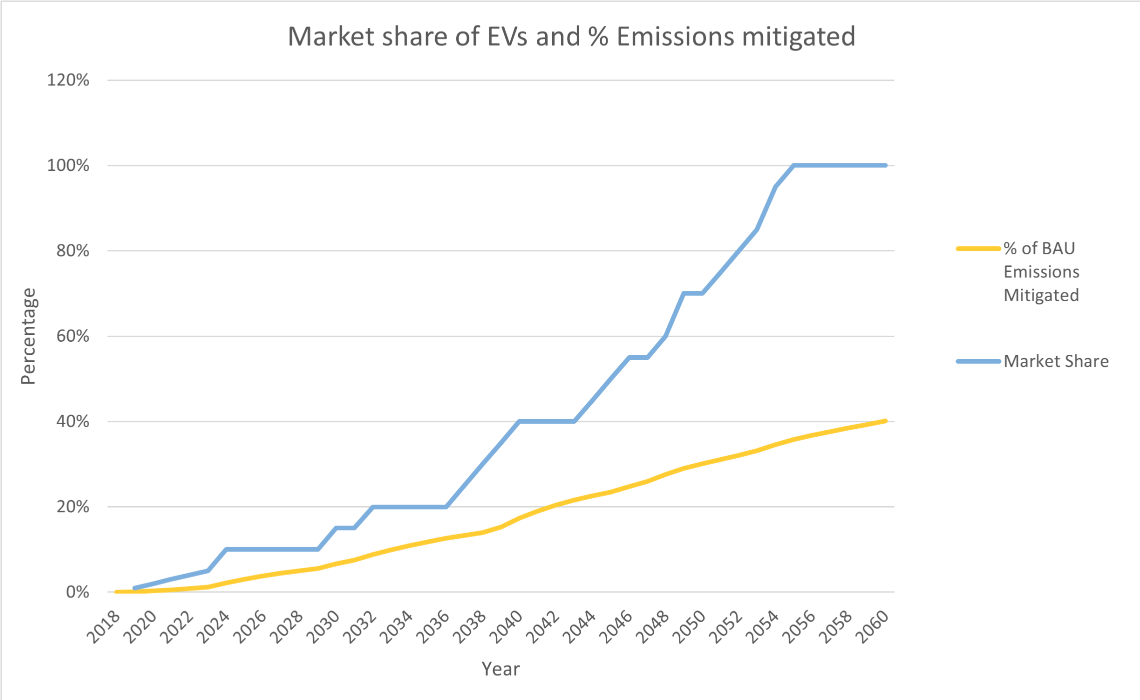


Figure 28: Late implemented EV market share and total CO2 mitigation

Barriers:
There are a number of barriers for this scenario to occur. First, as stated before, is the interdependency of EVs on the larger renewable energy transition. Unlike vehicles running on biofuels or even fossil fuels, EVs are very dependent on a capable electric grid to be able to operate. This means that barriers to the implementation of the larger electricity system also act as barriers for the implementation of EVs. A second barrier is the cost of production of EVs. The vehicle production lines as they are currently in operation are optimized for the production of combustion engine vehicles. Initially, the cost of production of EVs will be higher than that of normal vehicles due to the production cycle being less optimized, and missing knowledge. A third barrier is scarcity of natural resources. While Indonesia is rich in nickel, one of the main components of the battery by weight, other components of the battery in particular, are not present in Indonesia in large amounts. Materials such a lithium are already becoming scarce worldwide, and a large increase in battery EVs would further drive this scarcity. Recycling of these batteries will become necessary, although this is often not a cost-effective process. As can be seen in the above figures, time is also a significant factor when it comes to the success of this technology on its own.

Drivers:
There are also a number of drivers present for this scenario to occur. For one, Indonesia is located near a number of countries with high technological knowledge in China, South-Korea and Japan. These countries could help stimulate the growth of knowledge in regards to EVs, and companies originating from these countries could start production lines there. As stated previously, there are already plans on the table for this to happen (Hyundai, 2021). Second, Indonesia is rich in nickel, which is one of the main components for cheap but robust nickel-lithium batteries. As the batteries is the most expensive part of an EV, and nickel is the largest component of the battery by weight, local production of EVs would allow Indonesia to sell such vehicles at lower cost.

5.2.4 Mono-technology: Hydrogen

In the hydrogen scenario, only hydrogen is used to power vehicles. Hydrogen is produced using renewable electricity using hydrolysis of water. In line with the greater energy transition, the intermittency of the energy generation sources, mostly solar, increase the need for storage. The storage provided by electric vehicles would in this case not be enough, so the choice is made to use the excess electricity produced to produce hydrogen, which can be used as a feedstock for a number of processes in the industry, as well as fuel for the private vehicle sector and to generate heat. Like electric vehicles, vehicles that run on hydrogen have a higher efficiency than combustion engines. There are two methods a vehicle can run on hydrogen, either via combustion or via fuel cells. The amount of hydrogen needed in this scenario for the vehicle growth predictions as well as the energy needed to generate it are provided in the table below. The calculations made to reach these numbers, as well as a discussion regarding the validity of them can be found in Appendix A7.

Table 9: Hydrogen Scenario Data

	Situation in 2018	2060 scenario non-OECD based growth	2060 scenario population based growth	2060 scenario middling estimate
Total yearly energy consumed combustion engine (EJ)	0.7145	1.352	6.989	4.299
Total yearly energy consumed hydrogen fuel cell (EJ)	0.6046	1.144	5.915	3.635
Hydrogen consumed (million L)	75580	143000	739400	454300
Hydrogen consumed (million kg)	5038	9532	49290	30290
Total yearly energy consumed hydrogen production (EJ)	0.8061	1.525	7.887	4.847
Surface Area PVs needed (Sq. km)	540.9	1023.4	5291.6	3251.9

Potential Progression:
Once again, the progression of this scenario can be divided into three sections, short, intermediate and long. The progression of the hydrogen scenario is most likely similar to that of the EVs. There is likely a longer delay to mitigation in this scenario as a result of the time needed for necessary technologies to be commercially developed.

In the short term, it is mainly the electricity companies, knowledge institutes and businesses that will have to act. Hydrogen has barriers mainly on the technological aspect, which will have to be solve to ensure a smooth implementation. Knowledge institutes will have to work with electricity companies and businesses to create pilot systems that enable cheap and dense storage of hydrogen as well as create systems that can produce the hydrogen. In this scenario, the storage form in vehicles that will be used is metal hydrides, as it theoretically can create very dense storage at not too extreme conditions. The production method considered will be alkaline hydrolysis at first, which will shift to PEM and potentially high temperature water electrolysis once the technology has matured enough. The government and businesses will have to provide funds to enable the research and creation of pilot plants. The electricity companies and knowledge institutes generate knowledge, and the electricity companies learn to handle large scale hydrogen storage.

In the intermediate term, knowledge will have to be spread on a local level to introduce the technology to the wider public. Small scale implementations of hydrogen fuelling stations and fully hydrogen fuelled vehicles become available to the public. Electricity companies can start learning by doing. Initial hydrogen production facilities and storage are created. The government can start creating mandates for the use, sale and production of hydrogen. Further knowledge is gained and more pilot studies are done by the knowledge institutes, further funded by businesses and the government. The first commercially available hydrogen vehicles should become available to the public, allowing the government to start disincentivizing fossil fuels. Integration of hydrogen as a feedstock and fuel in the chemical industry can also start taking place, further promoting the production and use of hydrogen.

In the long term, knowledge of hydrogen vehicles should have spread significantly throughout the population. The government should promote the use of hydrogen vehicles and disincentivise the use of fossil fuels. Hydrogen infrastructure should be available in all relevant locations. Electricity companies should have generated enough knowledge to be able to safely work with hydrogen and work with, maintain and expand hydrogen infrastructure. Knowledge institutes should have provided businesses with a number of hydrogen generation and storage technologies that increase efficiency, decrease energy use, increase lifetime and rely less on expensive materials or extreme conditions. A number of different businesses have found niches to be able to produce and sell hydrogen and hydrogen based vehicles. Hydrogen based vehicles have become the dominant form of private vehicles.
Graphically, the progression of this scenario would likely look similar to that of the EVs scenario. However, since the implementation of hydrogen as a fuel technology is subject to a larger number of barriers, it is likely that there would be a delay in implementation. The progression would then likely be shifted several years into the future. This is displayed in Figure 29 and 30 below.

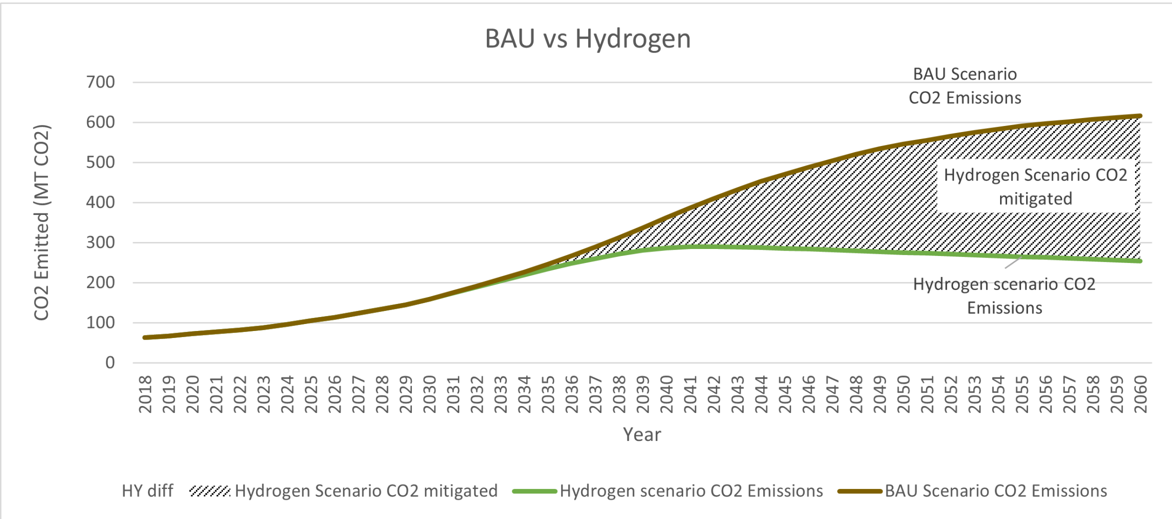


Figure 29: CO2 Growth estimation in a potential BAU scenario compared to CO2 growth scenario for a potential implementation of hydrogen vehicles

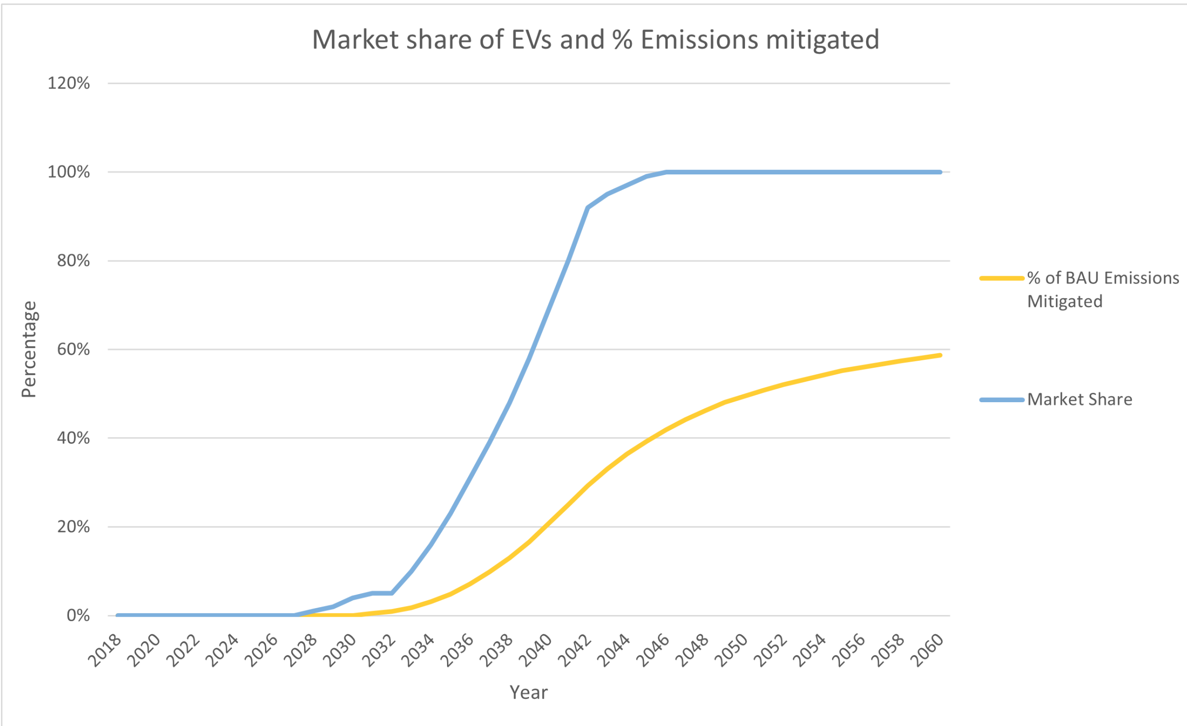


Figure 30: Hydrogen vehicle market share and total CO2 mitigation

Barriers:
There are some significant barriers to the implementation of this scenario. First, the production of hydrogen from water requires infrastructure that has access to either plenty of convertible fresh water or would require an even higher energy intensity and could make use of desalinated water from the seas. The electrolysers can be made into a number of ways, but the most efficient currently commercial one, PEM electrolysis, relies on a number of expensive materials and has a relatively short lifetime compared to alkaline electrolysis, which is far cheaper but has a lower efficiency. While both methods are likely to increase in efficiency over the 2060 scenario, both have the up and down sides. PEM in particular relies on expensive metals to perform electrolysis, with iridium and platinum being used as catalyst (Rashid et al., 2015). Furthermore, while hydrogen could be a promising fuel source for vehicles, there are some significant difficulties in storing it. Hydrogen can leak through most metal containers, is dangerous to store as it is easy to ignite and burns colourless and has a lower liquid energy density compared to most hydrocarbons due to its low overall density. Most storing methods require non-standard conditions such as cooling or pressurizing, which subtract from the overall useable energy available. While storing hydrogen under standard conditions is being done experimentally, this is often done in metallic hydrates, which have their own issues. These issues include short life times, brittle or expensive materials and extraction difficulties. Finally, using hydrogen fuel cells is more efficient than hydrogen combustion, as there as less thermal losses. However, using hydrogen fuel cells with hydrogen produced from electricity, the same cycle is used as would be used for electricity, except for hydrogen as the storage medium instead of electricity. The extra conversion steps to and from hydrogen mean that the overall efficiency of hydrogen is lower than that for electricity. This could be mitigated if hydrogen provided extra utility, for instance as feedstock in the industry. However, hydrogen currently only sees limited use there.

Drivers:
In a renewable energy situation, it is most likely hydrogen that would be used in most sectors of the industry to serve as feedstock for the creation of hydrocarbons for instance, or serve as fuel for heat or energy generation. In such a system, the integration of hydrogen could lead to it being used in the transport sectors as well as fuel. With Indonesia being an island nation, and most of the population living on the coast, water as a source for the production of hydrogen is present very near large urban centers, allowing for localized fuel production.

5.2.5 Pathway Dependency of mono-technological future scenarios

With the three mono-technological future scenarios laid out and with a basic progression framework in place, the pathway dependency of each of these scenarios can now be analysed. This is done by comparing the needs of each scenario and barriers present to that properties and trends of Indonesia, as explained in Chapter 3.

Biofuel:
Biofuel likely has the most potential to be implemented on a short term. It does not depend on the development of other sectors, like the industry to drive the progression and implementation, as biofuels are transport sector specific. Indonesia has a great pool of knowledge when it comes to the production of first generation biofuels, in the form of palm oil. Indonesia location near the equator as a tropic country also means the conditions are fairly favourable for the production of biomass, as the country receives plenty of sun and water and has nutrient rich, volcanic soil. The main barriers that are still present are that of CO2 production from change in land use, and the food vs feedstock question. Most of the arable land available for the production of palm oil is already in use. The clearing of additional land would require drying of peat land or clearing of rain forests, both of which would result in net CO2 being emitted from the land due to land use change. A significant portion of the palm oil being produced is also meant for export, as palm oil is one of Indonesia's largest exports by value. This can be mitigated by shifting from first generation biofuels to third generation biofuels, in the form of algae. These third generation biofuels can solve both of the barriers still present, as algae can be grown for the sole purpose of biofuel production and in nutrient ponds that are independent from the soil quality. These barriers are exchange for one other barrier however, in the form of cost. Currently, the production of algae in large quantities is expensive. Proper investment in knowledge institutes and commitment to larger scale pilot plants should help increase cost efficiency. A secondary smaller issue is the structure of production and sales of biofuels. Currently, only a small group of biofuel producers are mandated by the government to sell biofuels. This could lead to economic conditions like an oligopoly that disincentivise the population from buying biofuels

at large. Production of methanol, a reagent needed for the production of biofuels from fatty acid biomass, can also be produced from coal, which Indonesia is also rich in. This allows for a more renewable use for coal as well, and means that coal does not become completely obsolete after a renewable energy transition.

EVs:
Electric vehicles or EVs, specifically battery electric vehicles, show after biofuels the most potential to be implemented in Indonesia. Worldwide, this form of transportation is the most likely to be implemented as it has the most drivers behind it in a sustainable energy transition. The wider spread use of electricity in a renewable energy scenario as well as the intermittency of the energy generation methods make the need for storage almost a necessity. The storage in the batteries of the vehicles allow for this storage. Furthermore, Indonesia has rich deposits of nickel, which allow for the local production of cheap but efficient batteries. The local production of these batteries help overcome one of the main barriers to implementation of battery vehicles, the cost of the battery. Indonesia's location near other technologically advanced countries that already have a base for the use and production of battery electric vehicles, in South Korea, China and Japan. The main barrier present for the implementation of battery electric vehicles is the overhauling of the energy infrastructure at large. The effective distance that can be travelled on a battery is less than that of fossil fuels, meaning that more tanking needs to be made available. This means in turn that a larger and more robust electricity infrastructure needs to be in place to handle the intermittency of the electricity generation and the tanking of electricity by electric vehicles. For Indonesia in particular, this means better maintenance, expansion and reinforcement of the electricity grid, as the grid occasionally experiences blackouts. However, given the rest of the country is likely to also expand on the need of renewable energy and electricity during the renewable energy transition for Indonesia's 2060 goals, this barrier is one that cannot be avoided and must be overcome. Two other, smaller barrier come in the form of land use, as in the worst case scenario a total of 1719.7 km2 would have to be covered in currently commercially available PVs to be able to meet the demand of the transport sector, and coal would be completely phased out as a method to generate electricity. Compared to biofuels, the area needed is still way lower, and given the renewable energy transition requires production of electricity in a CO2 neutral or negative manner, meaning this barrier is likely also unavoidable and must be overcome. It lies with the knowledge institutes to find ways to increase the efficiency of the PVs without increasing the costs and thus lowering the area required, and with the government to find suitable locations for the generation. Coal, as well as other fossil fuels will be phased out in this scenario. Comparatively, Indonesia has a large amount of natural reserves of coal compared to oil and gas, which are mostly imported. If Indonesia still wants to utilize the coal, it will have to find other methods, such as methanol production which will come to play a significant role for biofuel production. It is likely that the role of coal as a fuel or feedstock will be greatly diminished in this scenario, however, meaning that the currently present infrastructure and stakeholder framework for the use of coal might form a barrier to implementation of an electric renewable energy transition and thus EVs.

Hydrogen:
Out of the three renewable fuel sources chosen, hydrogen is the least likely to be implemented. A large number of mostly technological barriers prevent smooth implementation of this fuel type. There are still large questions regarding method of storage, as each form of storage provides benefits, but downsides as well. Although metal hydride storage of hydrogen is one of the more promising storage technologies, it is still very much experimental and has still some downsides in the form of brittle and expensive material as well as limited lifetimes. The transportation of hydrogen and large scale storage also is difficult, as hydrogen is capable of leaking through metal pipes and is itself a hazardous material, as it is odourless, colourless and quick to ignite. The implementation of hydrogen as a fuel source would also require a complete overhaul of the transportation infrastructure, if hydrogen is to become available everywhere. Finally, while hydrogen production is a mature technology, it is still expensive. There are limited structural properties and beliefs or values that drive the use of hydrogen as a fuel in Indonesia. While the use of hydrogen fuel cells in vehicles have great efficiencies, these are cancelled out by the added loss of energy due to the conversion of electricity to hydrogen and back to electricity in the fuel cell. Electricity, and battery electric vehicles are in direct competition as a form of energy carrier and currently, electricity and battery electric vehicles are much more favoured over hydrogen. If Indonesia shifts away from a exporter of raw products such as palm oil and ferrometals to a more manufactured products exports, its industry might intensify and the increase energy intensity might lead to a need to produce more hydrogen, however, currently, increased production of electricity would still be favoured over hydrogen.

5.3 Need for a combined scenario

From the three mono-technology scenarios elaborated on in the previous sections, it should become clear that it is very unlikely for a single technology to be able to mitigate the full amount of expected greenhouse gas emissions presented in the BAU scenario. While it is theoretically possible for biofuels, it requires an almost tenfold increase in production of palm oil, or five times the amount of land currently devoted to palm oil production for algal biomass production to meet the worst case fuel demands. It is unlikely that such a large amount of (arable) land can be allocated for this production in time.

Similarly for EVs, unless market domination of EVs is reached in the near future, the fleet of ICEVs that will remain on the road mean only very harsh policies, such as a ban on ICEVs can realize this scenario. Even then, there needs to be very high scaling of production of EVs very quickly to be able to meet the demands of the upcoming middle class that is in the market for purchasing private vehicles.

For hydrogen, the situation is likely to little too late. Hydrogen production and use as a fuel requires such a large shift in production of fuel and vehicle infrastructure that it is extremely unlikely hydrogen can make significant impacts in changing the course of the BAU scenario. Even in the case of a quick market domination for hydrogen vehicles, the late start of hydrogen mitigation will mean that it will be unable to reach the 2060 goals set.

Each of the three technologies mentioned has either one or more constraints that limit the amount of CO2 a technology can mitigate. For biofuels, this constraint is total production, for EVs the constraints are infrastructure and market competition and for hydrogen, the constraints are infrastructure, knowledge, technological developments and market competition. To be able to make sure these constraints impact the scenario as little as possible, a mix of technologies can be used. Both biofuels and EVs are to be utilized to some degree in the plans made by the Indonesian government and have the most going for them in terms of properties present in Indonesia. Both these technologies have a number of drivers and barriers that can be overcome. Indonesia already has grassroot projects going on the implementation of EV technology, and already mandates 30% of their diesel mix to be made of biofuels. This gives precedent for a combined technology future scenario.

Both technologies also complement each other somewhat. Biofuels can mitigate a given amount of CO2 in the near future, but are hard capped on the total amount they can mitigate due to land availability as a limitation. EVs on the other hand are capable of mitigating much further in the future, once the necessary infrastructure is in place, with their CO2 mitigation potential only limited by their market reach and supporting capability of the necessary infrastructure.

This combined scenario will try to build on the early stepping stones set out by the Indonesian government in an attempt to reach the 2060 goals using a combination of biofuels and EVs. In the following chapter, this scenario will be further elaborated upon, and the course of this scenario will be explained, to see what it would take for a combined technology scenario to reach the 2060 goals.

6 Final Vision

As has been established in the previous chapter, it is a combined scenario that has the best chance of succeeding. In this chapter a combined best guess scenario will be created, based on the early steps towards this scenario taken by the Indonesia government. First, the progression of the combined scenario will be given, based on a number of constraints. Next, three stages, the short, intermediate and long term will be defined and explicit goals to be reach for each stage will be set. Then, for each of these goals, barriers will be examined. A number of these barriers will be explored in-depth, and a discussion with an expert will be held for further exploration. Finally, steps that could be taken to overcome these barriers, as advice to the Indonesian government, will be presented. Further iteration of the scenario could be done to refine it, with follow-up interviews. However, due to time as a constraining factor, the scenario and its results are left as is in this report.
The combined scenario will only make use of the biofuel and EVs (specifically, BEVs) technologies to reach their goals. A number of basic constraints will have to be established to make sure the progress of this scenario can be followed in real life. The calculations made to reach the graphs and data presented here can be found in Appendix B.5. A sensitivity analysis and discussion of the relevant factors that have to be estimated for these graphs to be formulated can be found in Appendix B.6. The sensitivity analysis and sale scenarios presented in these two appendices provide a number of constraints that will have to be taken into account including production delay, car service time, yearly number of units sold and market share.

6.1 Pathway Construction

The combined scenario will only make use of the biofuel and EVs (specifically, BEVs) technologies to reach their goals. A number of basic constraints will have to be established to make sure the progress of this scenario can be followed in real life.
First, a limit will be set on the number of EVs that can be sold at a given time, and a delay in production will be set before EVs can be sold. This delay, which starts in 2018, lasts 10 years. The limit of yearly EVs sold domestically will be set at 5 million. This is more than 5 times the total amount of vehicles sold in Indonesia in 2021, and in line to the total car sales in the US as of 2021 (F and I Tools, 2022; Statista, 2022e). While this number may seem high, Indonesia's population (270 million, estimated to grow to 320 million in 2060) is comparable to that of the US (330 million). Although the US has a higher number of vehicles per 1000 individuals, even compared to the expected scenario in Indonesia, this is offset by the number of new private vehicle market entries. Due to the large production volume of EVs, the market share of EVs will quickly rise to 50% of all private vehicles sold. After this point has been reached, a slow increase in market share for EVs will be sustained.
Second, for biofuels there is no hard limit set on the growth of yearly biofuel production, as there is much more knowledge and infrastructure already available for this technology. However, a maximum of 150 billion litres of biofuels from either palm oil or algal biomass will be set, three times the total production of palm oil in Indonesia currently, and twice the world's yearly production of palm oil. This is slightly below the middling growth scenario needed biofuels in 2060, and corresponds to roughly 86 million hectares of palm oil plantages needed, or 5.9 million hectares of algae plantages. As this is equal to nearly half the surface area of Indonesia, it is assumed that most of the additional biofuel produced either comes from increases in efficiency in harvesting from palm oil, or biofuel produced from algal biomass, which is a lot more space efficient. The calculations for this can be obtained from Appendix B.2.
Third, the percentage of biofuel in the fuel mix will follow the guidelines set by the Indonesian government for the first 15 years before advances in technology allow for increased amount of biofuels. Eventually, the fuel mix will consist of a pure biofuel mixture. Finally, the amount of vehicles that need replacing is based on a vehicle lifetime of 15 years, and it is assumed that private EVs will always be replaced by new private EVs. While limited current day research is being done on the lifetime of a vehicle 15 years is based on European data, and is likely on the high end (Held et al., 2021). The vehicle lifetime is very important in the speed of change of the overall vehicle composition, as is discussed in Appendix B.6. Raw data for the the market share of EVs, % of biofuel in the fuel mix, % of BAU CO_2 emissions mitigated, yearly ICEVs and EVs bought, biofuel production in L and emissions mitigated per source are given in **??**. The data from there is graphically displayed in the Figures 31, 32 and 33 below. Three stages can be identified from these graphs. The short term lasts from

2018 to 2029, and represents the stage in which EVs are not yet commercially sold. The intermediate term lasts from 2029 to 2045, when the number of EVs commercially sold yearly domestically has peaked and the majority of the BAU scenario CO2 will have been mitigated. The long term lasts from 2045 to 2060, when the remaining BAU scenario CO2 will have been mitigated, the market share of EVs reaches 100% and fuel mix consists entirely of biofuels.

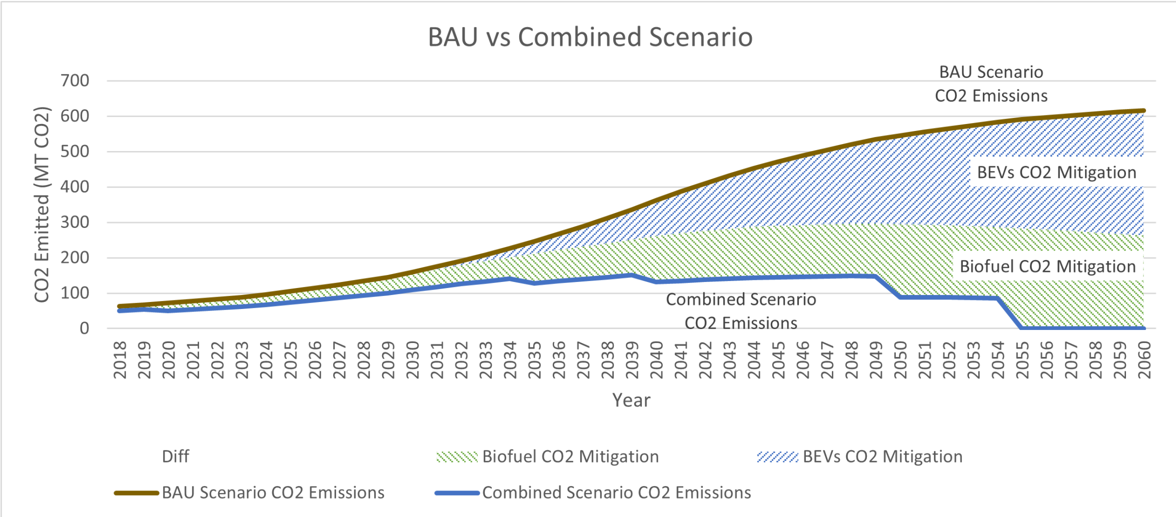


Figure 31: Mitigation of BAU CO2 emissions in a combined scenario by biofuel (green) and BEVs (blue)

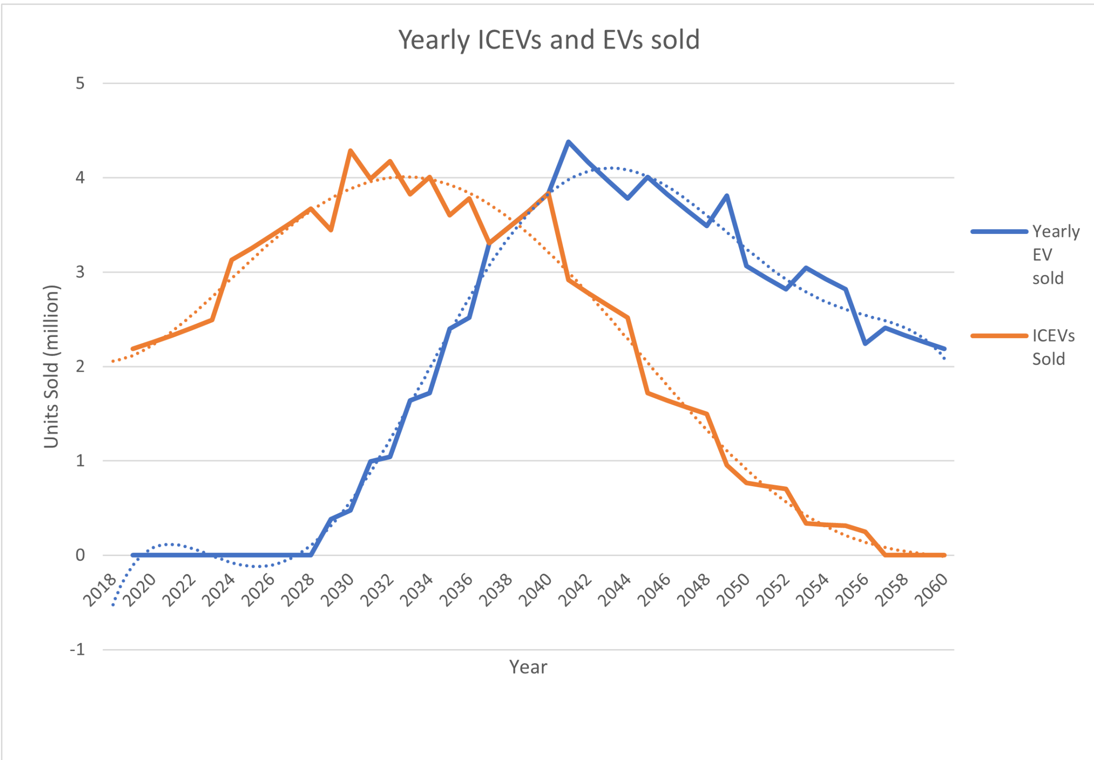


Figure 32: ICEVs and EVs sold yearly

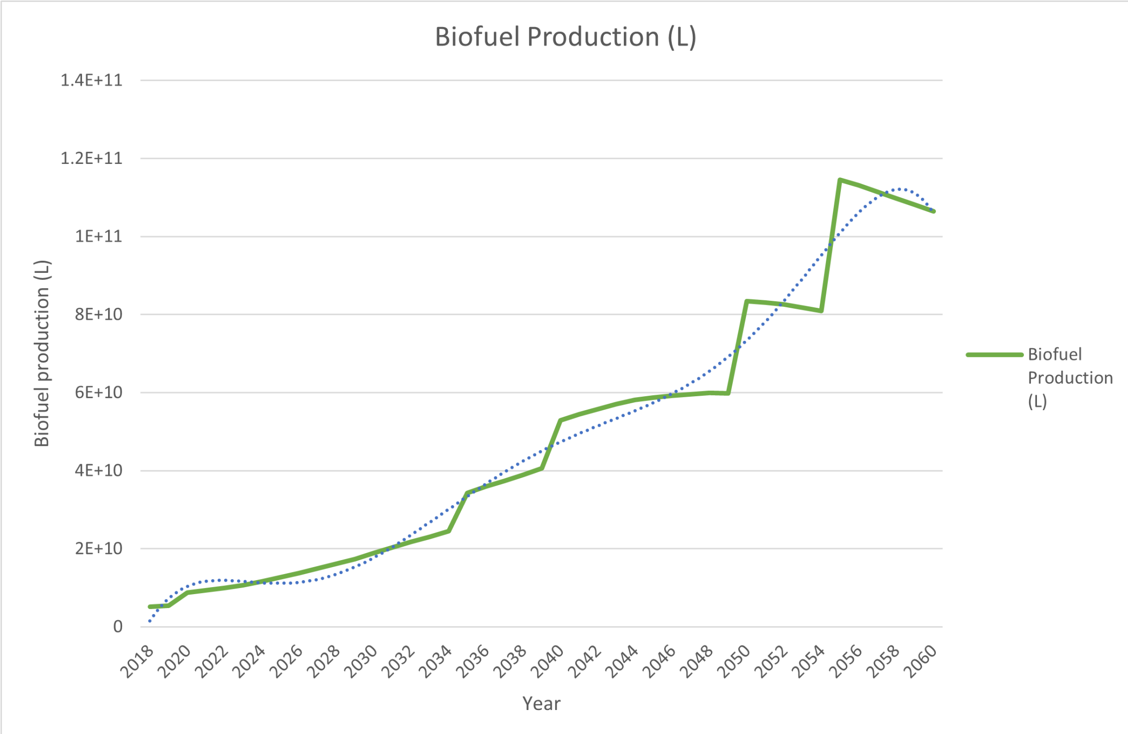


Figure 33: Yearly biofuel production

These stages become more clear in Figure 32 and 33, where on the dotted lines, changes occur in around 2028 and 2045. In 2028, sales of EVs start to ramp significantly and biofuel production goes from more or less stable, to increasing significantly. In 2045, biofuel production starts to ramp even further to completely supplant the use of fossil fuels in the fuel mix, and sales of EVs peak and start to decline towards the 2060 goals as the majority of the economically capable part of the population is in possesion of an EV. Biofuel production peaks in 2056 at 116 million litres, shy of the 150 million upper limit set as a basic constraint, before starting to decline as EVs become the main form of transportation. This production is just over 2.5 times the current production of palm oil in Indonesia. National sales of EVs stay well below the set constraint of 5 million yearly, and peak in 2041 at 4.37 million.

Note that this scenario comes with some assumptions. First, it is assumed that most of the production of EVs and biofuel production will be done domestically. While local production has some inherent advantages over importing products, the Indonesian transport system is not closed in reality, meaning that imports, exports and their related CO2 emissions should be accounted for. While exports should be considered in the later stages of this scenario, exports, imports and their related CO2 emissions will be left out of this scenario.

Second, it is assumed that the biofuel and the vehicles being produced will be done in a CO2 neutral manner. It is very likely that the CO2 emissions or mitigations for palm oil and algal biomass produced biofuels differ widely per source. This will not be accounted for here. It is also assumed that the electricity generated to run EVs is generated in a renewable CO2 neutral manner, either via solar, wind, geothermal or nuclear. The mining and transportation of the materials needed for the production of BEVs is likely also to be very energy intensive. For simplicity, it is assumed that this is done in a CO2 neutral manner as well.

Third, although technological advancements are partially considered in the implementation of different forms of biofuel production and BEV diversification, it is assumed that no radical advancements are made that can significantly impact progression of the scenarios previously presented. With the constraints set met, three distinct stages in this future scenario could be identified. These are the early stage (2018-2028), intermediate stage (2028-2045) and the late stage (2045-2060). For each of these three stages a what-how-why analysis can now be done, to determine the individual goals that have to be accomplished each stage. This analysis can be done for both EVs and biofuels, as the development of these technologies is mostly decoupled. Barriers for reaching these goals will be identified and a number of these barriers will be explored in-depth.

6.2 Stage I: Early stage

6.2.1 What needs to be done for EVs?

In this stage, there needs to be an infrastructure set up capable of producing at least 0.4 million EVs yearly for domestic sales with significant room for scaling as well fuelling and servicing this number of EVs. This goal can be split up in a number of sub-goals:

- Set up/attract deals with private companies/stakeholders for production infrastructure of batteries and EVs
- Create plans for setting up enough servicing infrastructure for future EVs
- Spread interest under local population
- Enable knowledge institutes to generate and spread knowledge in regards to EVs
- Hold feasibility studies on urban use of EVs

These sub-goals indicate how this goal for EVs will have to be accomplished. This goal will have to be accomplished in this stage to allow for timely growth of the EV industry to ensure a significant share of the private vehicle industry is taken over by EVs, lowering the load of needed production of biofuels and helping Indonesia's economy transform from a exporter of raw goods to one of manufactured goods. Initial systems for the generation and spread of knowledge for infrastructure and maintenance of EVs in this stage should help avoid bottlenecks in future stages. Seeds of interest should also be sowed in the population at this stage to ensure an economy can be built on EVs and that public awareness and knowledge spreads more easily. A number of these steps have already been taken by the Indonesian government to some degree. As has been discussed in 3.3.2 and 3.4, plans for the construction of a battery manufacturing plant and EV production have already being created, although the number of battery and EV units constructed on a yearly basis will not yet reach the expected numbers necessary by 2028. This means that further plans for production facilities will be necessary.

6.2.2 Barriers:

There are a number of barriers present that can hinder some of the sub-goals from being realised in this stage. While some of these barriers are directly relevant to this stage, a number of barriers that become significant in later stages are mentioned here as well. Addressing these barriers that could become a problem in a later stage early should be easier as they have not yet become widespread.

Supply line bottlenecks
Supply line bottlenecks forms one of the largest and most common barrier present. While not something that can prevent goals from being realised entirely, it can significantly decrease the efficiency of production and distribution of intermediary products and the final product, EVs. Bottlenecks in the supply line can take any number of forms and form a barrier that likely will never be entirely mitigated by policies. This is a barrier that can also be mitigated partially through learning by doing. Bottlenecks can form due to over- or under-supply of raw goods, inexperience in the labor force, missing knowledge, accidents among many other causes.

Protests against infrastructure
The construction of infrastructure for the production of intermediary products for EVs or production of EVs themselves can be protested against by the local population. This can slow down the realisation of setting up a production infrastructure significantly. The reason for protests can also vary widely, from complaints by local population to concerns of centralisation of work in a certain location, driving work out of other areas.

Infrastructural bottlenecks
While likely not a very large barrier in this stage yet, early adaptation of EVs during the early stage could be undermined due to a lack of charging stations, or the operational radius of early EVs could be severly limited due to the spread of available charging stations. Limited availibility of knowledge could also result into charging stations being out of service for significant periods of time, resulting in infrastructural bottlenecks.

EV monopoly formation
While inherently the formation of an EV monopoly might not be a barrier to the spread and sale of EVs, in the following stages the spread of EVs might become limited due to geographical or economical boundaries set

by the EV monopoly that has been formed. Increases in EV prices due to monopoly formation might dissuade less economically capable individuals from purchase.

Limited spread of knowledge

Spread of knowledge in regards to the maintenance of EVs specifically should be set up in time to ensure that there is a spread of service stations available. This barrier is related to the bottlenecks barriers. Like the infrastructural bottlenecks, it is likely that this barrier doesn't play a very large role in this stage yet, but should be addressed during this stage to ensure when the fleet of EVs increases in the following stages, the growth of service stations isn't left behind.

Lack of private sector interest

The private sector is next to the government the largest investor in the infrastructure for the construction and maintenance of EVs. Furthermore, larger private investors often have a branch that deals in the generation and spreading of knowledge as well. It is very important that enough private investors are attracted at an early stage of the scenario to ensure that the infrastructure projects necessary can be completed and relevant knowledge can be generated and shared.

Lack of public interest

The public will be one of the larger drivers for increase in CO2 emissions in a general BAU scenario due to the increase of the private vehicle fleet. If the public shows little interest in the purchase of EVs, the 2060 goals will very likely not be reached. It is very important that enough public interest and knowledge is generated in regards to the availability of EVs, so that EVs can occupy a significant market share.

6.2.3 Drivers:

It should be noted that there are also factors present that drive the early stage EV, although more limited in number.

Natural Resources

Indonesia is rich in nickel, which can be used to produce relatively cheap batteries, which when produced locally, have a cost advantage over imported batteries. As the battery is in most cases the most expensive part of a BEV, this gives locally produced BEVs an advantage to be sold locally as well.

Working Population

Indonesia has a large population of working age and will retain that at least until 2060. This large working population provides a domestic workforce that can be utilized to produce the necessary infrastructure needed to produce BEVs. A potential side-effect of this could be the spread of knowledge of BEVs under the local population and attracting more interest.

Scholarly Population

Indonesia has an increasing learned population and a large force of (university) students. They could help generate the knowledge needed for the early steps of this scenario to be implemented properly. A side effect of their presence working with BEVs is the further spread of knowledge and interest under the local population.

Nearby EV-producing countries

The presence of other countries that already have a working (B)EV producing industry mean that Indonesia does not have to reinvent the wheel. A lot of work has already been done to get BEVs working on a large scale and integrate their infrastructure in countries like China and Singapore. The steps they have taken may be taken as lesson to be learned for Indonesia to speed up their own progression.

6.2.4 What needs to be done for biofuels?

The production of biofuels will have to increase at least threefold, from 5.09 to 16.21 billion litres of biofuel. How this can be accomplished can be seen from the following sub-goals.

- Allocate more palm oil towards the production of biofuels
- Explore new sites for palm oil production
- Expand biofuel production infrastructure
- Set up knowledge institutes for generation of algal biofuel knowledge generation and coal reforming

- Explore sites for algal biofuel production

This goal has to accomplished to ensure a 30% biofuel mix is maintained in the fuel mix as the private vehicles fleet has been calculated to nearly double to 34 million in 2028, leading to significant increases in fuel consumption. The production of biofuels will have to increase at least threefold, from 5.09 to 16.21 billion litres. There are no to very few sales of EVs in this, meaning the impact on CO2 emissions in this stage will purely have to come from mitigation by biofuel mixing. Since biofuel makes use of the same fuelling infrastructure as fossil fuels, it is likely no expansion of the fuelling infrastructure will have to be planned for. To make up for the increase in biofuel consumption, more of the palm oil produced will have to be used in biofuel production. To ensure that exports of palm oil remain at a somewhat stable level, more sites for palm oil production will have to be found. As there is a limit on the total amount of palm oil that can be produced as a result of the total amount of arable soil available, other sources of biofuel, such as algal biomass, will have to be researched in an early stage of the scenario.

To ensure that enough knowledge and interest is generated, knowledge institutes and universities could cooperate on creation and handling of studies and courses in the field of biofuels, to ensure that a future workforce with enough knowledge is present for algal biomass to be produced and interest in the field is maintained and expanded on domestically.

Finally, to keep up with the production of biofuels, the production of other reagents, in this case methanol, will also have to be increased. As in later stages the production of these reagents has to increase even more, it would be ideal if a separate industry is formed for the production of these. This can come in the form of methanol production from coal, which only other purpose would be a product of export late in this scenario.

6.2.5 Barriers:

There are a number of barriers present that can hinder some of the sub-goals from being realised or be executed in a proper way in this stage. Some barriers mentioned here do not directly affect the progress of this stage, but do affect the progress of the following stages, and are thus mentioned here.

Supply line bottlenecks

The current fuelling infrastructure is already quite complex. Supply line bottlenecks will likely happen when this infrastructure is expanded and a fixed biofuel percentage is mandated. Similar to with EVs, it is unlikely that supply line bottlenecks can be entirely mitigated. They can be formed by over- or under-supply of necessary goods, accidents, missing knowledge and inexperience to name a few causes. It can be eased by learning by doing and making sure a knowledgeable workforce is present.

Protests against infrastructure

The expansion of biofuel infrastructure can be protested against in this case by both local groups and international groups of concern. The expansion of palm oil plantages are a difficult topic to handle, as the expansion of such plantages is mostly at the detriment of rainforest. The manufacturing infrastructure may be protested against due to concerns of work centralisation, or loss of jobs in areas where this infrastructure is not located.

Limited spread of knowledge

A number of companies in Indonesia are currently capable of producing biofuels. The amount of biofuels produced has to increase due to increased demand or a higher mandates fuel mix percentage. If the knowledge of efficient production is kept between the companies that are currently capable of producing biofuels, expansion is limited to these companies.

Lack of knowledge

Specifically with algal biomass, there is a risk that not enough knowledge is generated in time to be able to produce algal biomass on a large scale for biofuel production. This would mean that biofuel production has to pivot away from using palm oil as a source much later, which could have consequences for palm oil trade and expansion of palm oil plantages in favor of early large scale algal biomass production.

Lack of private sector interest

For the production of more biofuels, based both on palm oil and algal biomass, investments of the private sector are likely needed to fund research, development and expansion of infrastructure. If not enough private stakeholders are attracted, this research and development could take place at a much slower rate, or require larger investments from the government.

Rainforest destruction
Expansion of palm oil plantages to meet the increased demand for biofuels in this scenario would likely result in the cutting down of rainforest to make room for further plantages. Not only does the land change from rainforest result in a loss of biodiversity, it also lowers amount of CO2 that can be retained and thus decreases the lifetime CO2 reduction. Care has to be taken in reallocation of palm oil for biofuel production and palm oil meant for trade.
Cartel formation
Since there are only a handful of producers of biofuel that have been allowed by the government to produce biofuel, care has to be taken to prevent the formation of a cartel. Small biofuel producers are not allowed by the government to sell their product, while this handful is, allowing for price setting of the product in favor of the producers. Limiting the number of producers also decreases diversity and could make the biofuel production sector less adaptable to changes in the market.

6.2.6 Drivers:

There are also a number of drivers present that stimulate the progression of the biofuel part of this scenario.

Fertile Soil
Indonesia as a island nation around the equator of volcanic origin has led to it possessing very fertile soils. While most of these soils are utilized for other things than biofuel production, the overall production of biomass in Indonesia is very high, and interest to further make use of the waste streams it produces could lead to more biofuel production.
Working Population
Indonesia has a large population of working age which could be used to create the expanded infrastructure needed in this scenario. The creation of jobs in this sector could lead to the expansion of biofuel production capabilities. A side effect of this could be further spread and development of biofuel related knowledge under the local population.
Scholarly Population
Indonesia has an increasing learned population and a large force of (university) students. They could help generate the knowledge needed for the early steps of this scenario to be implemented properly or barriers for early expansion to be overcome. They could also work on solving the barriers present in future stages, such as the barriers currently present around large scale algal biofuels.
Present Producers
There are already a number of biofuel producers present in Indonesia. Indonesia is after Brazil the largest producer of biofuel. The effect of economies of scale could lead these producers to have a tendency to further expand, driving the production and use of biofuels.

6.3 Stage II: Intermediate stage

6.3.1 What needs to be done for EVs?

The intermediate stage is marked by a shift in the private vehicle fleet. The goal for EVs cant therefore be described in a single sentence. In this stage, the sales of EVs will ramp significantly, from small amounts in early sales from before 2028 to peaking above 4 million yearly sales from 2041 onwards. The supply lines and infrastructure established in the early stage will be tested and potential barriers that have arisen since will have to be fixed. Production infrastructure of EVs will be further expanded to allow for the sale of EVs abroad to help transition Indonesia's economy from a raw resource exporter to one that exports more manufactured goods. The goals for the EV side of this scenario in this stage can be summarized in the following points:

- Expand EV charging infrastructure
- Allocate supply lines for EV sales
- Spread knowledge and interest for EVs under local population
- Allow for diversification of EV models
- Expand EV production infrastructure

- Explore international markets

Significant increases in the market share of EVs and increased addition of biofuels to the fuel mix will lead to an overall reduction of 69% of emissions compared to a BAU scenario. This makes the goal for EVs slightly more complex, as the sales of EVs will have to significantly increase over the years. Unlike with biofuels, the sales of EVs and thus the market share of EVs can't be mandated by the government. The level of sales of EVs is determined purely by public interest and the effectiveness of the policies applied. This stage for EVs can be described as expansion and intensification of the process of production and expansion of the infrastructure and sale of EVs. Between 2041 and 2045 the largest number of EVs will be sold domestically, at 4 million units yearly on average. From this point on the number of vehicles sold will start to decrease as the market on newly economically capable individuals will start to decrease again. International markets should be explored at this point to make sure Indonesia's growing EV industry can be sustained.

6.3.2 Barriers:

There are a number of barriers present that can hinder some of the sub-goals from being realised in this stage. Most of the barriers in this stage have to do with sale of EVs, rather than their production.

Lack of public interest
The success of the EVs largely depend on the public interest to purchase the vehicles. There are a number of reasons why the public wouldn't be interested in the purchase of EVs. One of them is pure lack of interest. EVs might be seen as a novel vehicle technology that apart from early adopters fails to attract the attention of a wider audience. Furthermore, if not a sufficiently large enough percentage of the population is aware of the existence of EVs as a renewable vehicle technology it might also fail to reach a significant market size.

High competition from ICEVs
Currently, the car market in Indonesia is largely dominated by Japanese brands. The EVs confirmed to be produced are being produced by Hyundai, a Korean brand. The Japanese brands have so far yet to confirm that they'll will enter the car market with EV models on their own. This means that the market share hold by the ICEVs will likely be heavily defended. It is imperative that the EVs gain a significant market share early on as the majority of car ownership increase will take place between early 2030 and late 2040. If the EVs conquer a significant market share too late, this will result in a larger increase of ICEVs.

Stereotyping of EVs
Electric vehicles originally were brought on the market in the late 1910s. However, their implementation was a failure in part due to this type of vehicle being marketed towards and branded as a vehicle for women. This restricted sales from a significant portion of the population due to stereotyping. A similar trend has been happening recently, with Tesla specifically being stereotyped as a vehicle for rich individuals. If EVs want to reach a diverse range of the population, stereotyping has to be prevented.

Supply line bottlenecks
Similar to the early stage, supply line bottlenecks still pose a barrier to implementation. In this stage however, these supply line bottlenecks are likely to pose a larger problem in the distribution of EVs. Limited availability of EVs, or failure to identify areas where interest in EVs is high or low might pose a barrier to the sale of EVs.

Infrastructure bottlenecks
The use of EVs is in part dependent on the use charging infrastructure. Unlike fuelling for ICEVs, which takes a few minutes at best, charging of EVs often takes longer periods of time. This means either specialized fast-charging infrastructure needs to be available widespread or adaptation in driving routines would have to be made. If not enough of said infrastructure is available, it might lower potential sales in favor of ICEVs for which infrastructure is available.

Export favoured over domestic sales
Indonesia is intending to shift its exports away from export of raw goods to manufactured goods. The production of EVs can for a large part of its value be done with domestically obtained raw materials. A number of countries that have a significant portion of their population already on the economic middle class might become potential trade partners for these EVs. This might Indonesia to export a large section of the EVs produced to add to the export value. Care has to be taken to allocate a share not too large to exports, to allow enough EVs to be sold domestically first.

Foreign competition
While not directly a barrier, in this stage, the potential domestic market for private vehicles could be discovered by foreign producers. Introduction of new competitors in the market could complicate the transition from ICEVs to EVs. As Indonesia is a free market however, it could be difficult to prevent these foreign producers from entering the market. On the other hand, complete prevention from new competitors is also unwanted, as competition drives innovation.

6.3.3 Drivers:

The drivers of this stage are partly dependent on the success of the steps to be implemented in the previous stage.

Aware population
If the population has been exposed properly to the existence and benefits of EVs in the previous stage, the population will become a driver for the further production and consumption of EVs.
Scholarly population
Even if the population at large is not completely exposed to the existence and benefits of EVs, the scholarly population, mainly students, likely will. This has some limits to spread of the existence and benefits of BVs as it is dependent on the existence of a nearby knowledge institute like a university. On Java however, there are plenty of universities.
Companies
With the infrastructure completed, the companies will have to sell their products to be able to make a profit. Once these companies have been convinced of the existence of a market on Java in the previous stage, they will act to be able utilize the domestic market as much as possible, becoming a driver for the sale of EVs.

6.3.4 What needs to be done for biofuels?

Biofuel production in this stage will have to be scaled up significantly, as a larger part of the fuel mix (up to 50%) will have to be biofuels. Biofuel production has to be scaled from 16.21 billion litres in 2028 to 58.71 billion litres in 2045, which is nearly a fourfold increase.

- Increase allocation of palm oil to biofuel production if needed
- Increase biofuel production infrastructure
- Enable the use of algal biomass produced biofuels in the fuel mix
- Increase the biofuel in the fuel mix from 30% to 40% in 2035
- Increase the biofuel in the fuel mix from 40% to 50% in 2040
- Increase number of algal biomass production sites
- Integrate early coal methanation infrastructure in biofuel production

As production from palm oil and other sources reaches their limits due to lack of arable land, extra production will have to come in the form of biofuel from algal biomass. The significantly increased need for biofuel will also lead to a need for expansion of biofuel production infrastructure, especially when new sources of biofuel require different manufacturing processes. A significant sudden increase in the biofuel production is needed when the fuel mix changes from 30% biofuel in 2035 to 50% in 2040. This increase should be supplied mostly from algal biomass produced biofuels. Since the end of the initial stage, the biofuel industry has had 12 years to realise the large scale production of biofuels from algal biomass, and 22 years since the beginning of the scenario. This time frame should be long enough for the first large scale production sites to have come online. From this point on, an increasing amount of biofuels should be produced from an algal biomass basis.

6.3.5 Barriers:

There are a number of barriers present that can hinder some of the sub-goals from being realised in this stage. Most of the barriers in this stage have to do with starting the production of biofuel from algal biomass and its integration, as well as the increase of the percentage of biofuel in the fuel mixture.

Supply line bottlenecks

Supply line bottlenecks will likely continue to form a barrier to smooth implementation of biofuels. Now that biofuel produced from algal biomass is added to the mix, the complexity of supply lines increases. Again, this barrier can likely not be avoided completely, but its effect can be mostly negated over time by learning by doing. If the implementation of biofuels in the early stage didn't go smoothly and supply line bottlenecks occurred in that stage, it is likely more knowledge has been gathered in regards to this issue and the effects should be less this stage.

As the amount of biofuels being produced increases, so does the production of reagents necessary for the production of biofuels. One significant reagent is methanol. On a large scale, this can be produced from methanation from coal. The production of these reagents however, also has to be integrated with the rest of the supply line of biofuel production.

Cartel formation

Similar to the early stage, there is only a limited group of stakeholders that hold the government-licensed capability to produce biofuels. This could continue when biofuels produced from algal biomass are added to the mix. It is likely this group holds a significant amount of infrastructure and knowledge that they can use to gain a head start on the production of biofuels from algal biomass over other, smaller stakeholders. This could lead to the formation of cartels, which in turn could lead to more price-setting.

Limited spread of knowledge

The production of biofuels from algal biomass requires different knowledge than the production of biofuels from palm oil. While in earlier stage the promotion of knowledge generation has been advised, this knowledge could still be held by a small amount of individuals. Like with the previous barrier, the formation of cartels could led to a withholding of knowledge, leading to only a small group of individuals holding the relevant knowledge.

High costs of algal biomass produced biofuels

Currently, one of the largest issues with the transition of algal biomass produced biofuels from lab scale to industrial scale are the associated costs. Although the scenario allows for a large time frame in which these issues can be resolved, there is still a chance that these costs issues haven't been resolved by the time algal biomass produced biofuel could be added to the fuel mix. These high costs would likely then be transferred over to the consumer, resulting in high fuel prices.

Issues with higher percentages biofuel fuel mixtures

The 20-30% of the fuel mix that is made of biofuels does not affect the energy content of the fuel significantly. However, at higher percentages, the fuel mix starts to lean more to the properties of the biofuel, one of which is a decrease in energy content. Higher biofuel content might affect the performance of the fuel mixture, and should be monitored closely.

Difficulties integrating algal biomass biofuel production

The process of biofuel production from algal biomass differs from that of palm oil. This could mean that there are difficulties combining the two processes to lead to a consistent stream of biofuels. Algal biofuel potentially being produced by different stakeholders could produce this issue as well.

6.3.6 Drivers:

There are also a number of drivers present that stimulate the progression of the biofuel part of this scenario.

Scholarly Population

The growing learned population of Indonesia might produce enough knowledge to be able to help solve some of the issues currently faced by large scale algal biomass production.

Market conditions

If the biofuel market is stimulated properly by the Indonesian government, it will lead to the attraction of more actors to the biofuel market, in turn growing it. This is however dependent on the actions the Indonesian government takes in regards to the allocation of production and sale of biofuel to the transport sector.

6.4 Stage III: Late stage

6.4.1 What needs to be done for EVs?

The market share of EVs should overtake that of regular ICEVs at this stage. The sale of EVs can now be focused mainly on international sales, as the production methods and local materials used could give Indonesia and economic advantage over other neighbouring producers of EVs. The sub-goals for the EV side of this scenario in this stage can be summarized in the following points:

- Shift focus from domestic production to international production
- Allow for sharing of knowledge abroad
- Further diversify EV models
- Work on phasing out ICEVs

The late stage is the final stretch before CO2 neutrality is achieved. It sees a decrease in the total number of EVs sold domestically, as the largest part of the economically capable population has obtained an EV at this point. Normal ICEVs should begin phasing out at this stage, as the infrastructure and fuel pricing schemes prefer EVs. At this point the EV economy of Indonesia should have matured. Both EVs and knowledge could be exported at this point to countries that are still transitioning.

6.4.2 Barriers:

Although the number sales for EVs are expected to start declining from this point on, and the infrastructure should reach maturity by this stage, there are still some barriers present that could inhibit the progression.

ICEVs remaining relevant

To ensure that CO2 neutrality is reached by 2060, the share of ICEVs has to decrease enough that the remaining amount can be supplied by biofuels. This is largely dependent on the success of EVs getting control of the private vehicle market. Like in the intermediate stage, this provides another bottleneck for the success of EVs. While in the intermediate stage it had to be ensured that EVs reach a significant market share as early as possible, in this stage, EVs will have to become the dominant form of vehicles sold. If for whatever reason the share of ICEVs being sold remains too large, it is possible the production of biofuels is not large enough to reach a 100% biofuel fuel mixture.

Failure to penetrate the international market

While the success of this scenario is not really dependent on the success of the domestically produced EVs being sold abroad, eventually the domestic infrastructure will outgrow the domestic demand for EVs. Furthermore, the sale of domestically produced EVs could help with Indonesia's trade balance and confirming the success of Indonesia's shift in export strategies. The domestic production of EVs in Indonesia has to remain competitive on an international level to ensure it does not fall out of international relevance the moment the domestic market becomes saturated.

Limited diversification of EV models

The remaining groups of individuals that are holding out on the purchase of an EV have likely a reason to do so. A number of these have likely specification for vehicles that have not been met with the EV models already available for purchase. Limited diversification might lead to the demands of these groups not being met. Diversification might also be a costly process as the number of the vehicles for groups with specific demands are likely lower in number, resulting in higher production and distribution costs.

6.4.3 Drivers:

At this point the domestic market should be properly aware of EVs as a product and have had plenty of interaction with it for it to be spreading on its own. Drivers at this stage are mainly focussed on international expansion.

International focus of sellers

At this point the domestic market of EVs should reach saturation, where expansion of domestic sales in hardly possible anymore. As Indonesian domestically produced EVs have a significant advantage in cost due to locally sourced materials, the focus of sellers should turn to the international market at this point.

6.4.4 What needs to be done for biofuels?

Biofuel production will have to increase another two fold as the final two changes to the fuel mix are made to finally reach 100% biofuels in the fuel mix around 2057. Excess biofuels produced from algal biomass could be sold internationally or their constituents could be used in the chemical industry for the production of other products. The goals for the biofuel side of this scenario in this stage can be summarized in the following points:

- Shift biofuel production majority from palm oil to algal biomass
- Expand on algal biomass production sites
- Increase biofuel production infrastructure
- Increase the biofuel in the fuel mix from 50% to 70% in 2050
- Increase the biofuel in the fuel mix from 70% to 100% in 2055

The amount of biofuels produced will stabilize apart from these two increases and eventually start decreasing from 2057 onwards as biofuels as a fuel source are slowly phased out in favour of EVs.

6.4.5 Barriers:

Apart from increased percentages of biofuel in the fuel mix, which require larger amounts of biofuels to be produced, there are very few changes in this stage. This means not much barriers remain.

Issues with higher percentages biofuel fuel mixtures

As the biofuel percentage in the fuel mix changes from 50% to 100% during this stage, the fuel mix will adopt the properties of the biofuel completely. This means that properties like the lower energy density of biofuels will become more apparent. This could have adverse effects on the driving culture, which will have to adapt to these changes.

Issues with chemical industry integration

Compared to other reagents in the chemical industry, biofuels are quite a dirty product, made up of a number of different substances. If biofuels are to be used as reagents in the chemical industry, significant effort would have to be put in cleaning up the product before it can be used. The alternative is using biofuels purely for energy and heat generation.

Lack of secondary markets

With the amount of biofuels needing to be produced declining after 2055, the biofuel industry could be scaled down, or secondary markets for use of biofuels could be found. If this second option is chosen, the secondary markets have to be scouted properly beforehand to ensure there are options where the biofuel can be sold to.

6.4.6 Drivers:

Depending on the awareness of the population to Indonesia's plans for 2060, there should be a drive from the government and even the population to strive to eliminate the remaining fossil fuels from the fuel mix. This could be further stimulated by the Indonesian government setting deadlines for the fuel mix to be change to a higher percentage of biofuels.

7 Barrier exploration and policy recommendation

To further illustrate the complexity of some of the barriers that have been highlighted in the previous section, three issues will be explored more in-depth. These issues are illustrated here to highlight the difficulty for a single actor to overcome them. These barriers are then discussed with field experts to validate their presence and to discuss potential recommended actions.

7.1 Barrier Exploration

7.1.1 Fuel related issues

The form of fuel currently being used by the transport sector is fossil fuel based. Are a number of issues with this form of fuel, but the situation in Indonesia specifically brings up a number of other issues.

The majority of the fuel Indonesia uses in their transport sector is imported, as Indonesia has very limited domestic supplies of fossil fuels. To ease the cost of imported fuel, Indonesia makes use of a fuel subsidy policy. Indonesia is a bit of an outlier to the degree to which fuels are being subsidized, with very high subsidies compared to its relatively low domestic fuel production (Rentschler and Bazilian, 2017). The fuel subsidies were a 'hot potato' that has been tossed around in Indonesia politics since the 70s, but only recently have fuel subsidy policies had some successful reforms (Kyle, 2018; Skovgaard and van Asselt, 2018). The fuel subsidies tie a certain amount of Indonesia yearly budget, depending on the international fuel prices. This not only makes Indonesia more dependent on the international market, it also has to allow for a certain amount of its budget to be spent here. This budget could be allocated to other sources more efficient on reducing the amount of fuel used, such as infrastructure projects and development and implementation of more efficient forms of transport. Removal of subsidies has also been shown to reduce long-term energy usage (Durand-Lasserve et al., 2015). In of themselves, the policy was meant to stimulate industrialisation, economic growth and provide economic relief for Indonesia's poorer class. In reality however, it is often the middle and upper class who benefit more from the fuel subsidies and a number of unintended side-effects follow from the policy (Rentschler and Bazilian, 2017; Agustina et al., 2012; Commander et al., 2015).

It might seem that fuel subsidies are the cause of more harm than good. Removing such a policy is not easy however, as the economic relief it provides would have to be accounted for through other means, which are often not so simple, as fuel prices indirectly impact a number of consumer goods (Inchauste and Victor, 2017). The economic relief the fuel subsidies provide, as skewed as the effects may be towards other economic classes, can not be understated and proper substitutions would have to be found. Other substitutions for promotion of industrialisation would have to be found as well.

Finally, one last group of actors that might be affected positively from the removal of fossil fuel subsidies are the biofuel producers. The fuel price in Indonesia is significantly below the international price of fuel, removing the fuel subsidies and tying the Indonesian fuel price more to the international fuel will lead to fuel price increases. Biofuels, which on a large scale can be produced at lower cost than the international fuel price would benefit more from this increase in price. While in Indonesia the production of biofuel is still subsidized, increased fuel prices could attract more biofuel producers or lead to biofuel producers to intensify their production (USDA, 2022; Kharina et al., 2016). [5] The interaction of actors with fuel subsidies and the benefits and downsides of this policy are given in summary in the table below.

Table 10: On Fuel Subsidies

Benefits from maintaining fuel subsidies	**Benefits from removal of fuel subsidies**
(Economic) lower class, Small businesses	Government, Biofuel producers
Upsides	**Downsides**
Provide economic relief for economic lower class, Promote industrialisation, Promote economic growth and development	Economic middle and upper class benefits disproportionally, promote wasteful behaviour, increase CO2 emissions, discourage economic investment, lock-in of fossil fuels, drain state budget, increased dependency on international markets

[5] It is possible that the biofuel producers are currently being compensated to the equivalent of the international fuel prices in their subsidy scheme, in such a case biofuel producers neither benefit or suffer from the removal of the fuel subsidies. The actual method of subsidisation is not known

7.1.2 Market attraction and Actor interaction

It is likely that Indonesia will have one of the largest automotive markets in the near future, given the trends suggested in this report. The presence of a growing market is likely to result in new market actors being formed or entering the market. There are a number of points that are important here.

One important point that has to be discussed is in regards to whether the production of EVs or biofuels should take place domestically, or imported. Similarly, one can discuss whether or not to make use of already existing designs for EVs or to create one themself, based on the resources available. There are some arguments that can be made for both. For importation, Indonesia can make use of already existing economies of scale in nearby countries that already have significant production of EVs. Such countries are China, South Korea and Japan. This would save Indonesia from having to build construction infrastructure locally and having to invest into the local generation of knowledge in regards to the production and construction of a local EV model. Similarly for biofuels, Indonesia could import either produced biofuels or partially converted biomass for last step local biofuel conversion.

For domestic production, the economies of scale and knowledge pool would have to be constructed nearly from nothing. However, domestic production has some significant upsides to it as well. Domestic production of EVs and biofuel is more often than not economically advantageous to invest in for the Indonesian government due to returns on investments that can be made. The production would generate jobs, which in turn could generate tax revenue. Similar for the sale of produced goods, tax could be applied here as well. Domestic production isn't as dependent on international trade either, and in the case of Indonesia, this would help stabilize their trade balance. Alternatively, it would lessen the country's dependence on foreign trade. In short, domestic production can help create jobs, generate addition tax incomes to counterbalance government investments and stabilize the international trade balance. In the long run, it could be expected that Indonesia is capable of generating a sufficiently scaled EV production economy to compete on the world stage, given the natural and demographic resources it has available.

In regards of building a new design or making use of an existing one, Indonesia has so far chosen to go with existing designs. In partnership with Hyundai and LG Energy Solutions, Indonesia is in the process of building plants for batteries and EVs of their designs.

Another point is in the different needs for the two technologies that are to be implemented, although for both the eventual goal is the same. While early infrastructure for the production of biofuels is already established, it is expansion of the needed infrastructure that is needed for the progression towards the 2060 goals. Even in Indonesia's own plans, increasing the percentage of biofuels in the fuel mix calls for expansion of biofuel production. In later stages, it is technology that will be needed.

For EVs, it is market expansion to EVs that is the most important. In the case of domestic production of EVs, which seems to be the route Indonesia is planning to take, domestic production infrastructure will have to be established. It can be expected that the actors to which the market will be expanded hold the needed level of technology for the construction of the domestic production.

The difference between the two forms of technology is that for biofuels, intensification of infrastructure and increasing knowledge is needed with market diversification at a later stage, while for EVs, market expansion is the main need. The two forms of technology are complimentary in the presented scenario, but their needs to succeed are very different.

The interaction between the government and the producers of biofuel and EVs is also a point of interest. Many of the actors that have interactions with the EVs, the energy producers, infrastructure owners and maintainers are government related. Many of these actors act under orders directly from the government, while the producers of EVs could be allowed some form of freedom of acting. The government has produced mandates to who and who is not allowed to sell biofuels for the fuel mix. These are mainly big cooperations (Ministry of Energy and Mineral Resources of Indonesia, 2020a). However, roughly half of all palm oil produced in Indonesia is done by smallholders (Kharina and Searle, 2016). If Indonesia wants to increase the amount of biofuels produced, it will likely have to come to an arrangement with these smallholders. It is likely that a number of arrangements will have to be made to ensure that the goals of the various actors that act within this system align, and that they properly work together.

These points indicate a number of choices the Indonesian government will have to consider to ensure the scenario follows the path of progression. It is important to note that while these choices tangentially are about the technologies, they also include actor interactions about which decisions will have to be made.

7.1.3 Infrastructure

One final complex barrier is in regards to the expansion and implementation of new infrastructure. There are a number of factors to consider in regards to infrastructure that could seriously affect whether or not the future scenario can be realised or not. Large urban sprawls and lacking road infrastructure might have driven the population to adapt by purchase of motorcycles, which take up less space on roads and are capable of driving on a wider range of roads. Shorter supply chains, the distance one has to drive from home to work, might change when Indonesia shifts from being an exporter of raw goods to one of manufactured goods to longer ones. This would theoretically shift favor of vehicles choice more to cars, as they have a larger carrying capacity and larger operational radius. However, the urban sprawls present in Indonesia might limit the degree to which supply chains extend. This makes it difficult to judge whether or not more cars will be purchased when the average economic standard in Indonesia is raised. It is the interaction between the population and the change in these properties that will likely affect the amount of cars that will be purchased in a future scenario.

In turn, there is a chance that if Indonesia turns to resolving the growth of the road infrastructure in relation to the economic growth, the amount of cars present will increase as a result of induced demand. More available space on the road leads to more vehicles on the road. Judging what is the most important factor that affects that amount of cars that will be present in a future scenario has to be seriously evaluated. In this report, the increase in wealth of the average Indonesian as a result of a shift in the Indonesia economy has been taken as the most important factor, resulting in a significant growth of the amount of cars present in a future scenario, has been chosen. However, it might just as well be that it is the infrastructure present, not the economic standard, that determines from this point on whether or not the amount of cars present will increase or not.

Alternatively, one option that has largely been left open in the final future scenario is the mitigation of purchase of private vehicles in their entirety. This can be achieved by increasing the share of individuals transported by public transport, like rails and BRT or increasing the amount of individuals per vehicle per trip by means of promoting car-pooling for instance. It has been discussed in Chapter 3, Section 4 that public transport is not competitive compared to private transport due to current infrastructure and lack thereof and these (government-owned) companies largely not having a for-profit based business model. From expert interviews it turned out that investment in rail infrastructure is only done by the Indonesian government and a Chinese consortium under the belt and road initiative. Even so, it is not unlikely that given the long time span of this future scenario the option of improving infrastructure, better city planning and changing the business model of public transport is feasible. It is likely that the number of private vehicles purchased from 2018 to 2060 can be significantly lowered if effort is put into making public transport a significant competitor to private transport.

It should be noted that infrastructure is a key component for the future scenario to be realised. The realisation of the needed infrastructure is a process that relies on a number of actors. The responsibility of maintenance of fuelling infrastructure is dependent on the subsidiaries of PT. Pertamina, which in turn is the state-owned gas and oil company. However, from expert interviews it turned out that it is likely that if electric fuelling infrastructure were to be constructed, this would fall under the responsibility of PT. PLN, which is Indonesia's state owned electric company. The development of electric fuelling infrastructure for BEVs could cause indirect competition of fuel sales between two different state owned companies.

The responsibility of maintenance of roads is a distributed responsibility shared between owners of toll-roads, the Indonesian government and local municipalities. The realisation of the needed infrastructure is therefore a shared project between a number of actors with different interests and intentions. The difficulty lies in the realisation that improvements and expansion of the infrastructure is in the long term profitable due to increased inter-connectivity and efficiency of transport, while in the short term it is a massive budget expense. From expert interviews is was understood that there still is support for the construction and use of toll-roads, which could mean that the development expenses for road infrastructure could in part be shifted to the private sector.

The takeaway from the exploration of these barriers is that the solution to the barriers is not as simple as just introducing a technology to the barrier. Most of these barriers are still in place because of properties in Indonesia being kept in place due to existing systems(Unruh, 2000). Although efforts are being made to reform fuel subsidies, the subsidies have been kept in place for a long period of time due to the system formed around it making reform difficult, for instance. To be able to solve these barriers, the system around the barriers will have to be affected. A policy tool that can be used to address these barriers is policy package creation, as a part of an expanded form of backcasting, participative backcasting.

7.2 Recommended areas for policy actions

Although the actual discussion and formation of policy packages will be beyond the scope of this report, here, a number of recommended areas for policy makers will be suggested, along with a number of potential policies which could be further refined into policy packages which could be used for implementation to realise the combined scenario to reach the 2060 goals.

7.2.1 Policy package creation

The difference between a policy and a policy package is that while a policy is intended to address a single issue in a certain way, policy packaging makes use of synergistic relations between multiple policies to address potential side-effects from a policy and increase effectiveness. The definition of policy packages used here is as stated in Appendix A.1, and defined by Givoni et al (2013). There are a two number of key identifiers for policy packages that can be explored to explain policy packaging. These are effectiveness and efficiency.

Effectiveness

Effectiveness can be divided into two aspects, the effectiveness of the policy measure on the specified objective(s) and effectiveness of the policy measures on adjacent objectives. That policy measures affect multiple aspects of a problem has already been observed in the example given in the previous section. Givoni et al. (2013) define these two forms of effectiveness as *Immediate effectiveness* and *Collateral Effectiveness* respectively. While policy measures are generally selected for the effectiveness for their intended objectives, the effectiveness on adjacent, external objectives can also contribute to the net effectiveness. While for the intended objective this effectiveness can be considered net positive in all cases, the effectiveness on external objectives might be negative. Here, policy packaging is used as a tool that can help mitigate or "design out" these potential negative effects on external objectives, while making use of potential positive effects on external objectives (Gudmundsson et al., 2010).

Efficiency

Efficiency can be translated in terms of cost. There are two types of costs that can be considered. There are direct (financial) costs of implementation or enactment of a given policy measure and the indirect (financial) costs of overcoming barriers faced by the policy measure. For example, the direct costs for reallocation of urban infrastructure to allow for streamlined roads would be the cost of demolishing present infrastructure and constructing new infrastructure. The indirect costs would in this case (not limited to) lobbying for the construction of new infrastructure, setting up contracts, buying up the needed land and remunerate the individuals living on said land, for instance. Increases in efficiency can occur by selecting for policy measures that allow for decreases in these indirect costs.
Policy measures can further be divided into measure types. Measures have historically been divided into three groups, regulatory, economic and informative (Bemelmans-Videc et al., 1998; Hill and Hupe, 2002).

The goal of creating policy packages over enabling a large number of simultaneous measures is the potential synergistic nature of policy packages to allow for positive externalities while designing out negative externalities and their potential to lower indirect (financial) costs. To allow these effects of policy packages to be realized, there is a need for participative interaction in the creation of said policy packages, which will be accomplished by integrating interviews during the development cycle of the policy packages, which can be established using participative backcasting.

7.2.2 Need for participative backcasting

In reality, policy measures are comprised of all policy changes, interventions, realignments and modifications made. Therefor, it would be logical to assume that there is no shortage of policy measures that can be made. In previous established literature, no less than 120 measures were found for low-carbon urban mobility and

140 measures in regards to a walking and cycling based urban transport system in the UK (Hickman et al., 2009; Tight et al., 2011). There is however, something to be said about the effectiveness of a given policy measure. There are two qualitative methods to establish the effectiveness of a policy. For one, policy measures can be judged by their nature of *outcome or objectives*. To expand on the previous example, reallocation of urban infrastructure may result in decreased travel time, decreased pollution and may partially solve traffic congestion and may be viewed positively by commuters of which the travel experience is positively influenced, but negatively by locals who suddenly have a highway on their front door or are forced to relocate. Second, policy measures can be judged by the *process* by which their objectives are meant to be obtained.

There can be considered to be a split between academic actors and bureaucratic actors as to which method to use to determine the effectiveness of a policy. As is stated in Appendix A.2, with regards to the academic field, there is a lack of real world engagement, creating a focus on quantitative ex-ante analysis of potential policy options (Marsden and Reardon, 2017). In academic literature, there is often little acknowledgement of the bureaucratic actors and their role in formulation, transformation and implementation of academic transport policy research into real-world transport policy.

It should be noted that unifying these two actors is difficult which comes from the inherent difference in outlook on policy problems. While academic actors use an often systemic understanding that contextualizes the role of transport policy from an appreciative holistic and socio-cultural standpoint, bureaucratic actors often characterize the role of policymaking from a competitive coalition-filled and often antagonistic process across an institutionally fragmented networked polity (Ney, 2012). In essence, systemic scenarios created by academic actors in which (rigid) policy measures can be applied could be considered naive compared to reality in which a give-and-take relation between actors and the iterative process of competition between values and beliefs leads to more fluid policy measures. It can be said that academic actors therefor mainly judge the efficiency of a policy measure by their goals, while bureaucratic actors judge efficiency by the process, as a result of iterative competition between different values. The need for participative backcasting arises in the role each of these actors fulfill. While academic actors are very capable of identifying the presence of policy problems using a systemic framework for identification, bureaucratic actors provide a comprehensive understanding of the policy measures' characteristics and interrelationships between policy measure and affected actors (Givoni et al., 2013). To allow for the greatest efficiency, both actors are required in the process of policy measure creation and management. This can be accomplished using participative backcasting.

7.2.3 Policies for adressed barriers

Fuel subsidy fund redistribution

The first thing that can be considered is a redistribution of the fund currently available for fuel subsidies. The intended effects of the fuel subsidies are economic relief for the economic lower classes and promoting industrialisation. However, as previously discussed, there are also a number of unintended side-effects that arise from this policy. To allow for redistribution, care should be taken specifically for the economic lower class that they don't bear the brunt of the consequences of the redistribution. They should be compensated in another way, for instance by monetary remuneration or subsidies on consumer goods. Increases in disposable income has been shown to protect the economic well-being of the economic lower class (Durand-Lasserve et al., 2015; Skovgaard and van Asselt, 2018). The funds made available from the fuel subsidies can be used for the construction and maintenance of large scale infrastructure projects. This includes combined infrastructure projects of roads, rail and transport of electricity along the same lines.

Alternatively, the fuel subsidy funds can be used to further invest in the construction, expansion and intensification of biofuel production infrastructure, to allow for more biofuel to be put into the fuel mix, which could bring the price of fuels down. Large scale biofuel production has been shown to be economically competitive with fuel prices depending on the feedstock used, and is economically viable for palm oil (Acevedo et al., 2015) [6]. As palm oil, the feed stock for most of Indonesia's current biofuel production, is produced domestically, this would make Indonesia much less dependent on the international fuel market, which could counteract swings in fuel prices as a result of international effects.

[6] This is excluding the externalities that can be attributed to the emission of CO2, which are hard to attribute an economic value to.

Infrastructure

A given amount of the fuel subsidy funds can be reallocated to Indonesia's government-owned oil and gas company, PT. Pertamina, to invest in electrification of the private transport sector by constructing fuelling infrastructure for BEVs along the existing network of (fossil) fuelling stations owned by PT. Pertamina, which as previously discussed is quite intensive. This allows for early exposure of Indonesia's private transport sector to BEVs.

Indonesia's road infrastructure development has been outpaced by the economic growth for quite some time now. A large amount of Indonesia's roads suffer from significant congestion, and inefficiency of the road network negatively affects Indonesia's competitiveness and productivity (Chesheva et al., 2020). By using a part of the funds for fuel subsidies to invest in infrastructure and involving the private sector, the development of road infrastructure should be able to keep better pace with the economic development. There is however also a need to develop long-term plans and focus on efficiency and effectiveness, as while spending on infrastructure has increased, the effectiveness of the infrastructure in place has not increased to the same degree (Chesheva et al., 2020). By starting combined infrastructure projects that include energy transport, road and rails, interconnectivity can be increased and congestion can be decreased, in turn raising Indonesia's productivity and competitiveness, which in turn can attract more foreign investors and increase industrialisation.

Market attraction

To enable the domestic production and sale of BEVs in Indonesia, Indonesia must attract investors well enough to set up production. This has already been done with a cooperation between the government of Indonesia, LG Energy Solutions and Hyundai, to allow for the production of domestically produced batteries. For the scenario to succeed however, significant expansion of the production is needed. To attract more investors Indonesia will have to convince them that Indonesia is a place to invest in. This can be done in two ways, spreading awareness and making Indonesia more favourable to invest in. Indonesia is becoming a more favourable place to invest in as the available market for BEVs as a product increases due to increase in average wealth and by increasing and investing in Indonesia's road infrastructure. Spreading awareness is however something that doesn't happen automatically and can be done by holding investor meetings or summits during which Indonesia presents itself as a favourable location for production. Here, it can make use of the raw resources it has available, the increasingly learned population and large labour force. This does not have to be restricted to BEVs technology either, and can in turn promote general industrialisation of the country in general. Care has to be taken however, that the promotion of investment is not limited to a given area, as Indonesia's geographical constraints as a island nation make it vulnerable to uneven industrial development.

The policies that have been suggested here are summarized in the table 11 below.

Table 11: Potential fields for policies, policies that can be taken and their effects

Field	Policies taken	Intended Effect(s)	Involved Actors
Fuel	Restructuring of fuel subsidies, Consumer good subsidies Monetary support for lower class Investments in biofuel production	Liquidation of government funds without serious consequences for the economic lower class, Increase of biofuel production, Stabilization of fuel prices, Lower CO2 emissions from transport	Government, Economic lower classes, Biofuel producers
Infrastructure	Investing in BEVs fuelling infrastructure Combined road, rail and electricity infrastructure investment, Attracting private sector investment, Creation of long term infrastructure planning	Expansion of BEVSs infrastructure, Exposure of the public to BEVs, Increased infrastructure efficiency, Mitigation of congestion Increased competitiveness and production, Lower CO2 emissions from transport, Attraction of investors for domestic production of goods	PT. Pertamina and its subsidiaries, Government, Private sector, PT. KAI
Market Attraction	Investor meetings and summits, Government-company cooperation	Attraction foreign investors, Spreading awareness of Indonesia as a suitable investment location, Promoting industrialisation	Government, Knowledge institutes Foreign actors, Foreign Companies

It can be seen that although the policies taken here are tangentially related to the scenario, they are not really to effect the implementation of the renewable technologies suggested in the scenario, but rather the systems surrounding them. There are a number of other actions that can be taken to further ensure that the policies can be discussed, shaped and implemented successfully.

7.2.4 Further Recommended actions

Apart from the potential policies and the steps taken in the future scenario suggested above, one thing that can be done to ensure further efficiency of implementation is the creation of a number of working and discussion groups where plans can be formed between the actors relevant.

One such group is the group involved in the construction, maintenance and expansion of the necessary infrastructure. Such a group would contain members from PT. Pertamina, PT. KAI, the private investment sector, the Ministry of Infrastructure and municipal governments. In this group plans can be discussed for the implementation of infrastructure, such as roads, rails and fuelling stations. It is important that both bureaucratic and academic actors are involved with these plans to be able to judge policies on the fields the actors specialize in for efficiency, as has been discussed earlier.

Another such group is one that helps with the further industrialisation of Indonesia through the attraction of foreign investors form domestic production of goods. Such a group would be comprised of commercial branches of the government, local businesses, already investing foreign investors and knowledge institutes. The goal of such a group would be to spread awareness of Indonesia as a good location for investment, thus creating jobs and promoting industrialisation.

One final group is made of biofuel producers and knowledge institutes. Currently it is only possible for a select group of biofuel producers to sell biofuel to be used in the fuel mix. This group is mainly made up of the largest producers of biofuel, a large number of which have organised into a group called APROBI (APROBI, 2022; Ministry of Energy and Mineral Resources of Indonesia, 2020a). To prevent cartel formation and grandfathering

of right to sell biofuels once the amount of biofuels that need to be added to the fuel mix increases in the proposed scenario, more producers of biofuel would have to be added to the list of sellers. Small-scale producers make up approximately half of the total production of palm oil (Kharina et al., 2016). Including small-scale producers and knowledge institutes provides variety to the group which can be utilized once biofuel from different sources has to be included to make up the difference between what can be produced from palm oil and is needed.
These groups could be formed through the means established in the participative backcasting framework, where a backcasting scenario is used as a basis for workshop in which policies for that scenario are created and worked out by a group consisting of relevant stakeholders. Aside from the formation of groups for policy package discussion, formation and implementation as a continuation of the participative backcasting framework, the backcasting scenario itself could be further refined and applied on a more local scale to allow for more specific properties of a given area. For this, a number of potential weaknesses and oversights are elaborated on in the Discussion. Finally, it should be stressed that for effective and efficiency formation of future scenarios, plans and policy packages, the formation of a unified group who holds the sole responsibility of forming such plans is necessary. Currently, due to the spread of responsibility of difference branches of government over different sections of transport, each groups has attempted to form plan individually. A restructuring of responsibility over transport and the formation of a number of groups in which scenarios can be formulated and discussed should help solve this.

8 Conclusion

In this report, an investigation was done into the things that have to be done for Indonesia to realise their 2060 goals of CO2 neutrality for the private transport sector. Indonesia is looking to shift its export economy from raw goods to manufactured goods. Combined with increase in average wealth due to this shift, a trend was established, in which it is likely that the fleet of vehicles in the private transport will increase significantly. Indonesia's own plans so far to combat the CO2 emissions from the transport sector as a whole only include the use of biofuels in their fuel mix. This measure has been deemed as being likely not enough to be able to reach the 2060 goals.

A BAU scenario was established to get a scope of the increase in CO2 emissions based on trends that were established. Potential 2060 emissions range from 120 to 616 MT of CO2 emitted yearly by the private transport sector, depending on the method of calculation used. Based on three renewable transport technologies that could help mitigate the predicted CO2 emissions, biofuel, BEVs and hydrogen, three scenarios were created to illustrate how much CO2 could be mitigated from these technologies on their own. None of these technologies are capable of mitigating the worst case scenario on their own. However, a pathway dependency of biofuel and BEVs make these two technologies the most likely choice for a combined scenario. Available resources such as nickel and soil for palm oil production as well as a large workforce and increasing learned population are capable of driving these two technologies.

A combined scenario was made combining biofuels and BEVs that was tweaked to be able to mitigate the worst case scenario CO2 emissions. This scenario could reach CO2 neutrality as early as 2055. However, its success is dependent on resolving a number of barriers that emerged. Significant barriers of a complex nature emerged in the fields of fuel, infrastructure and market attraction. Resolving these barriers likely requires a concerted effort of multiple actors from both the academic and bureaucratic fields. To be able to help resolve the emergent barriers, the use of participative backcasting, in which the established combined scenario could be used to create workshops in which actors from different fields could discuss the barriers it presents, refine the scenario and formulate policy packages to efficiently and effectively deal with the barriers. To help with the potential onset of such a workshop, a number of involved stakeholders were mentioned, potential policies that could be taken and further recommended actions were suggested for the emergent barriers.

While the issue of CO2 emission growth can be resolved, it is important to note that the solution to the issue and the barriers that emerge from the system that surround it can not be solved by technology alone. It requires a combination of the right (pathway dependent) technology and the combined effort of multiple actors from both academic and bureaucratic fields for effective and efficient policy package formation to be solved. To be able to achieve this, Indonesia should establish groups containing actors from different field to allow for plans to be further worked out, barriers to be identified and a proper scenario to be created.

9 Discussion and Recommendations

There are a number of issues that have not been properly addressed throughout this report due to time constraints and risking the report becoming too diverse. A number of these issues will be briefly addressed here, combined with a number of interesting findings that may help the reader build further on the research done here. Limitations to the methodology used in this report are also highlighted here.

9.1 Points of interest

9.1.1 Parallels between fuel subsidies and the electricity market

9.1.2 Parallels between nuclear energy and infrastructure investments

9.2 Limitations of the methodological framework used

The choice of using pathway dependency to select for sustainable transport technologies that can be back-casted in individual and combined future scenarios to provide solutions for the established problem have some limitations that will be discussed here.

9.2.1 Blind spots in stakeholder analysis and stakeholder relations

There are a number of blind spots in the stakeholder analysis done here. This is mainly due to the limitations that come with remote investigation of the issue. One large blind spot is the influence the Users, or the public holds over the situation. It is hard to determine remotely what and how the Users can influence the progression of the scenario. In-depth local investigations would have to be done to properly explain the relation the Users have with the other stakeholder groups and how big their level of influence is in reality. In this report, based on the data available, it has been assumed that of the main four stakeholder groups, the Users have the least power in influencing the progression of the scenario.

It is also possible for the relation of influence to change over time, as more institutions are developed or changed. For instance, it might be that when producers of biofuel from algal biomass become more prevalent for the progression of the scenario, the influence the biofuel producers as a whole have on the scenario changes, as the group could effectively split between the different producer types. The Users might also gain more influence as the sale of BEVs becomes more prevalent for the progression of the scenario. The potential change in relations between the stakeholders as the scenario stands and progresses is something that could warrant further investigation.

Finally, one thing to note about the stakeholder relations is that the western model of stakeholder relations, in which there are four or five groups, Government, Companies, Knowledge Institutes, Users and Societal Organisations, might not hold up for Indonesia. From what has been discussed in the report, it seems like the Government holds a more than equal relation over at least the companies as a stakeholder, due to the nationalisation of number of companies. This could result in a more top-down stakeholder relations situation, in which the Government, with a limited direct control over a number of Companies, could exercise their influence over the other stakeholders more easily. A more in-depth exploration of the relations between the stakeholder groups, and the assumption that they can act on an equal level should be investigated to further elaborate on the future scenario proposed in this report.

9.2.2 Effectiveness of backcasting over the timeframe discussed

There is something to be said about the timeframe used in this report. While most studies that have been investigated during the literature study have backcasting timescales often in the range of 15 to 25 years, the range of this backcasting study is nearly 40 years. Including the complexity of a topic like changing the makeup of the private transport sector to a sustainable one, there is a large chance of inaccuracies made in this study because of the large timescale. The large timescale might lead to compounding of inaccuracies as the scenario progresses, leading to wide differences from the actual reality.

Inaccuracies might also follow from unpredictable world events, which may or may not act in favor of the progression of the future scenario. One such event is the Russian war in Ukraine, which in Indonesia has led to greater exports of coal, which benefitted the trade balance. These events lie mostly outside the range of prediction, and are ignored in this report. One way the effects of the large timescale have been partially mitigated is by splitting the future scenario into three stages, each with its own goals. Although this does not completely remove the chance of inaccuracies, it allows for each stage to be backcasted somewhat independently in potential followup workshops or studies which can further refine the scenario and stages. The inaccuracies can then be treated per stage, which is more in line with literature, with each stage being between roughly 15 years long.

9.2.3 Limited coverage from expert analysis and writer

Although barrier validation was done using expert analysis, there still exists a chance that barriers may present themselves from angles that weren't considered in this report. One such angle already has been discussed in regards to the public as a potential influential stakeholder that hasn't been significantly considered in the development of the scenarios. It might be the case that more of these barriers are hidden from view due to the angle of approach taken by the writer. Lack of local input might have led to development of future scenarios that have a 'western bias' and have only limited application to the culturally and socially different Indonesian population. Variety on viewpoints for development should help mitigate the bias presented.

9.3 Discussion on scenario creation

9.3.1 Likelyhood of the BAU scenario being followed

There are a number of gaps in the knowledge needed to confirm that if nothing is done, the BAU scenario will be the scenario that will play out in the near future. While car ownership has been set as a key determinant for reaching an economic level (upper middle class) by the World Bank, and it is very likely that a large section of the population will trend towards this economic level in the near future, this doesn't have to guarantee that the car ownership will increase drastically. There are a number of properties present in Indonesia that might inhibit the further growth of car ownership, even if the average wealth grows in Indonesia to an extent that a large section of the population becomes capable of purchasing a private vehicle. These properties are the large urban sprawls in combination with shorter supply chains and the growth of the road infrastructure of Indonesia not being able to keep economic growth. A large number of roads has seen significant traffic jams.
There is a chance that the lack of road availability, or congestion, promotes the use of alternative forms of transport, such as motorcycles, over that of cars. In such a case, the proposed scenario would have to be altered to take such changes into account. The emission level and behaviour of private transport sector of which the majority is made up of motorcycles might be different than that predicted here.

9.3.2 Validity of algal biomass being viable in 20 years

There are still serious barriers present for the large scale production of algal biomass for biofuel production, and one can still seriously debate whether or not algal biomass can be produced at an economically viable rate in 20 years. While a lot of research has been done on a number of different species of algae, under various conditions, resulting in a number of favourable results, there are still a number of significant problems present that prevent this research from being scaled up to industrial levels. Most of these have to do with the way algal biomass is produced. Algae are grown in an aqueous environment, which on large scale, results in a number of problems.
One significant problem is the nutrient availability in a large scale production facility. While on small scales, the nutrient availability can be easily adjusted, this is something that is not easily regulated on a large scale. A related problem is the re-use of the nutrients. Algae, like most other plants, require a number of essential elements and minerals for their growth, significant ones being phosphorus, potassium and (bioavailable) nitrogen. For the production of a large amount of algal biomass, a large amount of these elements has to be available, and would end up locked inside the biomass. Phosphorus in particular is currently already an element with limited availability. This would mean that a method would have to be found to extract these elements in their bioavailable form from the algal biomass for re-use in growth of new biomass.
Another problem is the availability of oxygen for the growth of the algae. While on smaller scales, like with the nutrient availability, the oxygen content is easily adjusted, this does not have to be the case on larger scales. While oxygen could be sparged through the liquid, this is a very energy intensive process, lowering the overall net energy content of the produced biofuels.
One final significant problem is in the removal of water from the algal biomass. When the biomass is produced,

it has to be removed from the aqueous solution. The water content of the biomass has to be lowered before processing can be done, however. This means that the biomass has to be dried, which is either an energy or time consuming process.
These are the main problems that have to be overcome for algal biomass to become an economical alternative to palm oil, although it is likely that a number of smaller, specific problems will also emerge. A solution to most of these problems will have to be found in the near future for algal biomass to become viable. To speed up finding solutions to these problems, enough funds and knowledge will have to be gathered by Indonesia.

9.3.3 Co-evolution of the energy sector alongside the transport sector

The transport sector is inherently linked to the energy sector, especially in this scenario. The large fleet of EVs present will have to rely on the production of enough renewable energy from the energy sector to be able to keep running. The energy sector in turn, will have to rely on the fleet of EVs to be able to store in and draw from the differences in energy needs and supplies due to its intermittency of generation. The inter linkage of these two sectors, and the success of the future scenarios is for a large part dependent on the development of the energy sector to be able to supply enough energy and ensure that this energy is produced in a renewable manner. This in itself would be quite a difficult feat, as Indonesia pushed for the use of coal to reach a 100% electrification rate. Further increases of electricity usage will therefore also likely come from coal first, before being produced from renewable energy sources.
The same goes for the biofuels. Biofuels have to be chemically produced from fatty acids sourced from either palm oil or algal biomass, and this production requires energy. This energy also has to be produced in a renewable manner to ensure that the biofuels are at least CO2 neutral. Unlike the EVs however, the production of biofuels put a constant demand of energy on the energy sectors. This is added to the potential increase in constant energy demand as Indonesia shifts from an exporter of raw goods to one of manufactured goods, resulting in intensification of its industry. Although Indonesia has potential for the production of renewable energy mostly from solar, and potentially the more exotic geothermal energy production, the question of whether or not the increased demand for renewable energy can be met has to be answered during the course of this scenario.

9.3.4 Road vs Rail

One of the would be significant competitors to road for transporting freight and individuals is rails. Compared on number of individuals and tonnes of freight transported, it is by far outclassed by road currently. Rails is a viable option to mitigate CO2 emissions from the private transport sector by shifting mode of transportation away from cars. It is also a transportation option that has be considered to be intensified by the Indonesian government for the shift in export of products.
However, as turned out from expert interviews, there is very limited investment into the rail infrastructure. Only the government under their government owned railway company, PT. KAI and a Chinese consortium are currently investing in railway infrastructure. Road currently transport around 90% of all passengers and goods transported in Indonesia, holding a monopolistic position in the transport sector.
There is however, still potential for expansion of the railway infrastructure as Indonesia further industrialises. Transferring transportation of goods from roads to rails might provide a reason to invest in rails, as it can help decrease congestion on roads. There is however, a serious question as to how investment can be stimulated. Using backcasting on the Indonesian railway system, providing future scenarios and pathways, might be a potential option for further research.

9.3.5 On delay and speed of market share gains for implementation of EVs and hydrogen

It has been modelled in the scenarios presented here that there will be a delay before EVs and hydrogen as a sustainable energy vehicle technology will impact the yearly CO2 emissions in Indonesia. Delays of 10, 5, 3 and zero years have been simulated for all market shares, the results of which have been presented in Appendix B.6. The conclusion drawn here was that for low market shares the best solution for reducing CO2 emissions is to increase the market share, for high market shares, the best solution is to increase the replacement rate or the total number of vehicles replaced.
However, this limit has only been tested for up to 10 years. Whether this result holds for periods longer than 10

years is not known. This has not been tested in this report because for the scenarios presented here, a delay of implementation longer than 10 years would alter the scenario in such a way that the 2060 goal of CO2 neutrality becomes increasingly unrealistic. For scenarios being considered that are longer than the time frame used here, or that allow for a longer delay, it should be investigated whether or not this result still holds.
Whether or not this delay is realistic is a difficult question to answer. One can look at the emergence and commercial application of a number of technologies and find that the time between the two varies wildly. The time between these two is dependent on the surrounding systems and is something that can be analyzed by using different techniques, including strategic niche management. In this report, the longest simulated delay of 10 years is used. It could however very well be the case that this delay period in reality is shorter.

9.4 Economic class definitions

The importance of the economic weight of the middle class for the outcome of the scenario should be indicated properly at this point. However, the definition of the middle class itself is somewhat vague across literature. In most economic literature, rather than defining the middle class by their economic capability, the middle class is statistically defined. The middle class is seen as a percentile around the median economic level of a given country. While this gives a good indication of the wealth distributions within this country, it does not allow for comparisons between countries, as the absolute levels of wealth may vary wildly per country.
The World Bank, in their research into the middle class, used an economic level to determine the middle class however, using monthly income. The classes were further divided by their economic capability for certain activities. The upper middle class and upper class for instance, where characterized by their level of car ownership and increased intensity of travel and tendency to travel for pleasure. This gives an absolute comparison between classes, and could be used to allow for comparisons between countries. However, there is no global economic standard for certain activities. The use of cars in a countries that has a domestic source of fuel and/or subsidizes the cost of fuel comes at a lower economic standard than the use of cars in countries that do not have the resources or do not take these measures.
There are thus at least two ways in which a middle class of a country can be defined, one by statistical economic standards and one by a degree if emulation of behaviour of the wealthiest section of the population. Both do not allow for a fair comparison of population of different countries. Thus, determining a method of comparing the state of private transport in Indonesia and the degree to which it will develop by using the economic evolution of the wealth classes of Indonesia compared to other countries will be inherently flawed as the middle class definitions used are not functional for comparisons between countries. By combining the definitions, and using some other factors, such as total average car ownership and CO2 emission evolution for non-OECD countries in general a slightly more accurate line of progress of development can be drawn, but flaws will still be present. This should be taken into account when viewing the (BAU) scenarios viewed here.

9.5 Recommendations

The work done in this report has led to a number of interesting points that could be investigated further. For future research that is done on this topic using methods described in this report, a number of recommendations can also be made.

Use of Pathway dependency as a selector mechanism Pathway dependency is usable as a selector mechanism for the method or technology for use in backcasting. The synergistic nature of pathway dependency to select for a method or technology when doing strategic problem orientation allows to investigate trends for future vision development. This is useful for when a selection has to be made in regards to the method or technology to be implemented.

Involvement of local actors To allow for unbiased development of future scenarios, local actors and experts should be involved at an early stage in the future vision development to allow for their input to be used. In this report, a total of 16 actors were attempted to get involved with the development of the final vision produced, although due to distance between the actors and writer of the report as well as language barriers their input was limited. To prevent a number of the limitations previously discussed, contact should be established beforehand or early in the process of setting up the report to ensure that input of local actors and experts can be utilized properly.

Use of demographical analysis for longer backcasting While in normal backcasting frameworks the timeline is usually between 10-20 years long, in this framework the timeline is 40 years long. The effect of this is that factors that could be considered relatively constant for shorter timelines will start to have effect on the development in longer timelines. One of these factors is demographics. The development of the population in turn affects the capability of said population to some degree, which in turn can affect predicted trends for a future scenario, or future drivers or barriers which will have to be dealt with. For longer timelines in backcasting frameworks, these factors will have to be accounted for.

9.5.1 Backcasting on transport in the global South and meta-analysis

Early in the literature study a clear divide emerged between locations chosen for studies on backcasting for transport. Out of the 51 papers for which a region could be determined, only 3 were in the global South. There is one obvious explanation for this divide, being that most of the western countries are located on the northern hemisphere. These countries often have had the resources available to keep track of important statistics in the transport sector for many years, creating an important backlog of data that can be used to plot future trends more accurately. However, there are a number of countries in which one could expect that there is more data available to allow for backcasting studies on transport. These include the southern BRICS countries, Brazil and South Africa, as well as the more western countries present on the southern hemisphere, Australia and New Zealand. It could be that is it possible for backcasting to be used as a policy tool in these countries as they could have enough data available.
Another issue that could be investigated is potentially why such a limited amount of papers on backcasting appear to be available on east Asian countries. An assumption can be made for a number of southern countries that due to lack of funding or poor or unstable governmental organisation the data isn't available to create reliable backcasting scenarios. However, this shouldn't be the case for east Asian countries such as Japan, South Korea, and Singapore, for which in the literature study only a single paper could be determined to be from one of these countries. Historical analysis of the use of backcasting reveals the centres in which this policy tool has been used the most to be England, Sweden and the Netherlands, seeing use as early as the 1970s. Meta analysis on the spread of the use of this policy tool in combination with the data available for policy makers in a given country might give indication for the potential inhibition of the use of this tool in some parts of the world.

9.5.2 Backcasting in Indonesia on transport infrastructure

With trends in this report indicating a change in export economy and increases in wealth while economic growth outpaces growth of infrastructure, research on the future development of infrastructure in Indonesia might be a topic of interest for further research. Although research is being done is this field, it is far from saturated. The dynamics between different forms of transport, with road transport holding a form of monopoly currently, and the responsibilities of different levels of government between municipal, local, private and national make the system for development of infrastructure quite complex.
This extends beyond just the transport infrastructure in energy and fuelling infrastructure as well, as has briefly been touched on in this report. To allow for the 2060 CO2 neutral goals to be realised, Indonesia has to either be able to mitigate the CO2 emissions from burning coal or shift to more renewable sources of energy. Changes in infrastructure and how these changes will be accomplished are also still active topic for research.

Appendices

A Definitions and Literature Analysis

A.1 Definitions

A.1.1 Pathway Dependency definition

As stated in the introduction, a pathway dependency is defined as: "*the tendency of institutions or technologies to become committed to develop in certain ways as a result of their structural properties or their beliefs and values*", according to the Britannica (2022). First, the thing being developed here is a technology, or rather a yet undefined set or combination of sustainable transport technologies to be implemented in private transportation. This set will be a combination of sustainable transport technologies. This will be limited to a combination of three promising technologies, namely EVs, biofuels and hydrogen-fuelled vehicles. It is these three technologies that have seen applications in the transport sector already in other countries, and have been commercially applied. There are a large number of variations and combinations available using only these three technologies, and thus the future scenarios that can be generated. To limit this, only a limited number of combinations will be considered for future scenarios.

Next, there are three parameters that can apparently influence the development of the set of technologies in a given way. These are "Structural properties", "Beliefs" and "Values". The structural properties here can be defined into two sets of properties. These are the properties of the technologies themselves, and the properties of the institution, in this case the island of Java, they are implemented in. The properties of the institution have effect on the actors and technology that is favoured by the institution, and thus also play a significant role in the effectiveness of implementation of or variation in a given sustainable technology. The properties of the island of Java specifically can then divided further into two more categories. These are the 'hard' and 'soft' properties of the island. With 'hard' properties, the properties of the island that are inherent to it and those that cannot be changed are meant. These include such things as the natural resources available to the country as well as the geography of the island. The 'soft' properties are the more intangible and changeable properties of the island. These include the demographics of the island, as well as the relevant legislation and infrastructure. The difference between hard and soft properties is that while soft properties can directly be influenced and interacted with using policies, hard properties will need a technological intermediary. Furthermore, the timescale of change in interaction between soft and hard properties is also different.

Like the soft properties of Java, the beliefs and values of an institution are more intangible. Here, they refer to the things that are considered to be of high value or importance to those the technology is of importance to. While this could be defined as the 'zeitgeist' of the general population of Java, it would be impossible to accurately gauge the interests of the population as a whole. Instead, to gauge the beliefs and values of those that hold a significant 'stake' in the development and implementation of given sustainable transport technologies, a stakeholder map will be created to measure the beliefs and values. This will then give the final definition for the pathway dependency that will be explored in this report: "*the tendency of a certain combination of sustainable transport technologies to become committed to develop in certain ways as a result of the soft and hard properties of Java, the properties of the technologies used and the parameters considered important by its stakeholders*". It should be noted that this pathway dependency is likely to follow to some degree a 'path of least resistance', where the method of development, if sudden shifts in the beliefs and values are not accounted for, is likely to follow a path that has the most developed institutions already present and the barriers are minimal. This will be explored in the future scenarios, where the ease of implementation of certain combinations of technologies, depending on the barriers and drivers present will determine whether or not a pathway dependency is present.

A.1.2 Policy package definition

A policy package is defined in this report in manner defined by Givoni et al. (2013), as "*A set or combination of policies or policy measure design to address one or more policy objectives, created in order to improve the effectiveness of the individual policy measures, and implemented while minimizing the possible unintended effects, and/or facilitating interventions' legitimacy and feasibility in order to increase effectiveness*". The policy packages as determined here are not meant to be as what has been determined by the OECD (2008) to be policy packages, which were actually a large number of individual decisions in relative isolation, resulting from short term political imperatives (Givoni et al., 2013).

A.2 Literature Analysis

Backcasting, which forms the main theoretical framework behind the development of policies based on created future scenarios is a relatively new form of policy management. It is relevant to review the literature that has been created so far to get an indication whether this study is reinventing the wheel or is in fact exploring new grounds. In the graph below, the number of documents in which the term '*backcasting*' or '*back-casting*' was used in the title, abstract or summary per year is given.

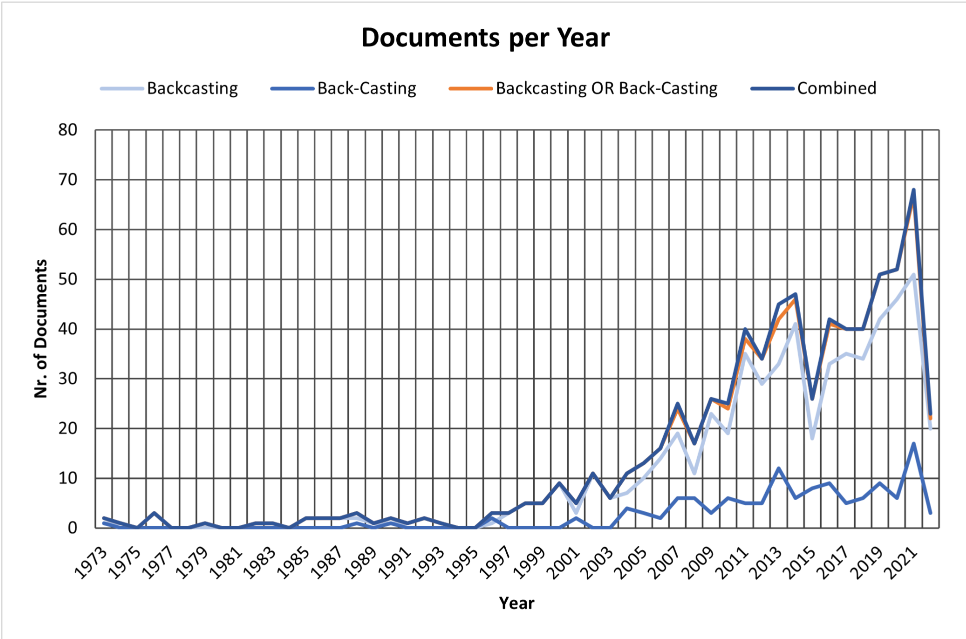


Figure 34: Historical emergence of the term backcasting and back-casting in papers

From the data in the graph it becomes clear that both the terms backcasting and back-casting become more widespread after the year 2000, with the occasional paper being published with this term included. It should be noted that the large drop in papers in 2022 is largely due to the year not being finished yet. This data analysis was done on 01-04-2022, meaning more than half the year is still remaining for papers to be published. There is a small discrepancy between the combined number of literature that has either backcasting or back-casting and the number of literature that is found using the Boolean OR term in Scopus. This is likely due to some papers using both backcasting and back-casting interchangeably. Also note that no qualitative research has been done into whether or not the terms backcasting or back-castings have been used in the same sense that is meant here. Coincidental use of the individual words back and casting may still result in a hit, even though they might not be relevant in such a case.

For this study, analysis of literature was done using Scopus for all papers (A) and time-relevant papers (newer than 2015, B) and scoped to the relevant subject area, Indonesia and transport policies. The list of relevant papers is then exported to csv and analysed for the relevance of the word present. Literature regarding Indonesian transport policy and sustainability appears to be a '*hot topic*' as the majority of the titles published have been published in the last 6 years, although this still includes conference papers, book chapters and reviews. Selection is done based on actual relevance of the topic, transportation policy, meaning the literature is checked whether the search queries actually appear in the literature in a relevant manner, and are not just accidentally both mentioned. Furthermore, book chapters and reviews will be ignored.

Table 12: Search query variations on backcasting papers on transport policies and Indonesia in different subject areas

Search query	Type A	Type B	After Selection
TITLE-ABS-KEY (indonesia AND transport AND policy)	242	167	12
TITLE-ABS-KEY (indonesia AND transport AND policy) AND (LIMIT-TO (SUBJAREA , "SOCI"))	97	65	6
TITLE-ABS-KEY (indonesia AND transport AND policy) AND (LIMIT-TO (SUBJAREA , "ENVI"))	72	54	4
TITLE-ABS-KEY (indonesia AND transport AND policy) AND (LIMIT-TO (SUBJAREA , "ENGI"))	63	46	2
TITLE-ABS-KEY (indonesia AND transport AND policy AND sustainable)	52	39	1
TITLE-ABS-KEY ((indonesia OR asean) AND transport AND (policy OR policies))	280	191	13

A.2.1 Evaluation of the presence of a research gap regarding transport policies

In Marsden and Reardon (2017), peer-reviewed literature is analysed on their study of transportation policy. It found that the majority of the papers didn't discuss or debate policy aims, engage with real world-policy examples or that they focused on quantitative ex-ante analysis of potential policy options. The paper states that there is a clear lack of engagement of government issues, disproportionally creating a field of science of applied policy making that is distant from reality. It becomes clear that there is a '*blind-spot*' in the range of research topics regarding the science of policy and decision making. As found in the literature review, there appears to be a rift between two groups with regards to transport policies in Indonesia, in which little to no bridging research has been done. The one group is keen on studying existing policies and their effectiveness, sometimes compared to other countries or does case studies to test effectiveness of a policy on a limited scale (Bakker et al., 2017; Erdiwansyah et al., 2019; Gunawan et al., 2019; Dirgahayani and Sutanto, 2020; Wijaya et al., 2017; Shao et al., 2020). For case studies specifically, of the 167 relevant literature, 12 were case studies and 8 were papers comparing countries. Most of these researches are also not focused on a renewable energy transition but just the policy itself. The other incorporates the transport sector as a part of the energy usage of Indonesia to use a model that analyses some part of the energy system as a whole or explore scenarios given certain policies are to be implemented (Fragkos et al., 2021; Destyanto et al., 2017; Neofytou et al., 2020; Deendarlianto et al., 2017; Ruamsuke et al., 2015). Of the 167 relevant literature, 17 were evaluating models. In total (last row), after adjusting for correct terms, eliminating reviews, editorials, surveys, books and books chapter from the search, and removing irrelevant search results that got through the initial selection, a total of 13 results were found. Of these, 5 are case studies (Dewita et al., 2018; Dhina and Permana, 2021; Gunawan et al., 2019; Ismiyati and Hermawan, 2018; Putra and van der Knaap, 2020; Hidayati et al., 2019), 3 discuss the effectiveness of a single policy (Dhina and Permana, 2021; Ichsan et al., 2021; Muzakir et al., 2021), 2 are modelling studies (Setiawan et al., 2019; Deendarlianto et al., 2020) and 3 are comparative studies or not Indonesia-specific but ASEAN (Bakker et al., 2017; Li and Chang, 2019; Fulton et al., 2017). None of these papers appear to bridge the gap between the science of policy making and real world decision making. Only one paper by Hidayati et al. (2015), makes an attempt at applied policy making, explaining path dependency of transport policies using spatial-historical evidence for the Greater Jakarta region. One can compare this to the result for transport policy for western (OECD) countries:

Table 13: Search query on backcasting papers on transport policies for a number of western (OECD) countries

Search query	Type A	Type B	After Selection
TITLE-ABS-KEY (netherlands AND transport AND policy)	718	239	48
TITLE-ABS-KEY (usa AND transport AND policy)	573	165	32
TITLE-ABS-KEY (sweden AND transport AND policy)	542	314	59

A.2.2 Evaluation of the presence of a research gap regarding back-casting

The method that is used to come to the needed policies for sustainable energy transition in Indonesia, back-casting, should be evaluated. This will be done in the same manner as the evaluation of the research gap regarding transport policies. Selection here is only on basis of relevance to transport. Literature analysis in Scopus gives the following results:

Table 14: Search query variations on backcasting papers on transport and Indonesia

Search query	Type A	Type B	After Selection
TITLE-ABS-KEY ((backcasting OR back-casting) AND indonesia)	7	4	1
TITLE-ABS-KEY ((backcasting OR back-casting) AND indonesia AND transport)	1	1	1
TITLE-ABS-KEY ((backcasting OR back-casting) AND (indonesia OR asean))	7	4	1
TITLE-ABS-KEY ((backcasting OR back-casting) AND policy AND indonesia)	3	1	1

From the results from Scopus, only a single paper, by Feng, X. et al (2010), is relevant towards using back-casting as an academic method to provide policies for the transport sector in Indonesia.

Further literature research on the use of back-casting on the transport sector of Indonesia using the search query "back-casting Indonesia", google scholar yields the following relevant papers:
'System dynamics models for planning long-term integrated municipal solid waste management in Bandung City' by Rahayu, N. et al. (2013), 'A micro scale study of climate change adaptation and disaster risk reduction in coastal urban strategic planning for the Jakarta' by Rahayu, H. et al. (2019), and 'Scenario planning to leap-frog the Sustainable Development Goals: An adaptation pathways approach' by Butler, J. et al. (2016), which were also found using the Scopus literature search.
A working paper, 'HOW CAN INDONESIA ACHIEVE ITS CLIMATE CHANGE MITIGATION GOAL? AN ANALYSIS OF POTENTIAL EMISSIONS REDUCTIONS FROM ENERGY AND LAND-USE POLICIES' by Wijaya, A. et al. (2017), makes use of back-casting to study policies, but policies regarding the energy sector and land use.
'Household Hazardous Solid Waste (HHSW) Management Schemes in Sleman Regency for Future' by Iswanto et al. (2019), uses backcasting to plan HHSW management schemes.
'Low-Carbon City Scenarios for DKI Jakarta Towards 2030' by Dewi, R.G. (2016), studies actions the DKI Jakarta provincial government can take to reach their normative goal of low carbon cities in 2030 by using back-casting.
Other papers do contain both keywords, but have a different goal in mind, analysing air pollution or biodiversity for instance (Erawan and Karuniasa, 2020; Brooks and Kennedy, 2004).

In comparison, these are the results for the use of back-casting as an academic method to provide policies for the transport sector in general:

Table 15: Backcasting papers on transport

Search query	Type A	Type B	After Selection
TITLE-ABS-KEY ((backcasting OR back-casting) AND transport)	93	40	34

It appears that one a global scale, although the amount of papers published on the use of back-casting as a method to provide policies is still quite limited, it is more scoped towards sustainability and energy transitions. Scoping the global results to order them by country or region of relevance gives the following results:

Table 16: Backcasting papers published by region or country

	Number
Total Papers	61
Undetermined region	61
World	5
Europe	5
Sweden	12
UK	6
Spain	4
Japan	3
China	3
USA	2
Netherlands	2
Finland	2
France	1
Malta	1
India	1
Indonesia	1
Costa Rica	1
Brazil	1
Tanzania	1

Note that the total number of papers here is different as no scoping is made on recent results, meaning the 93 papers that appeared using the search query mentioned above has been selected for. It appears quite clearly that there has not been a focus on developing countries of the global south, which here include the countries of Brazil, Tanzania and Indonesia. These papers, 3 of the 51 of which a region of focus could be determined, represent a minority. This in combination with the results shown previously should give a clear indication of the gap in knowledge and the underdevelopment of the field of transport policies in Indonesia, and the use of back-casting as an academic method to select for these policies. A larger trend of lack of research on transport policies in the global south and on non-OECD countries could also be inferred, but this trend can't be established from this review of literature alone. It is also possible that similar research is being done in these fields, but using different key words than are explored here. More in-depth reviews should be done into how much research in done on these fields and if trends can actually be established.

B Calculations

B.1 BAU Scenario Calculations

B.1.1 First Method:

According to the latest data from the IEA, Indonesia's transport sector as a whole emitted 150 MT of CO2 in 2019, or 25.7% of the total greenhouse gas emissions of the country that year (IEA, 2019). The transport sector can be divided into land transport, transport by air, sea and transport by rail. However, over 90% of all transport of individuals and freight, happens by road (Asian Development Bank, 2012). Given the dominance of road transport in Indonesia because of the state of other forms of transport, like rails, it is likely that such

a share will still be held in 2060. Compared by amount of freight carried per distance per amount of CO2 emitted, ships and rail are far more efficient (IEA, 2020b). Since no data is available for Indonesia in regards to the emission of transport per mode a conservative estimate of 90% of all transport emissions is attributed to land transport.
The increase in private vehicle ownership has yet to be saturated. The amount of motorcycles owned in Indonesia doubled between 2010 and 2018, from 60 million to 120 million, the amount of passenger cars grew from 12.3 million to 14.8 million from 2015 to 2018 and the amount of freight cars increased from 4.1 million to 4.5 in the same period (Badan Pusat Statistik, 2018). Although the number of passenger cars is unlikely to replace the amount of motorcycles in Indonesia by 2060 as a luxury alternative, this amount will likely increase significantly as a result of the growing middle class. It is difficult to establish a line between the use of private vehicles purely for private use and for informal transport of goods, especially for cars. Motorcycles also emit a lower amount of CO2 compared to passenger cars, buses and trucks, even though their number is much higher and their purpose is much more defined as a form of transport for individuals, and not freight. Although no data is given for Indonesia in regarding to the emission per form of land transport, the IEA attributes 45.1% of all transport emissions to road transport of individuals, visible in the table 17 below (IEA, 2022).

Table 17: Emission distribution per transport form

Form of Transport	Road (passengers)	Road (freight)	Aviation	Shipping	Rail	Other
Percentage of emissions attributed	45.1%	29.4%	11.6%	10.6%	1%	2.2%

This includes taxis and buses, however, it also attributes a far larger share of emissions to (international) aviation and shipping than is observed in Indonesia at a combined 22.2%. The assumption here is made that the 90% of total transport emissions is shared between the 74.5% of emissions made by different forms of land transport. Given the higher efficiency of travel by bus in persons transported per amount of CO2 emitted, the relatively low popularity of buses in Indonesia and the relatively higher cost of taxis, 42% is attributed purely to individual transport of passengers in either passenger cars or motorcycles. This is then 50.74% of the total transport emissions.
According to the EIA, non-OECD countries are expected to increase in carbon dioxide emissions from 23 billion MT (metric tons) in 2020 to about 32 billion MT in 2050. This estimation was based on a business-as-usual trend estimate, given known technology and technological and demographic trends, and indicates a roughly 1.1% increase in emissions per year (EIA, 2021). Applying this increase to the transport sector in Indonesia and extending the trend to 2060 will give 234.9 MT of CO2 emitted. This will give us the first estimate of the amount of CO2 that will have to be mitigated, and is displayed in the calculations below.

$$\begin{aligned}
\text{Total CO2 emissions in 2019} &= 584\text{MT} \\
\text{CO2 emissions by transport sector in 2019} &= 584 * 0.257 = 150\text{MT} \\
\text{CO2 emissions by transport in 2060} &= 150 * (1 + 0.011)^{(2060-2019)} = 150 * 1.011^{41} = 234.9\text{MT} \\
\text{CO2 emissions by land transport in 2060} &= 234.9 * 0.9 = 211.41\text{MT} \\
\text{CO2 emissions by private vehicle transport in 2060} &= 211.41 * 0.5074 = 119.17\text{MT}
\end{aligned} \tag{1}$$

The total amount of carbon emissions that will have to mitigated as a result of the private transport sector in Indonesia is 119.17 MT of CO2.

B.1.2 Second Method:

The amount of people in the middle class and upper class can also be used to indicate the amount of emissions that need to be mitigated. The middle and upper classes have the economic stability to be able to purchase private vehicles, and are expanding. The trend in economic stability can to some degree be observed in the large increase of motorcycles owned in Indonesia (Badan Pusat Statistik, 2018). This trend is likely to continue

to 2060, but with increase in the purchase of cars instead of motorcycles, which pollute more than motorcycles do, contributing to a significant increase in greenhouse gas emissions (IEA, 2020b). The amount of cars and motorcycles owned in Indonesia are 60 and 450 per 1000 individuals in 2018 respectively (Adiatma et al., 2020). While it can be assumed that the amount of cars per 1000 individuals will not reach the level of motorcycles, a significant increase can be expected.
The total amount of privately owned cars in Indonesia is approximately 16 million as of 2018 (Adiatma et al., 2020). While previously 14.8 million was used, this number does not include all forms of private owned vehicles [7]. According to the World Bank, the car ownership of upper class is 80% and that of the upper middle class is 60%, compared to the motorcycle ownership, which is above 40% for every class including the poor class as of 2016. The middle and upper class only represent about 20% of the total population, however. The World Bank divides the population into 5 different groups, based on their monthly per capita consumption. These five groups are poor (P), vulnerable (V), aspiring middle class (AM), middle class (which in itself is subdivided into lower (MC1) and upper middle class (MC2)) and upper class (U) (World Bank and Australian Government, 2019). The distribution is given in the table below. Data is given for 2016.

Table 18: Economic Class distribution in Indonesia

Class	P	V	AM	M (MC1 + MC2)	U
Percentage of population (%)	10%	24%	45%	20% (17.1% + 2.9%)	1%
Number of individuals (milion)	26	62.4	117	52 (44.5 + 7.5)	2.6
Montly per capita consumption (Rp/month)	< 354k	354-532k	532k-1.2m	1.2-6m	6m >

It should be noted that the expansion of the middle and upper class is mostly due individuals from the vulnerable class and aspiring middle class moving up. The poor class seems to remain relatively stable (World Bank Group, 2020). Trending towards 2060, it is likely that a large number of the aspiring middle class, which is the largest economic group in Indonesia by far, transitions to the middle and upper class, reaching enough economic stability to be able to purchase cars. The total population of Indonesia is also still growing, and is expecting to peak near 2065 at 337 million individuals (World Population Review, 2022). Given the growing population and the economic upwards movement of the population, one can look at countries that have gone through a similar trend to make projections about the economic makeup of the population of Indonesia in 2060, and thus estimate the amount of cars owned. Compared to China, which underwent an economic transformation sometimes called nothing short of a miracle, the private car ownership percentage went from less than 2.5% in 1985 to over 60% in 2005 (Deng, 2007). Although it is unlikely that this percentage will be reached in Indonesia, this percentage is similar to the car ownership percentage of the upper middle class. It is very likely that the income of all the classes will increase as Indonesia transitions its economy to a goods producing one. It is therefore assumed that the car ownership in Indonesia stays at an insignificant level for the poor and vulnerable groups, but increases to 10% for the aspiring middle class, 30% for the lower middle class, and remains at 60% for the upper middle class and 80% for the upper class, to be in line with more western car ownership. A comparison to car ownership is given in the table below.

Table 19: Car ownership in 2016 and 2060

Year/Class	P	V	AM	MC1	MC2	U
2016	<1%	1-2%	4-6%	22%	60%	80%
2060	<1%	4-6%	10%	30%	60%	80%

To determine the percentage of the population in each group, again a comparison is made to other, more

[7] Adiatma's data is based mainly on the previously mentioned 14.8 million, which is data obtained from Indonesia's State Police, published on Badan Pusat Statistik, Adiatma likely correctly assumes that the actual number of privately owned vehicles is higher, with some not being accounted for by the ISP, thus resulting in a total of 16 million privately owned vehicles, this number will be used as a baseline in the calculations in the rest of this report

developed countries. China in comparison has about 0.33% of the population in the poor class, over 50% in the upper class and the rest spread over the remaining classes according to the World Bank classification used above. Comparing Indonesia to western countries (including Japan, Malaysia and Singapore) would result in a upper class that makes up at least 60% of the total population, according to this classification (ChinaPower, 2022). Most western countries also have a car ownership rate of somewhere between 350 and 700 cars per 1000 individuals (Eurostat, 2019). Shifting the population classes to be more in line with China in a potential 2060 scenario for Indonesia, the population distribution is given in the table below.

Table 20: Economic Class distribution and car ownership in 2060

Class	P	V	AM	M (MC1 + MC2)	U
Percentage of population (%)	<0%	1-2%	13%	60% (34% + 26%)	24%
Number of individuals (milion)	3	7	44	202 (114.6 + 87.4)	81
Number of cars (million)	0.03	0.28-0.42	4.4	86.82	64.8

The total amount of cars in 2060 using this population distribution is 156.47 million cars in 2060. This would make Indonesia the third country when ranked for the most cars, behind China and the USA, when placed in 2019. This amount of cars increases the amount of cars per 1000 individuals to 464, putting Indonesia in line with eastern countries like Malaysia, Bahrain and Qatar. Compared to the amount of cars in use in 2018, it is almost a tenfold increase in cars. If there is no increases made in efficiency of combustion, this would also result in a tenfold increase in greenhouse gas emissions. Using data obtained using the first method, the 16 million cars in 2018 are responsible for a total of 63 MT of CO2 emitted. In 2060, this amount would then increase to 616.1 MT of CO2.

Table 21: Emissions based on number of cars in 2060

Year	Amount of cars (millions)	CO2 emitted (MT)
2018	16	63
2060	156.47	616.1

B.1.3 Discussion:

Combined, it is likely that the first method give an underestimation while the second is an overestimation of the actual CO2 emissions in 2060. For the second method, although the increase in vehicles seems to be very large, there is historical precedent for this in countries like China. In fact, the same has already happened in Indonesia for motorcycles, which increased from 20 million in 2003 to 120 million in 2018, which is a sixfold increase in just 15 years (Adiatma et al., 2020). Furthermore, the intensity of travel is also likely to increase, as the middle class and above have a higher tendency to travel for pleasure more (often) than the lower classes (World Bank and Australian Government, 2019). Given the large middle class as defined by the Global Bank, and potential development of the country followed by increase in average wealth, it is not unlikely that such an increase of car ownership will actually occur.

The increase in vehicles, how small it may be, would still pose a serious threat to reach net neutral carbon emissions. If the increase of cars in 2060 is just a doubling, to 32 million, which would mean less than 3 of the 5 individuals of the middle class would own a vehicle today. This would still lead to a total of 126 MT of CO2 emitted in 2060 by private vehicles which has to be mitigated. This amount is more than Belgium or the Czech Republic emitted in total as of 2016 (WorldoMeter, 2016b).

The amount calculated using the second method is likely too large. The amount of emissions by private vehicles in 2060 would be more than the entirety of emissions produced by Indonesia as a whole in 2016. However, it seems more likely that the amount of emissions will lean more towards the amount calculated using the second method, as Indonesia is an outlier when it comes to non-OECD countries and development due to its large population and middle class, making the first method a likely underestimate. This is also because Indonesia will start emitting significantly more as it transitions from a developing to a developed economy. This is reflected in

the CO2 emissions per capita, which is 2.03 tons per capita for Indonesia, compared to a 4.79 tons per capita global average (WorldoMeter, 2016a).
Furthermore, for the second scenario an argument could be made that this is still a low estimate due to the emissions in 2060 being purely scaled based on the amount of cars. Especially with such a large amount of motorcycles being present in the country, it could be expected that the amount of greenhouse gas emissions in 2060 would be significantly higher as this amount could increase as well. However, from the analysis of the World Bank it becomes clear that the market for motorcycles is far more saturated than the market for cars, as even a significant portion of the lower classes own a motorcycle (World Bank and Australian Government, 2019). Furthermore, motorcycles emit less CO2 than cars, making them a far smaller contributor, even if their number were to increase still (IEA, 2020b). Even if other forms of private personal transport were to be taken into account, their total number and increase for a 2060 scenario would not make them the dominant CO2 contributor. Therefore, it can be judged that scaling the emissions to 2060 by taking into account only cars would result in a relatively accurate future prediction. Predictive trends made in 2010 by the National Council on Climate Change of Indonesia, which only predicted trends up to 2025, showed results that would trend more in the direction of the second method (National Council on Climate Change of Indonesia, 2010).
However, a more in-depth analysis would have to be done to determine the actual emissions in a business-as-usual scenario more accurately. There are too many factors to be considered, and the timescale is likely too long to make a fully accurately prediction of what the emissions of the private vehicle transport sector would look like in 2060. Based on current trends, however, the amount is guaranteed to increase.

B.2 Biofuel Scenario Calculations

To have biofuels as a mono technology in a future scenario, one will have to figure out how much potential there is in biofuels and how much CO2 this can mitigate and compare this to the amount of CO2 generated in the BAU scenario. For this, the total amount of sustainable biofuel production will have to be charted and the CO2 lifecycle of the biofuel production will have to analysed. The amount of biofuel needed given the increase in cars as prediction in the BAU scenario will also have to be calculated. This can be done by comparing the energy density of regular fuels to that of biofuel, and scaling appropriately.

B.2.1 Calculating needed biofuels

The amount of biofuels needed can be done in three steps. First, the amount of diesel consumed in the future scenario will have to be calculated. Next, the efficiency of biofuels in comparison to diesel will have to be calculated. Finally, the amount of biofuels needed can be calculated. First, the amount of diesel consumed will be calculated. Although the amount of diesel consumed depends on a number of factors including length of the trip, behaviour of the driver and weather and road conditions, the amount of CO2 produced by burning a litre of diesel chemically is a fixed amount. This means that the amount of diesel consumed in a future scenario can be calculated based on the amount of CO2 produced. Diesel produces 2.64 kg of CO2 per litre burnt based on chemical stoichiometry, although the actual amount burnt depends on engine conditions, with emissions ranging from 2 to 3.6 kg of CO2 per litre diesel burnt (Lean Green Europe, 2019; Ecoscore, 2022; Comcar, 2022). For simplicity, the amount of CO2 produced will be set at 2.75 kg of CO2 per litre, to include slight inefficiencies of the engine. Using the amount of CO2 produced, this then gives the yearly consumption of diesel. This is displayed in the table below.

Table 22: Yearly diesel consumption in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Emission (MT)	63	119.17	616.1	379
Diesel consumed (billion L)	22.9	43.3	224	137.8

This number comes close to the total amount of diesel imported, which was 33.25 billion litres ($3.325*10^{10}$) in 2018 (Statista, 2019). As Indonesia doesn't have much domestic oil production or distillation, the amount imported indicates that the amount of diesel consumed by private vehicles is likely in the right order of magnitude, as it would represent almost 69% of the imported amount. Next, the efficiency of biofuels in comparison to diesel will have to be calculated. The energy content of biofuel blends is generally considered to be lower than that of diesel, between 1%-3%, based on engine performance and behaviour (Roy et al., 2013). Furthermore, properties of biofuels are generally dependent on the feedstock that is used (United States Environmental Protection Agency, 2002; Wu et al., 2009). The main form of biofuel in Indonesia will most likely come from palm oil, as mixing diesel with a palm oil blend of 20% (B20) is already common practice and is currently undergoing expansion to 30% and higher ratios. Palm oil has been shown to have similar chemical and physical characteristics to diesel in biodiesel blends of up to 30%, specifically the methyl ester palm oil blends (El-Araby et al., 2018). Heating values of the higher blends, up to 100% (B100) are up to 10% lower than that of normal diesel (Gad et al., 2018). Since the diesel consumption has to be completely replaced with that of biofuels, a large part of which will likely be of palm oil basis, this is the difference in efficiency that will be used. The previously used table can then be expanded to include the amount of biofuels on palm oil basis needed.

Table 23: Yearly diesel and palm oil biofuel consumption in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Emission (MT)	63	119.17	616.1	379
Diesel consumed (billion L)	22.9	43.3	224	137.8
Palm Oil biofuels consumed (billion L)	25.44	48.14	248.8	153.1

This means that in the best case scenario a total of 48.14 billion litres, and in the worst case scenario a total of 248.8 billion litres of biofuels would have to be produced to satisfy the consumption of the amount of cars in 2060. To compare, this would be almost 7.5 times the amount of diesel that is currently being imported.

Assumptions and discussion: There are a number of assumptions that have to be made for these amounts to be reached. First is that the efficiency of a diesel engine can be stated as such that the average production of CO2 per litre of diesel burnt is slight above the chemically calculable amount. This assumes that the behaviour of drivers, weather and road conditions, build of different engines, difference in loads, and a number of other factors that impact the efficiency of a diesel engine can be aggregated into a single efficiency, one that is slight above stoichiometry. If this is actually the case is likely impossible to tell due to the large number of factors involved that can influence efficiency. Second is that this efficiency will stay this way in the future. It is unlikely for engines or the on-board computers in more modern vehicles to remain at the same efficiency as they had in 2018 in 2060. However, calculating the increase in vehicle efficiency is likely another factor that is impossible to calculate as while trends in efficiency can be predicted to a certain degree, the same factors mentioned in the previous point also affect the increases in efficiency. Third is the energy content of biofuels in comparison to diesel. While generally they can be considered to be less energy dense than diesel, the degree to which they have a lower energy density is completely dependent on the source of the biofuel, as well as the fabrication process and the degree the biofuel is blended with diesel. In the case of biofuels completely replacing diesel as a fuel, B100, the characteristics of the fabrication process as well as the source determine the energy content and thus the efficiency of the biofuel compared to diesel. In the case of methyl ester palm oil B100, their heating values are roughly 10% lower than that of regular diesel, thus their energy content can be judges to be lower by a similar margin as well. In the next section it will be calculated if palm oil can serve as a replacement to diesel. However, in the case that more forms of biomass are required to be able to satisfy the 2060 demand of diesel, one would once again have to take into account these points of discussion and assumptions, making the overall calculation more difficult once again.

B.2.2 Calculating biofuel production potential and prerequisites

To get a ball park figure of the potential of biofuel production, one can take a look at the production of palm oils in Indonesia currently. As of 2021, Indonesia produced a total of 46.2 million metric tons of palm oil (Statista, 2022d). This is equal to 51.11 billion litres ($5.111*10^{10}$) of palm oil. This means if one were to use palm oil to fuel vehicle directly, it would satisfy the current diesel demand two times over, and satisfy the non-OECD 2060 demand as well. However, it would not satisfy the other growth demands. Furthermore, the conversion of palm oil to actual biofuels, in the form of methyl ester palm oil, would lower the total amount of available biofuel as well. There are a number of methods to get a relatively high yield of biofuels out of palm oil, however. Experimental setups using catalytic transesterification with sodium hydroxide at 44C have predicted yields of 92% (Satya et al., 2019). Production of methyl ester palm oil due to esterification of palm oil fatty acids in supercritical methanol at 300C has been studied to have a yield of 94% (Petchmala et al., 2008). Catalytic transesterification of palm oil using potassium hydroxide at 60C in a methanol mixture in a CSTR has been studied to have yields of up to 97.3% (Darnoko and Cheryan, 2000). Going by the smallest yield here, the potential amount of palm oil biofuels that can be produced in 2021 would have been 47.02 billion litres. A more pressing issue is the amount of other reagents that are needed to produce the biofuel. In the case of palm oil, this would be methanol, which is needed in a molar ratio of 5:1 methanol to palm oil for the highest conversion results (Satya et al., 2019). This would mean an equivalent of 11.03 billion litres of methanol would also be needed. Methanol is another compound that can be produced from biomass. However, it can also be produced from coal, a resource Indonesia has in abundance, using coal gasification and subsequent methanol synthesis (Wagner et al., 2008; Henrici-Olivé and Olivé, 1984). Preliminary feasibility studies for a large scale coal-to-methanol industrial plant are undergoing (China Dialogue, 2022). The total land area needed to produce all this palm oil reached a size of 14.6 million hectare as of 2020 (Statista, 2021). In the case of the worst case scenario, 2060 pop growth, the amount of palm oil for biofuel would need to grow nearly ten-fold. The amount of land needed for palm oil production and biofuel yield is given below in the expanded table. For the palm oil needed, the smallest yield is used.

Table 24: Palm oil demand and surface area needed in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Emission (MT)	63	119.17	616.1	379
Diesel consumed (billion L)	22.9	43.3	224	137.8
Palm Oil biofuels consumed (billion L)	25.44	48.14	248.8	153.1
Palm Oil needed (billion L)	27.66	52.33	270.4	166.4
Palm Oil plantage hectares needed (million)	14.60	27.63	142.79	87.86

The total land area of Indonesia is roughly 181.15 million hectares, meaning nearly half of all the land in Indonesia would have to be used for palm oil production in the middling growth scenario, and nearly 80% of all land would be needed in the worst case scenario. As palm oil also sees significant other use in culinary industry as an Indonesia (value) export, the full production of palm oil cannot be diverted to the production of biofuels, and expanding the production would not be enough to provide enough. Another form of biomass that can be used to produce biodiesel in a similar manner as palm is also available to Indonesia, however. This is biodiesel derived from algal biomass, which can be produced due to Indonesia's favourable location near the equator (Knothe, 2011). These are the so-called 'third generation' biofuels (palm oil would be a 'first-generation'). While algae could theoretically produce 10 to 100 times more oil per acre compared to conventional oil producing crops, this has yet to be reproduced on large scales (Greenwell et al., 2010; Hu et al., 2008). Although expensive on large scales, algae can produce oils year round, compared to the one or two yearly harvests of other oil producing crops. The exact yield depends on a large number of factors, including culture of algae used, nutrient availability, light availability and temperature. Finding the most optimal form of algae for biofuel is a study in of itself, so the exact type of algae used will not be studied. Estimated yearly yield of oil from algae is between 25000 and 50000 litres per hectare, with higher yields of up to 100000 litres per hectare being claimed (Ullah et al., 2014). Here, a modest estimation of 30000 litres per year per hectare will be used. Using a 92% yield of conversion to biodiesel, this would give a yearly production rate of 27600 litres per year per hectare. The efficiency of consumption of biodiesel made from algae is here assumed to be the same as that of palm oil. The table can then be converted to visualize the need amount of algae and land needed.

Table 25: Algal oil demand and surface area needed in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Emission (MT)	63	119.17	616.1	379
Diesel consumed (billion L)	22.9	43.3	224	137.8
Algal biofuels consumed (billion L)	25.44	48.14	248.8	153.1
Algal oil needed (billion L)	27.66	52.33	270.4	166.4
Hectares needed for Algae production (million)	1.002	1.896	9.797	6.029

In this case, the amount of land needed would be much more feasible, with even the worst case scenario requiring less land than the amount of land currently in use for palm oil production.

Assumptions and Discussion: There are a few assumptions that have to be made to reach the amount of land needed for the production of biofuels. First, the yield of biofuel from palm oil is mostly determined experimentally, and doesn't have to match this value in reality. As given, there are a number of different methods that give similar values for the yield. For these methods, while the core methodology stays the same, the temperature and catalyst differ. Since the yields still seem to reach the same value, it can be judged that the methods developed to produce biofuels from oil have reached a level of maturity that even on larger scales these yields can likely be reached. Second, the yield of algae is vague for the comparison to palm oil made here, and it is hard to judge whether or not the comparison made here holds. Research into production of biofuel from algal biomass often uses different terms for the production of material that is to be processed into biofuel. Yield is often given in term of dry mass or 'oil'. For dry mass, an indication of the lipid content of the algae used will also have to be include if an accurate comparison is to be made. For 'oil' this term can means several things, and is used somewhat freely. It can refer purely to the lipid content of the algae or saturated or non-saturated fatty acids. While fatty acids are lipids, not all lipids are fatty acids. Estimating the actual yield is also made difficult by the fact that these papers often use experimental setups, which favours expressing yield in other terms such as grams per square meter per day or even hour. Yield is also very much determined by what culture of algae is used, as well as a large number of physical parameters. For simplicity, a review paper was used to give a clear indication of what the likely and potential aggregate yield of biofuel producible biomass from algae would be. There is a wide spread in the land needed to produce enough biomatter for the production of biofuel. Even now, the land area needed for palm oil production is more than the total land area of Greece, and in the worst case would need most of the land area of Indonesia. This would bring into question the quality of the land used, which would be less of an issue with the use of algal biomass, which not only can be produced on lands which have no agricultural use, but in and on the seas surrounding Indonesia as well. Finally, one has to consider that the biofuels used can only be considered CO2 neutral or negative in the case that the transportation of materials, processing and transportation of the biofuels themselves is also done in CO2 neutral manner, either by also using biofuels or renewable generated electricity or power. Furthermore, the land is used for the production of the biomass that is to be used for the production of the biofuels, has to retain an equal or larger amount of CO2 than in its previous state for it to be considered CO2 neutral. A proper lifetime analysis of the CO2 cycle of such a production facility and land use will have to be done to ensure this is the case, however.

B.3 EVs Scenario Calculations

To have electric vehicles as a mono technology in a future scenario, one will have to figure out how much electricity will be needed to generated. There are two things that will have to be figured out. The amount of travel that is done during a year to figure out the total electricity consumption during a year and the maximum amount of charging that can be done at any given time. To calculate these things, one can scale the amount of CO2 produced to an amount of kms travelled, and the amount of cars present can be used to determine the maximum amount of electricity that can be charged at any given time.

B.3.1 Energy consumption calculation:

To calculate the total yearly consumption in the future scenario, one would need to figure out how much is travelled overall. This can be done by scaling the amount of energy expended either in terms of L diesel used or CO2 produced to the amount of electricity needed. In this case, the diesel consumption is used as the CO2 production due to energy use might be difficult to scale or be scaled incorrectly. The amount of energy expended can be calculated using the amount of diesel consumed, which was calculated in A5, and is given in the table below. The energy content (LHV) of a litre of diesel (E10) can be calculated to be around 31.2 – 32.4 MJ/L (U.S. Department of Energy, 2022). The motion average energy efficiency of a diesel engine is 22% (Cullen and Allwood, 2010). Using 31.2 MJ/L as the energy content and an efficiency of 22%, the total and effective energy consumed can be calculated.
In the worst case scenario, almost 7 EJ (Exajoules, 10^{18} joule) are consumed yearly, of which a little over 1.5 EJ are used effectively. To determine the electricity needed to be generated, one would need to know the efficiency of an electric engine. The motion average energy efficiency of an electric motor or AC/DC induction motor is 60% (Cullen and Allwood, 2010). This means the total energy consumed using electric motors in the place of combustion engine also can be calculated. This is shown in the expanded table below.

Table 26: Yearly diesel and energy consumption in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Diesel consumed (billion L)	22.9	43.3	224	137.8
Total energy consumed combustion engine (EJ)	0.7145	1.352	6.989	4.299
Effective energy consumed (EJ)	0.1572	0.2974	1.538	0.945
Total energy consumed electric engine (EJ)	0.262	0.4957	2.563	1.575

An electric engine would consume only 36.67% of the energy required to run a diesel engine. The total energy consumed using electric engines is therefor also significantly lower than using diesel engines, at only 2.56 EJ in the worst case scenario.

Assumptions and Discussion: A number of assumptions will have to be made to reach the numbers obtained here. For one, Indonesian diesel differs from E10, it is a blend that contains more biofuels, actual energy content will be lower slightly. The energy content is dependent on the type of fuel blend that is used. Here, the calculations are made using a standard 10% ethanol containing diesel blend. This is a slightly different blend from the one used in Indonesia. Indonesia is currently using a B30 blend, which contains up to 30% biofuels. However, as calculated by Ge and Choi (2020), the energy content of B30 is only 3.8% lower than that of pure diesel. The difference between the fuel blend used in Indonesia and the one used in the calculations is therefore minimal to a degree. Second, the efficiencies of vehicles depend on a large number of factors, as was also previously discussed in the biofuel calculations in appendix A5. The same would hold here. The efficiencies used here both for the combustion and electric engines are number obtained from the same paper, by Cullen and Allwood (2010), which in turn aggregates the data used from a number of other, older papers. While this relies on some old, outdated efficiencies, attempts are made to turn these into more, up to date numbers. However, the efficiency of the engines, because they are from aggregate data, are likely to be slightly different in Indonesia, where the climate especially may have some effect on the efficiency. This change is likely to be smaller, and is thus not further addressed here. Third, the CO2 emissions could have been used to create a check against the energy consumption based on the diesel consumption. However, since the diesel consumption is calculated in appendix A5 based on the CO2 emissions, checking the energy consumption here based on the CO2 emissions will not provide an independent result. Both the energy and diesel consumption are based on the CO2 emissions.

B.3.2 Calculating Capacity limits

The maximum amount of electricity that can be stored at any given time is calculated to perform a form of mitigation of the electricity system that needs to be in place in the 2060 scenario due to the intermittency of the energy generation methods. It is extremely unlikely that a situation were to occur where a majority of the electric vehicles would have to be discharged at the same time. It will give a good indication how a significant change in the number of EVs will change the fluctuations that occur in Indonesia's power grid and how much the storage of the EVs can help mitigate the intermittency of the renewable energy generation methods.

To calculate this, one would need to know the capacity of an EV and the number of EVs present. While the amount of cars for the middle and non-OECD growth were actually never calculated, they can be determined from the amount of emissions produced in each growth scenario. The capacity of the average electric car currently available on the market in 61.5 kWh, which is equivalent to 221.4 MJ (Electric Vehicle Database, 2022). Using this, the total capacity can be calculated, and is displayed in the table below.

Table 27: Total EV capacity in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Electric vehicles present (million)	16	30.27	156.47	96.27
Total capacity (GWh)	984	1861	9622	5921
Total capacity (PJ, $10^{1}5$ J)	3.542	6.67	34.64	21.31

The total capacity gives indication for the total available storage of the fleet of EVs in the private transport sector. For reference, the total final electricity consumption of Indonesia in 2018 was 263.32 TWh (IEA, 2019). Compared to the capacity EVs could have in 2018, this would mean that the EVs could store enough energy to provide for all sectors in Indonesia for 1.36 days straight if fully charged for an average day. Of course, in the case that the renewable energy generation is not capable of meeting the demand, mitigation will have to be done first and non-essential energy consumption would have to be cut. As no data for the Indonesian (day ahead) electricity market can be found, no accurate indication can be made as to whether or not this amount of storage is good enough or not. However, Java in particular experiences massive blackouts every several years. While this is more of an indication of the quality of the electricity net, it also gives indication that storage of electricity could help mitigate the effects and ensuing costs of such blackouts. The biggest of these blackouts occurred in August 2005 and August 2019 and lasted 7 hours and 8-34 hours respectively (AP Worldstream, 2005; AP News, 2019).

Assumptions and discussion: The main assumption made here is that the capacity of an EV can be aggregated to be 61.5 kWh. The capacity of an EV is likely to change over time and depends on the vehicle type. It can also be assumed that the capacity of EVs is likely to increase ever slightly still due to improvements in storage technology, although accurate numbers for this would be hard to calculate. Due to the number of uncertainties to the capacity, this aggregate number was used for commercially available vehicles. The added benefit of EVs being able to serve as additional storage for the intermittent energy system that would likely be in place after a renewable energy transition has taken place is hard to accurately gauge. It mainly depends on the quality of the energy system itself. If accurate prediction software is used, or a combination of other grid-integrated mitigating technologies such as micro grids, the added benefit of additional storage from EVs could be diminished. However, storage in of itself is already very expensive, so adding storage to an energy system that has no further use in itself already provides less benefit than EVs. The amount of CO2 that can be mitigated from EVs largely depend on the amount of CO2 that is produced during its lifetime. This should include the fabrication of the components of the EV. While in most cases this might add significantly to the CO2 emissions and cost of an EV, Indonesia has the competitive advantage that it has one of the main components of the battery, which is the most expensive part of an EV, nickel, as an abundant natural resource within its border. This might provide an extra edge for Indonesia to produce EVs locally, and in turn reduce the lifetime CO2 emissions due to reduced transport of components required.

B.3.3 Calculating production area

Finally, the surface area needed to produce the needed amount of electricity can be calculated. There is a large variability in solar PVs that can be used to generate the electricity needed, and a large variability in efficiency. Commercially available solar PVs include mostly silicon solar cells, which have efficiencies of between 20-23% (Smith et al., 2014). Here, due to the age of the citation used, the higher efficiency of 23% will be used. Finally, the average solar irradiance on Java is about 1800 kWh/m2 or 6.48 GJ/m2 per year (SOLARGIS, 2022). The total needed energy, as well as the surface area needed in total, is given in the table below.

Table 28: Needed PV area in multiple scenarios

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Total energy consumed electric engine (EJ)	0.262	0.4957	2.563	1.575
Surface area needed (km^2)	175.8	332.6	1719.7	1056.7

In the worst case scenario, a total of 1720 km2 would be need to be filled with solar PV to be able to generate the electricity necessary. This is roughly the size of the island of Kobroor, or half the size of the urban centre of Jakarta.

Assumptions and Discussion: The main assumption here is that one is able to clear an area large enough to be able to fit the generation units as required. The area needed would in reality be larger as controller units and regulation would also have to be fit in. This expands the needed production area by about 10%. The difficulty comes from having the space available. As Indonesia is in the tropics, direct sunlight is plenty available. However, this space is often occupied by tropical rain forest, the removal of which would drastically increase the CO2 production due to change in land use. The second assumption comes from allowing the average solar irradiance to be the number taken here. One cannot be entirely sure that for such a large area the solar irradiance averages out this nicely. Local variations are likely to occur. One big upside of using this technology is the amount of land needed for dedicated fuel production. In this case, the surface area needed for production is 1719.7 km^2 in the worst case, not taking into account controller units, compared to 9797 km^2 for algae, the best biofuel production option. This is almost one sixth of the surface area needed. The production area also does not have to take into account soil quality, as would be the case for palm oil biofuel production.

B.4 Hydrogen Scenario Calculations

To have hydrogen be the only fuel source of the private vehicle sector, a number of calculations will have to be made to check their viability. There are two variations on hydrogen vehicles. In one, energy is generated via direct combustion of hydrogen to water. In the other, hydrogen electrochemically reacts with oxygen in a fuel cell to produce electricity current and drive an induction engine, somewhat similar to an EV. Both these variations have a different efficiency and the amount of hydrogen needed to be able to run both will have to be checked.

B.4.1 Hydrogen Demand Calculations: Combustion

First, the energy consumption for only hydrogen combustion vehicles will be checked. This can be done by once again using the total amount of energy consumed from diesel, and scaling accordingly to hydrogen. The calculation is the same as is done in A6, and is displayed once again in the table below. The efficiency of converting electricity to hydrogen is about 67%. The efficiency of combustion of hydrogen in a combustion engine is about 20-25%, dropping the overall efficiency of hydrogen combustion to about 13% (Agora Energiewende, 2018; Hosseini and Butler, 2020). The energy content of hydrogen is about 120 MJ/kg on mass basis and 8 MJ/L on volumetric basis (Office of Energy Efficiency Renewable Energy - U.S. Department of Energy, 2022). The below table can then be expanded to include the energy needed to produce the hydrogen needed for the private car sector as well as the amount of hydrogen that needs to be produced.

Table 29: Yearly diesel, energy and hydrogen consumption in multiple scenarios for a hydrogen combustion engine

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Diesel consumed (billion L)	22.9	43.3	224	137.8
Total energy consumed combustion engine (EJ)	0.7145	1.352	6.989	4.299
Effective energy consumed (EJ)	0.1572	0.2974	1.538	0.945
Total energy consumed hydrogen combustion engine (EJ)	1.209	2.288	11.83	7.269
Hydrogen consumed (billion L)	151.2	286.0	1479	908.7
Hydrogen consumed (MT)	10.08	19.06	98.59	60.58

In the worst case scenario, this means that 98.6 MT or 1480 trillion litres of hydrogen need to be produced on a yearly basis. In comparison, the worldwide production of hydrogen, including carbon intensive methods and as by-products, was 87.77 MT. The large majority of this, 60.53 MT, was done using carbon intensive methods, like producing hydrogen from natural gas, without carbon-capture techniques (IEA, 2021b). The amount of hydrogen needed is even higher than the amount of diesel needed. This has to do with the low density of liquid hydrogen compared to that of diesel. The low efficiency of combustion engines make this option less favourable compared to the second option, however.

B.4.2 Hydrogen Demand Calculations: Fuel Cells

The efficiency of converting electricity to hydrogen, as stated before, is about 67%, and lowers to 26% when using in a fuel cell of an electric engine (Agora Energiewende, 2018). A similar calculation can be done as was done for the combustion engine, resulting in the total energy consumed by hydrogen fuel cells, as well as the total amount of hydrogen that needs to be produced.

Table 30: Yearly diesel, energy and hydrogen consumption in multiple scenarios for a hydrogen electric fuel cell engine

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Diesel consumed (billion L)	22.9	43.3	224	137.8
Total energy consumed combustion engine (EJ)	0.7145	1.352	6.989	4.299
Effective energy consumed (EJ)	0.1572	0.2974	1.538	0.945
Total energy consumed hydrogen fuel cell (EJ)	0.6046	1.144	5.915	3.635
Hydrogen consumed (billion L)	75.58	143	739.4	454.3
Hydrogen consumed (MT)	5.038	9.532	49.29	3.029

Since the overall efficiency of fuel cells are twice as high, the amount of higher needed is half that of combustion engines. Here, in the worst case scenario, 49.3 MT or 7390 trillion litres of hydrogen would need to be produced yearly. Since the amount of hydrogen needed to be produced for fuel cells is much more reasonable than that for combustion engines, these numbers will be used to calculate the energy needed to produce this amount of hydrogen.

B.4.3 Energy and Area demand calculations

Hydrogen can be produced in a sustainable manner by performing electrolysis on water. This requires energy. By calculating the amount of electricity needed, one can estimate the surface area needed to generate this amount of electricity using PVs. Water electrolysis has an energy efficiency of 70-80% for mature alkaline electrolysis and 80-90% for the more expensive and developing PEM electrolysis (Shiva Kumar and Himabindu, 2019). It is assumed here that most of the electrolysis will be done using alkaline electrolysis, so an aggregated efficiency of 75% is used. There is a large variability in solar PVs that can be used to generate the electricity needed, and a large variability in efficiency. Commercially available solar PVs include mostly silicon solar cells, which have efficiencies of between 20-23% (Smith et al., 2014). Here, due to the age of the citation used, the higher efficiency of 23% will be used. Finally, the average solar irradiance on Java is about 1800 kWh/m2 or 6.48 GJ/m2 per year (SOLARGIS, 2022). The same calculation is used here as was done in appendix A6, with the added conversion from electricity to hydrogen. The total needed energy, as well as the surface area needed in total, is given in the table 31 below.

Table 31: Yearly energy and hydrogen consumption and surface area needed in multiple scenarios for a hydrogen electric fuel cell engine

	2018	2060 non-OECD	2060 pop growth	2060 middling growth
Total energy consumed hydrogen fuel cell (EJ)	0.6046	1.144	5.915	3.635
Total energy consumed hydrogen production (EJ)	0.8061	1.525	7.887	4.847
Surface area needed (km^2)	540.9	1023.4	5291.6	3251.9

To be able to generate the amount of electricity necessary to supply the entire private vehicle sector with hydrogen in the worst case scenario, almost 5300 km^2 of land is needed. In comparison, the surface area of the entire island of Java is almost 130.000 km^2, and the larger metropolitan area of Jakarta is a little over 7000 km^2.

B.4.4 Assumptions and Discussion:

A number of assumptions had to be made to reach the numbers calculated here. Most of these assumptions have to do with uncertainty in the efficiencies used. A number of the efficiencies used are from somewhat older sources, and have a chance to not be completely up to date. However, in this paper only commercially viable methods are discussed, making completely experimentally obtained efficiencies somewhat redundant. Most efficiencies can be expected to increase somewhat over the period to the 2060 scenario due to optimizations that can be made. The number given here are thus likely somewhat higher than would be actually needed. A large crux is especially present in the surface area needed for the production of the electricity needed. Even small changes in efficiency could means multiple square kms less surface needed to be used for the electricity production. There is something to be said about the redundancy of using hydrogen fuel cells in vehicles as a main form of fuel as well. The complete cycle from solar irradiation to hydrogen fuel to be used in fuel cells is exactly like that of battery vehicles except with the conversion of electricity to hydrogen.

B.5 'Best Guess' Scenario Calculations

Even when the scenario is adapted perfectly, one will still have to take into account for the EVs and hydrogen vehicles that their mitigation only takes effect when the vehicle used is replaced by one using a sustainable energy technology. In this appendix, a number of these sale scenarios will be laid out and their feasibility will be discussed to determine the likelihood the scenario becomes a reality. In every scenario, the worst case, a total of 157 million cars will be present in 2060, and the CO2 emission in a given scenario is based on this number.

Scenario 1: All vehicles replaced: In this scenario it is assumed, the moment there is demand for a new vehicle, or an old vehicle breaks down, it is replaced with a vehicle using a sustainable energy technology (SETV), be it EV or hydrogen. It is also assumed that vehicles that break down are always replaced by SETVs. The lifetime of a diesel engine under good conditions is expected to be around 30 years. Whether this lifetime is correct will be assessed in the next Appendix. To simulate the breaking down of old vehicles, 1/30th of the vehicles using fossil fuels with diesel engines is to be replaced by SETVs. This scenario is visualised in the two graphs 35 and 36 displayed below.

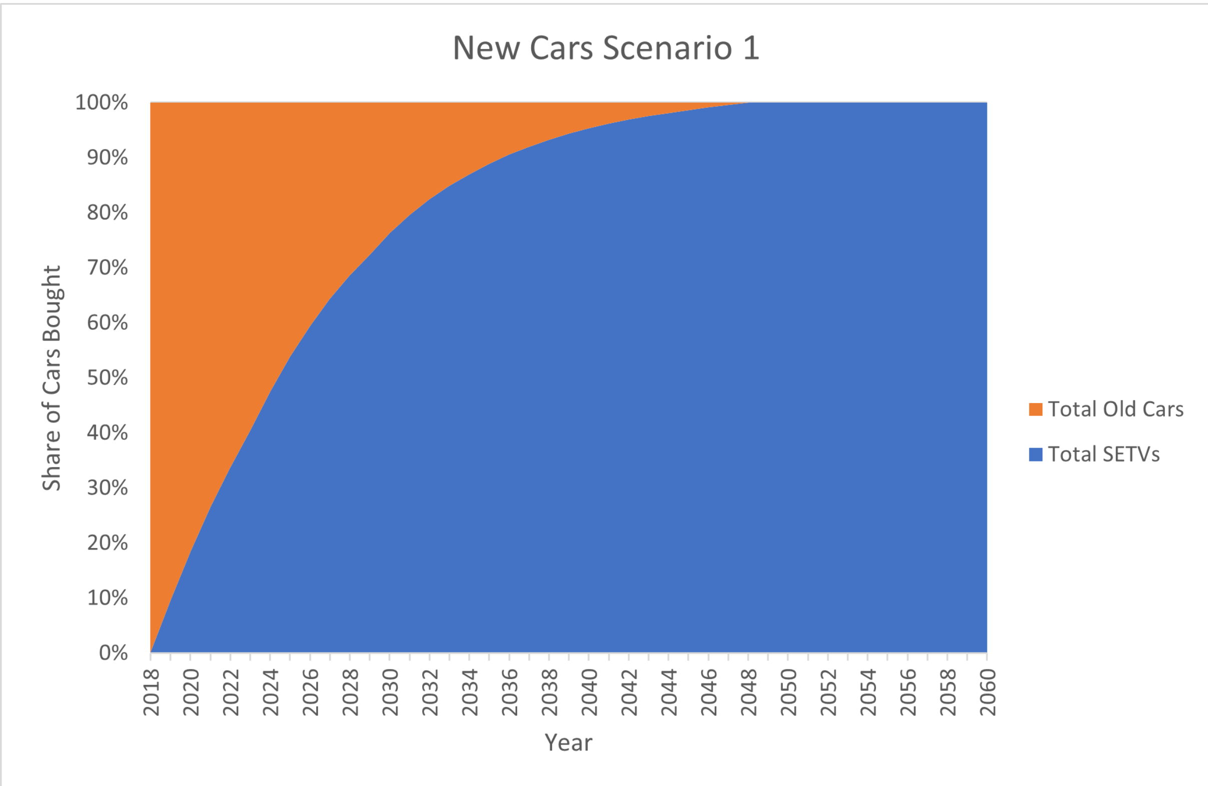


Figure 35: All vehicles replaced with SETVs

All the cars added are new cars, with the exception of the starting year, as no added demand or replacement is done in the starting year. Vehicles using diesel engines would be completely phased out in 30 years in this scenario, in 2048. Carbon neutrality would then be reached at this date. However, this puts serious constraints on the manufacturing industry, making this scenario pretty unlikely to actually happen. The unlikeliness of this scenario becomes clear in the second graph. In the span of 42 years, a total of 156.5 million vehicles would have to be produced. At the lowest rate, when only replacement serves as demand for new vehicles, a total of 1.12 million vehicles would have to be produced in 2060. At the highest rate, from 2037 to 2043, over 6 million vehicles would have to be produced yearly, peaking at 7.14 million in 2040. To compare, in 2021, a total of 79.1 million vehicles were to be produced worldwide (ACEA, 2022). To produce this amount of vehicles, Indonesia would become the world's 5th largest producer of vehicles compared to current numbers. Indonesia currently produced about 1.1 million vehicles yearly, although the vast majority of those can be expected to be not using sustainable technologies (OICA, 2021). A second argument against the feasibility of this scenario is the unlikeliness that from the get go 100% of new vehicle sales will be of a SETV. Unless the government takes some draconic measurements in favour of sustainable energy technology vehicles or against diesel engines, or outright bans the sale of diesel engines, 100% sale figures are nearly impossible due to competition and existing barriers for the implementation of said sustainable energy technology vehicles. Third is the likely delay in sales of SETVs as the infrastructure for production, maintenance and refuelling is still in its infancy, and will take time to expand.

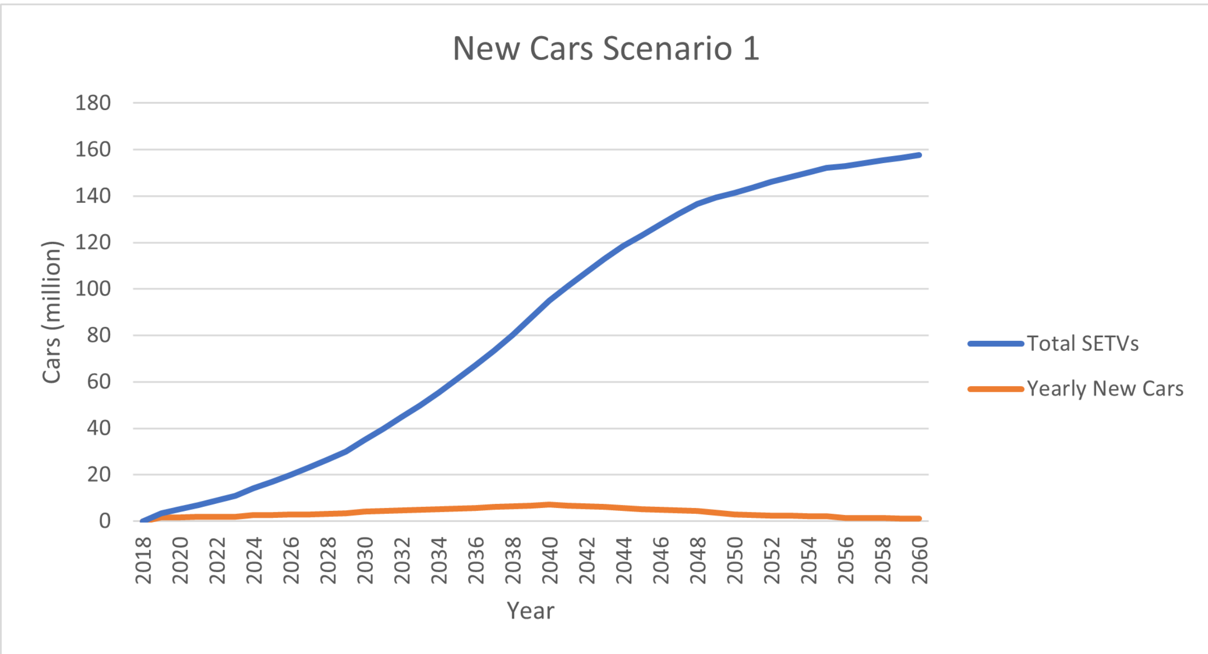


Figure 36: Total SETVs and Yearly SETVs purchased

Displayed below is the amount of CO2 emitted yearly by the private vehicle industry in this scenario. Since the CO2 emission directly scale with the amount of diesel vehicles present, this number decreases directly proportional to the decrease of diesel vehicles present. Each yearly 1/30th of the original CO2 emissions is reduced, leading to CO2-neutrality in 2048. This means that if SETVs are used to reach CO2-neutrality only, sales of SETVs would have to reach 100% of all sales by 2030 at the latest.

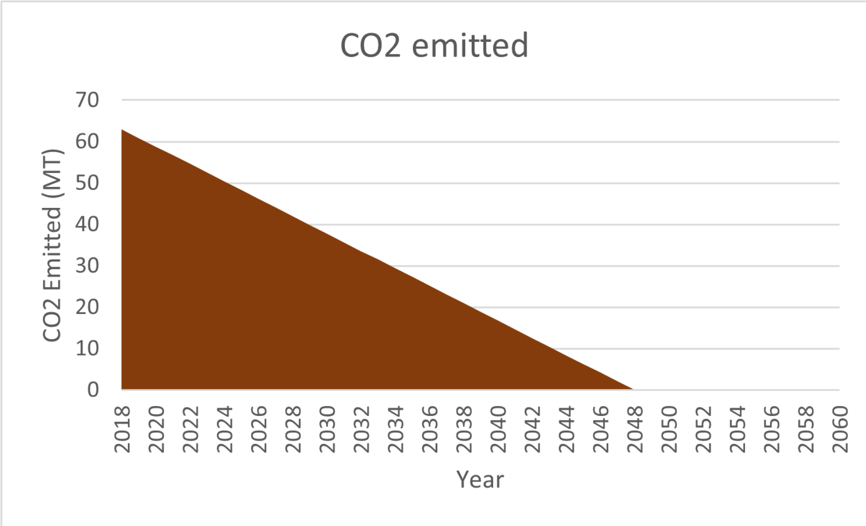


Figure 37: Yearly CO2 emissions

Scenario 2: Significant Competition / Limited Market penetration: In this scenario it is assumed only limited action is taken to ensure SETVs become the dominant form of private transport. Demand of new and to be replaced vehicles is initially for 20% satisfied by SETVs, and reaches 50% by 2060, at an increment of 10% increase every 10 years. In this scenario, the importance of policies and removal of other barriers for implementation of SETVs is tested. The results are given in the graphs 38, 39 and 40below.

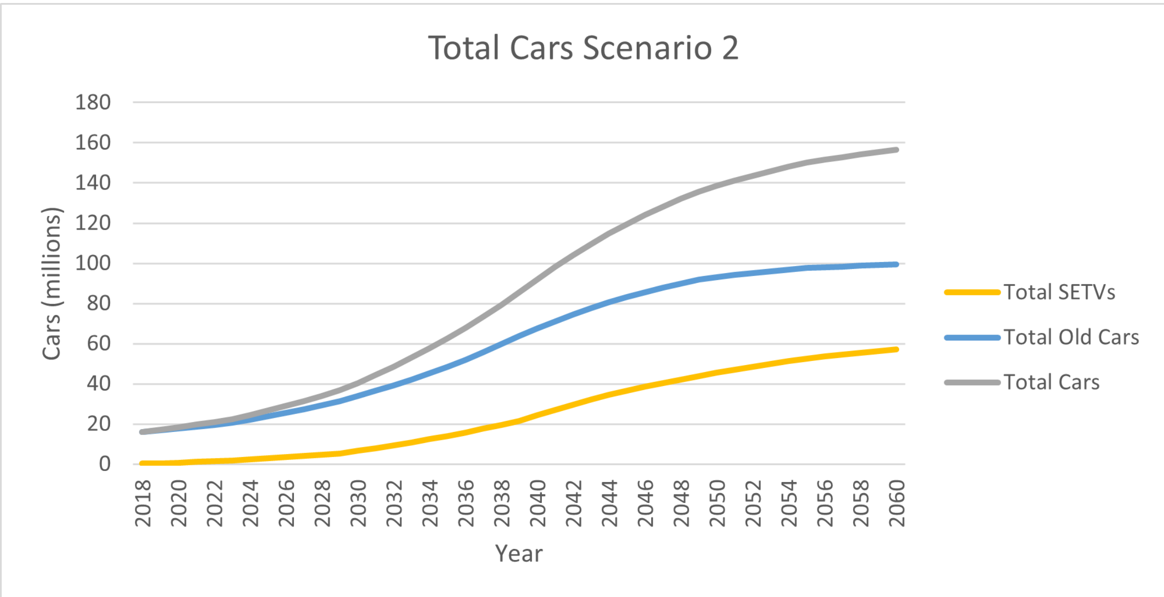


Figure 38: SETVs and 'old' combustion engine vehicles present yearly

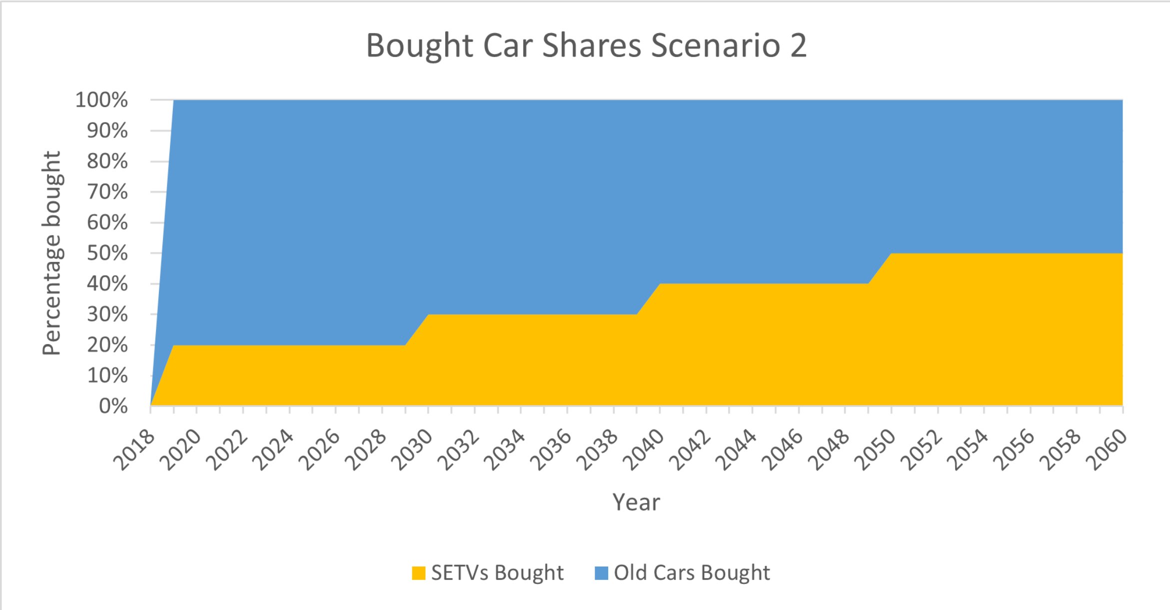


Figure 39: Market shares of 'old' vehicles and SETVs

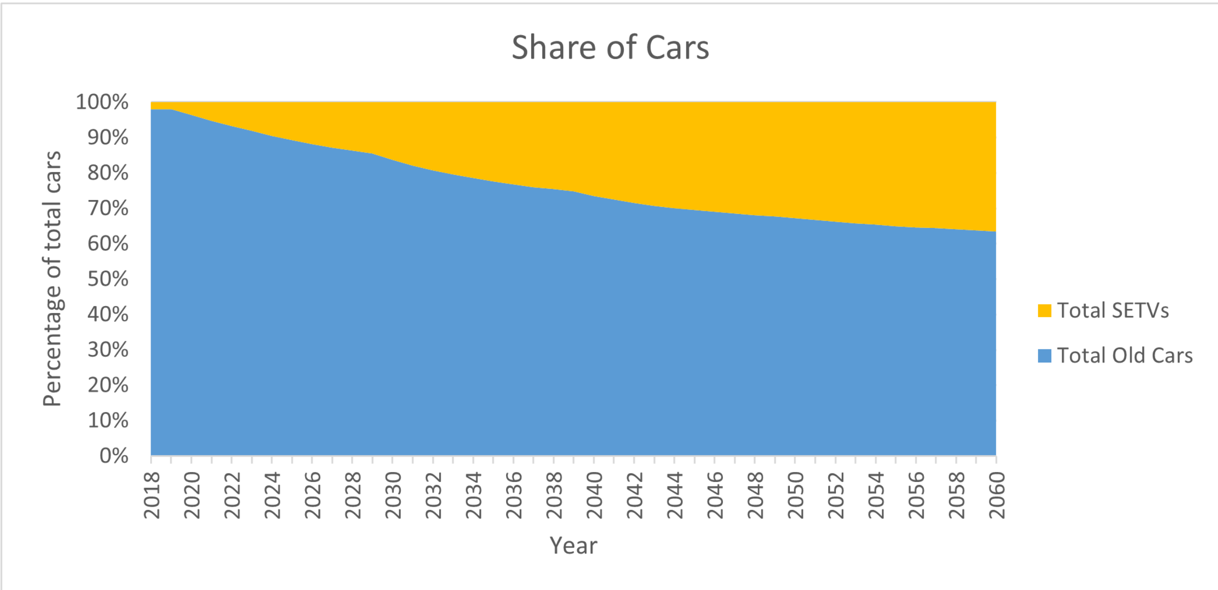


Figure 40: Share of all cars present in 'old' vehicles and SETVs

The increase in percentage of SETVs bought is clearly visible in Graph A8 5, with increases of 10% each year. The total number of SETVs reaches a respectable 36.4% in 2060, but this will not be enough to reach the goal of CO2-neutrality. The yearly production of SETVs also never exceeds 2.9 million in this scenario. The competition leads to a total of almost 100 million diesel engine vehicles and 57 million SETVs in 2060. The CO2 emissions are shown in the graph 41 below.

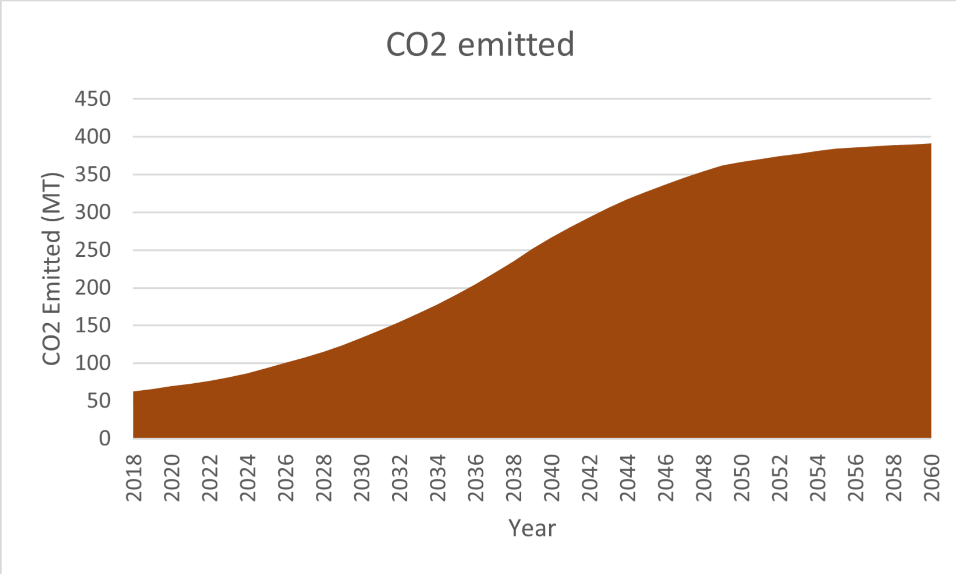


Figure 41: Yearly CO2 emissions in a competitive scenario

With these relatively low sales of SETVs, there is no successful decrease in the CO2 emitted. There is even a slight increase, although this increase is much less than would be the case in the BAU scenario. In 2060, there is 391.3 MT CO2 being emitted yearly, compared to the 616.1 MT in the BAU scenario. While this is a reduction of 36.4% in comparison to the BAU scenario, it is still far from CO2 neutral. This gives a clear illustration for the need for policies to ensure that SETVs become the majority of vehicles on the road.

Scenario 3: Delay in implementation: As discussed in Scenario 1, it is likely that it will take a while of SETVs to properly penetrate the market, and for the necessary infrastructure to be constructed. In this scenario, it is assumed that the government does mandate a the use of SETVs and provides policies, leading to an overall higher percentage of SETVs being in the latter half of this scenario. Overcoming bottlenecks in infrastructure is presented by rapid increases in the percentage of SETVs of total vehicles, and the delay is presented by setting the percentages of SETVs to 0 for the first 10 years. Sales of SETVs slowly increase until they reach 100% of all sales, around 2055. The results are presented in the graphs 42 and 43 below.

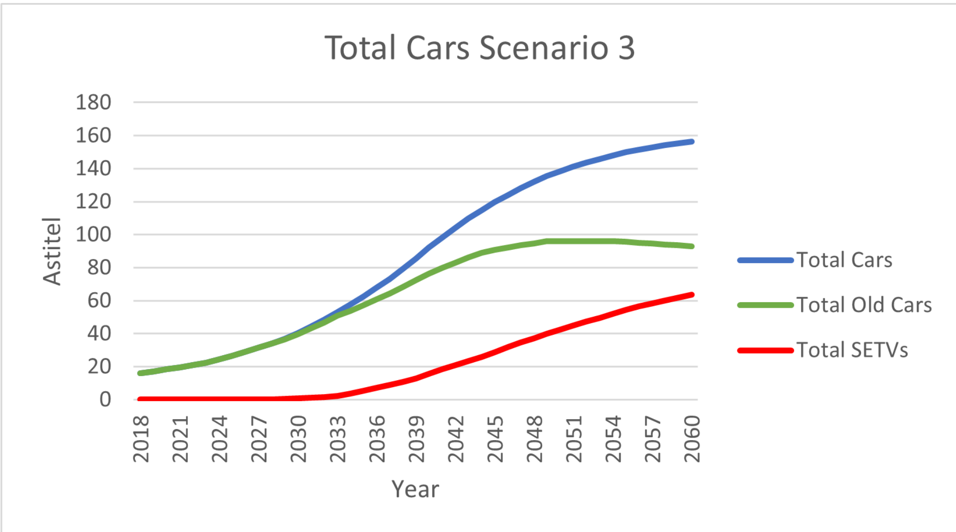


Figure 42: Number of 'old' vehicles and SETVs in a delayed implementation scenario

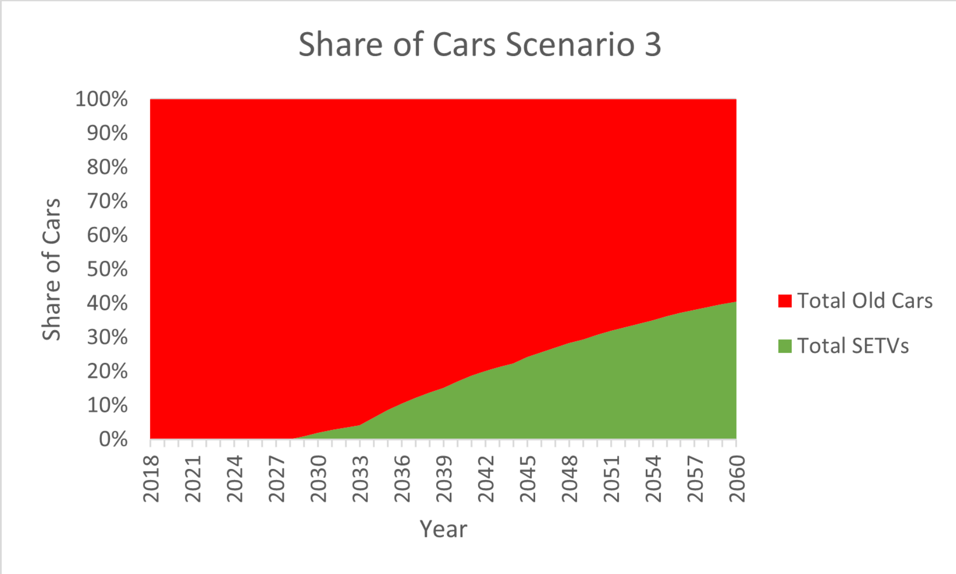


Figure 43: Share of total vehicles for 'old' vehicles and SETVs in a delayed implementation scenario

Due to the delay in sales of SETVs, the total number of old cars, using diesel engine, far outweighs the number of SETVs even in 2060, when all new cars bought are SETVs. A delay in sales due to the presence of bottlenecks severely hinders the chance for this scenario to be able to reach CO2-neutrality in 2060. The CO2 emissions for this scenario are displayed below in Graph 44.

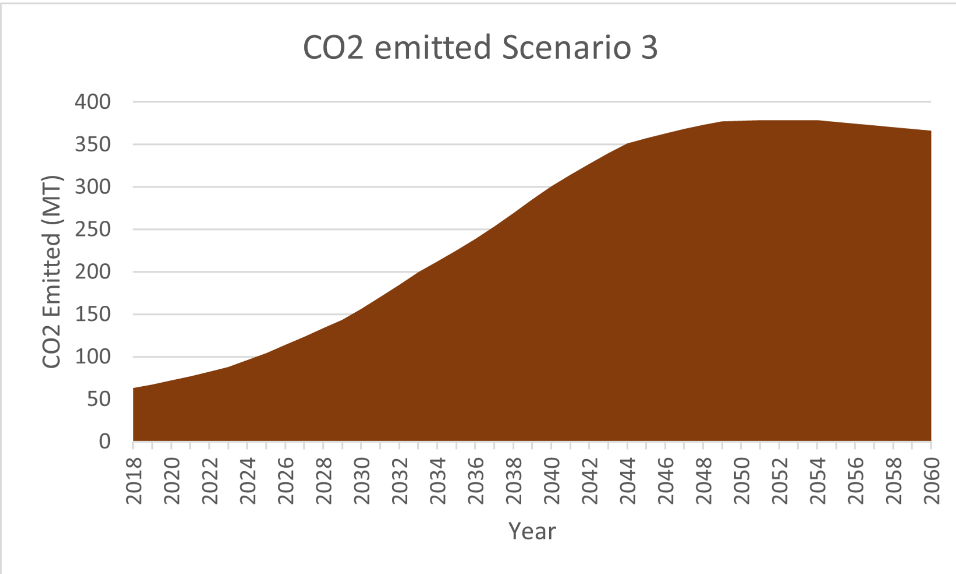


Figure 44: Yearly CO2 emitted in a delayed implementation scenario

Although the CO2 emissions in this scenario significantly increase, it can be seen that there is an eventual decrease as the sales of SETVs begin to make up a significant portion of all sales. However, the delay in sales does mean that most of the vehicles bought during the growth of the middle class will mostly be old, diesel engine vehicles, resulting in the increase in CO2 emissions given here.

B.6 Scenario Sensitivity Analysis

Using fixed sale percentages that as a result of a newly established equilibrium after a period of change of roughly 5-10 years in which infrastructure and policies are created and implemented, one can get an idea of what the sale percentage has to be to ensure there is a CO2 emission reduction based on the sale of SETVs alone. The period of change will be represented by linear ramping of sales to their final number. This period of change is set to 10, 5, 3 and 0 years, indicating different ramping times. The change in total vehicles is determined by the population growth and the number of individuals estimated to reach an economic standard in which they are able to afford private vehicles. The CO2 emission is scaled to the number of vehicles with combustion engines present and the number of vehicles using a form of sustainable energy technology. The change in vehicles is determined by the market share of both forms of vehicles, the number of vehicles that are bought each year and the number of vehicles that need to be replaced every year. This is displayed in the figure 45 below.

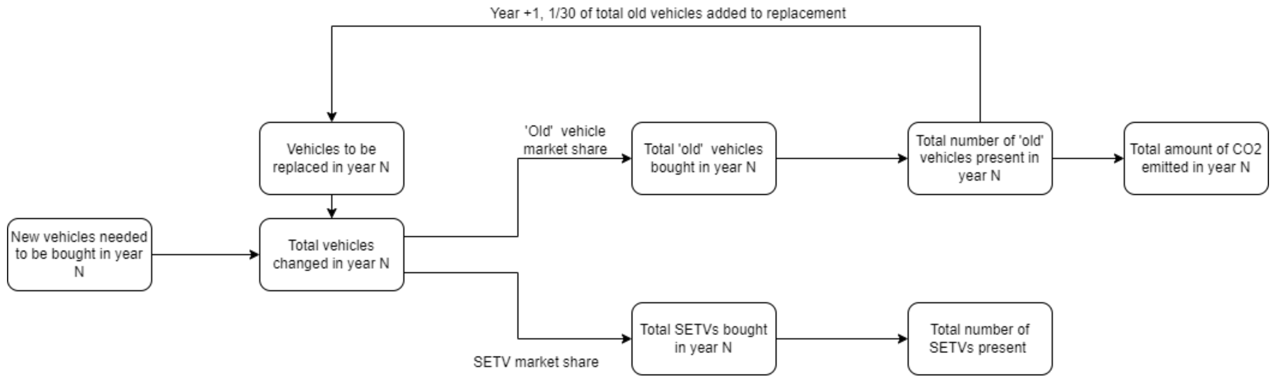
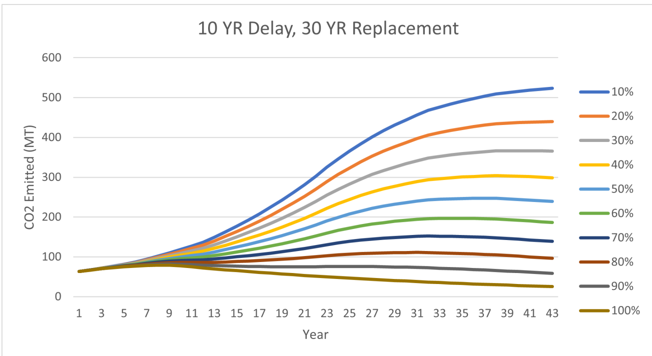
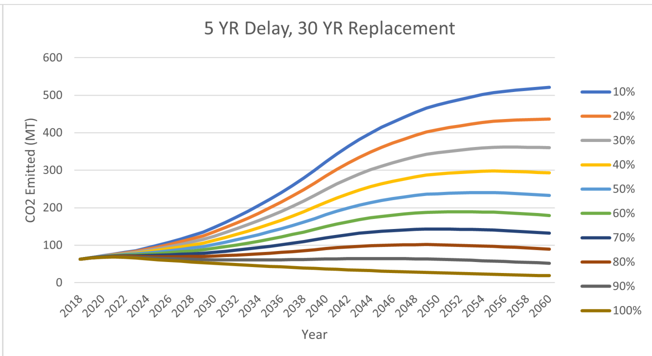


Figure 45: Flowchart of iterative process of CO2, SETVs and 'old' vehicles calculations

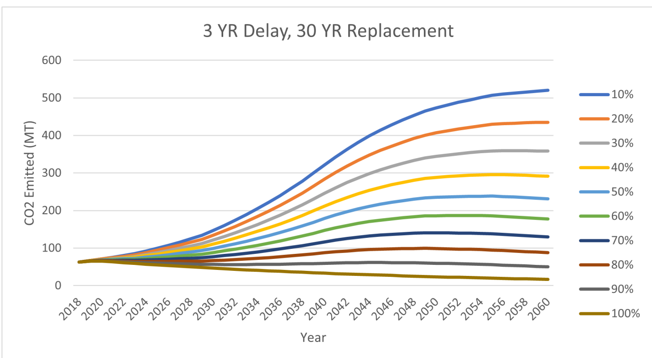
The number of vehicles that need to be replaced is determined by the amount of serviceable years a vehicle has. This is initially set to 30 years, which translates to a replacement rate of 1/30th of all the combustion engine vehicles. It is assumed that all vehicles that make use of the new sustainable energy technology are always replaced by vehicles of the same type. The emissions as a function of the total market share and delay in implementation is then displayed in the figures below.



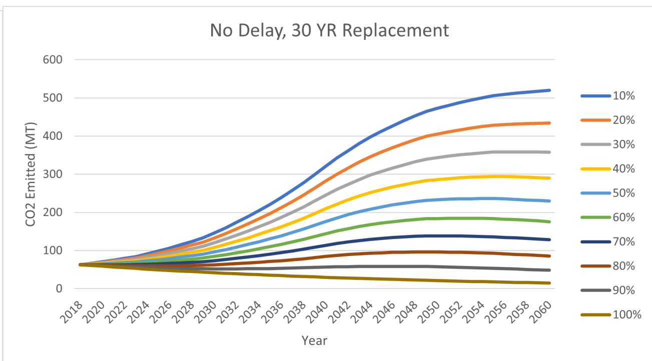
(a) 10 Year Delay



(b) 5 Year Delay



(c) 3 Year Delay



(d) No Delay

Figure 46: 30 years of service before replacement, different delay of implementation and market shares

The effect of market share of SETVs on the amount of CO2 emitted appears obvious. The higher the market share, the lower the eventual level of CO2 emissions. Only high market shares are capable of dropping the CO2 emission levels below those observed in 2018, however, and none of the market shares appear to be capable of dropping the CO2 emissions to zero. Why this is, will be explained in the next section. The market shares seem to paint a pretty good picture, as even low rates of market shares seem to be able to slow or stabilize the growth of CO2 emissions, even if that is at quite a high level. However, it should become clear that if the 2060 goals are to be realized, it is imperative that a hgih market share is reached.

Replacement rate:
Although it might seems strange that in no cases, even if the market share of SETVs is 100%, the CO2 emissions reach zero. However, this is easily explained by the fact that each year the replacement rate of the combustion engine vehicles is a share (1/30th) of the total amount of combustion engine vehicles present. If the number of combustion engine vehicles replaced each year had been a fixed number, say 1/30th of the original 16 million vehicles present in the country, or 0.5333 million vehicles each year, the number of combustion vehicles in Indonesia in the case that the market share of SETVs is 100% would become negative. In such cases, the ends of the graphs appear a little differently. The case for a 10 year delay with such fixed replacements is given in the figure below.

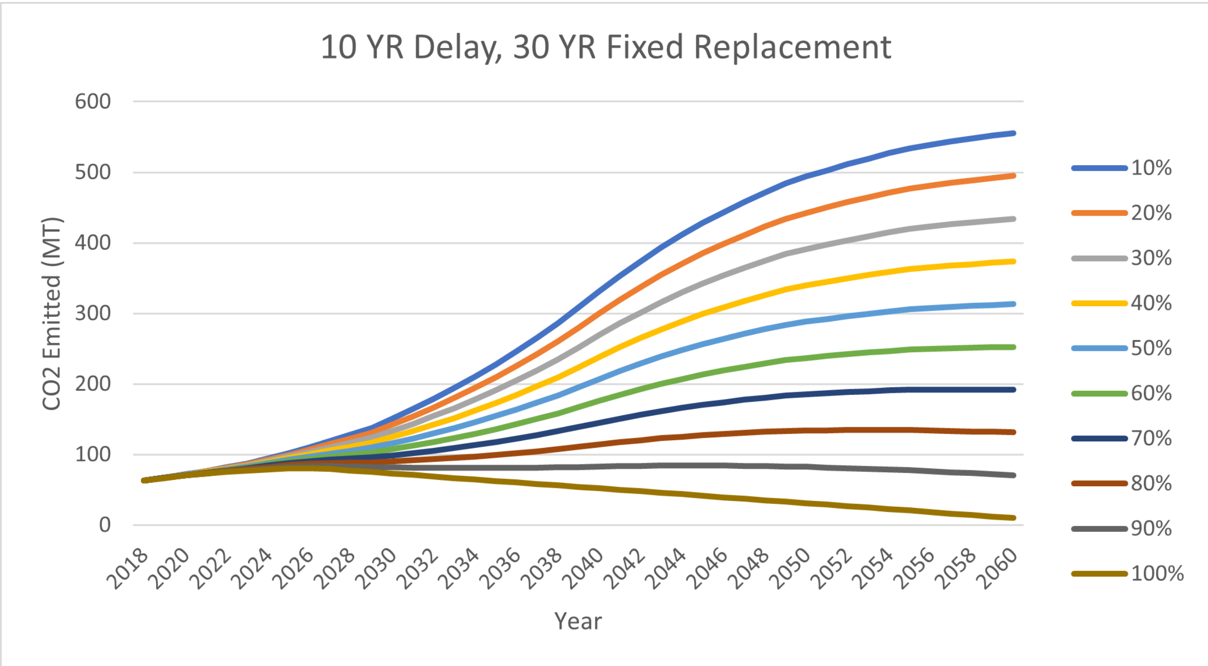


Figure 47: CO2 emissions in the case of a fixed replacement rate at 30 service years for 10 years implementation delay

With a fixed replacement rate, only if the market share of SETVs is above 70%, a downward trend in CO2 emissions can be observed. Compare this with a percetile replacement rate, where even with market shares as low as 40% a downward trend can be observed. In the figure below the 2060 CO2 emissions are given for both the fixed and percentile replacement rate for the same scenario, a 10 year delay in implementation and 30 years of service per vehicle.

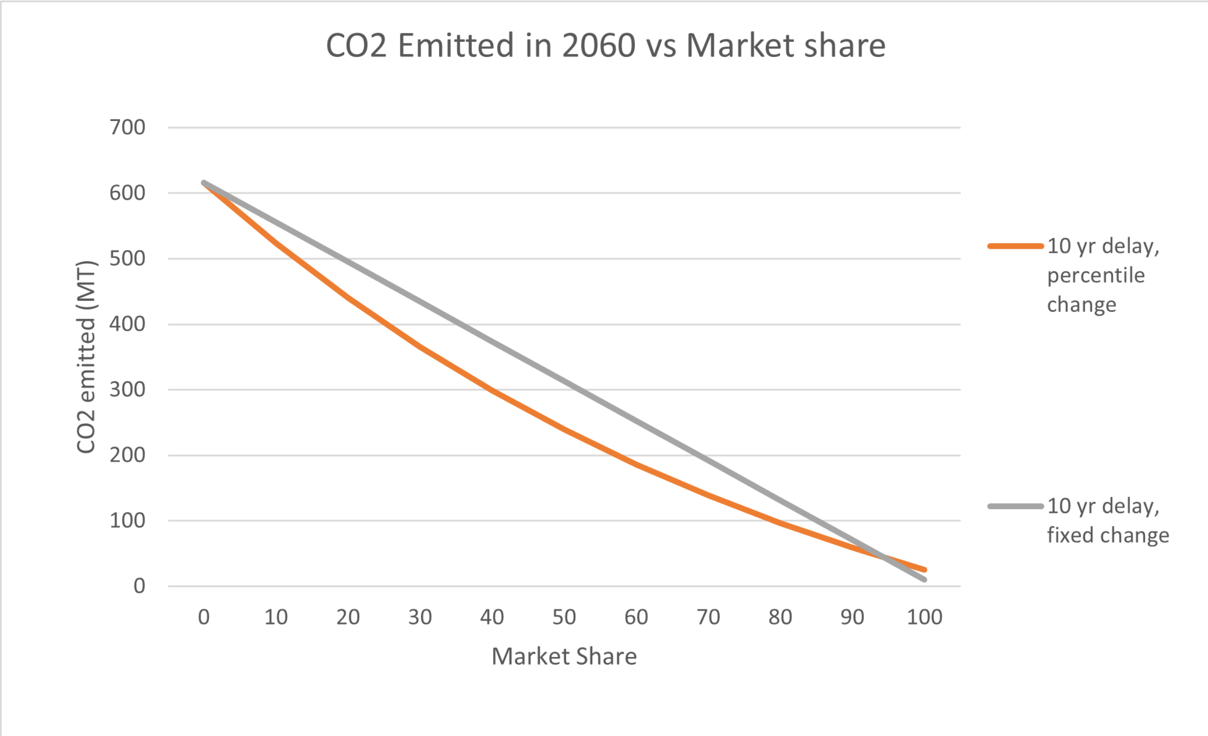
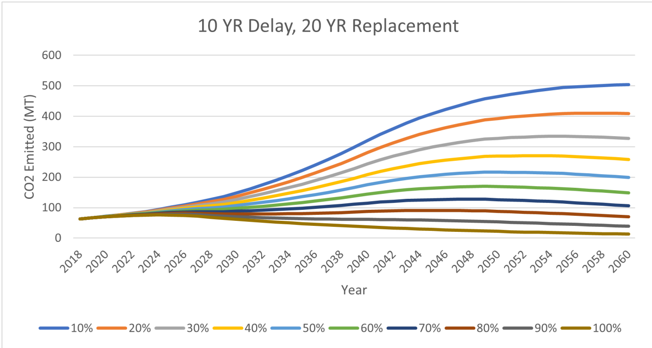


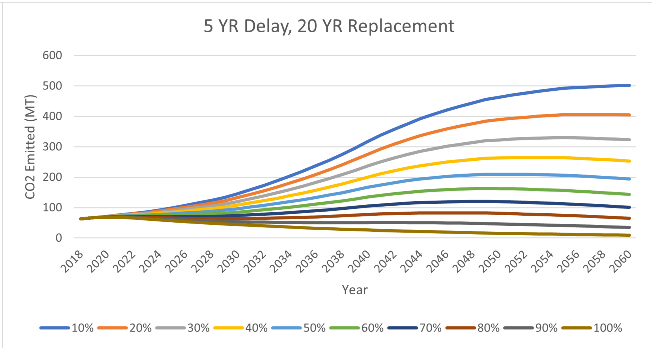
Figure 48: Fixed vs Variable replacement rate

Only in the case of 100% market share does the fixed replacement perform better than the percentile replacement. What should als be noted is that fixed replacement rate makes the amount of CO2 emitted by market share a linear function, with a decrease of roughly 60 MT CO2 emitted per 10% increase in market share.

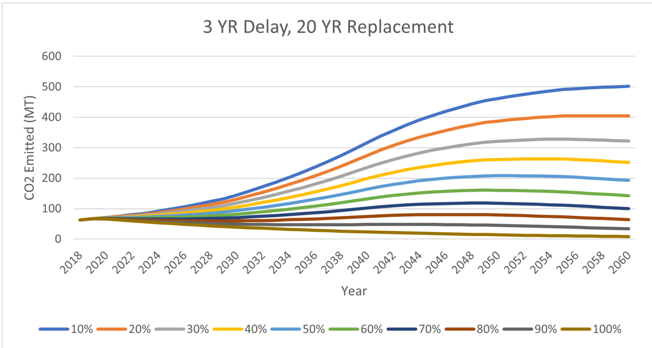
Another thing that can be changed about the replacement rate is the time it takes for combustion engine vehicles to be replaced. One could assume the servicable lifetime of a vehicles is 20 years, or even 10 years. This would make the replacement rates 1/20th and 1/10th of the current amount of combustion engine vehicles present. These lifetimes, with changed replacement rates are given in the figures below.



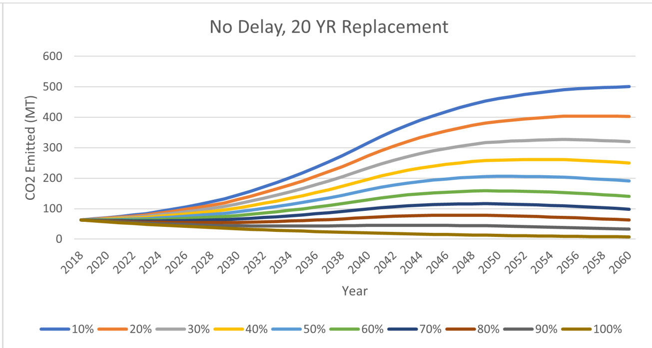
(a) 10 Year Delay



(b) 5 Year Delay

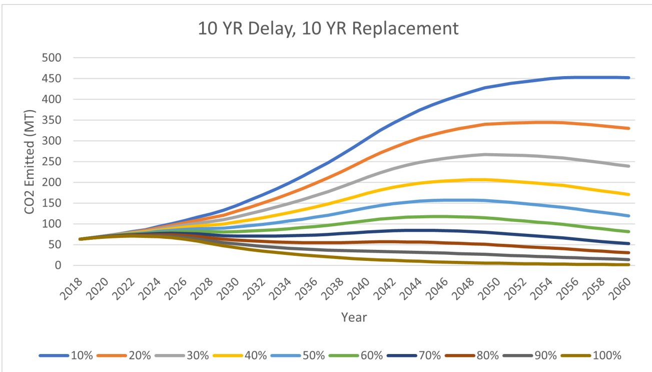


(c) 3 Year Delay

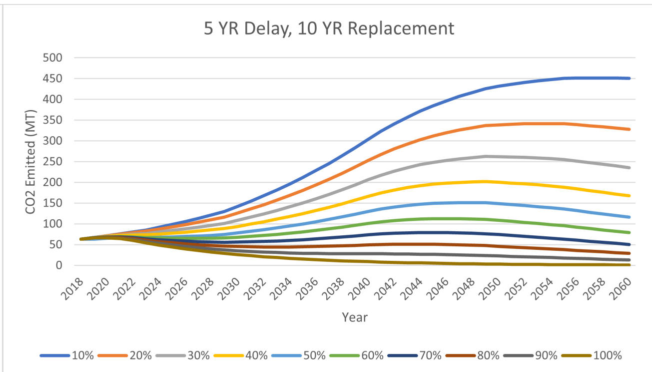


(d) No Delay

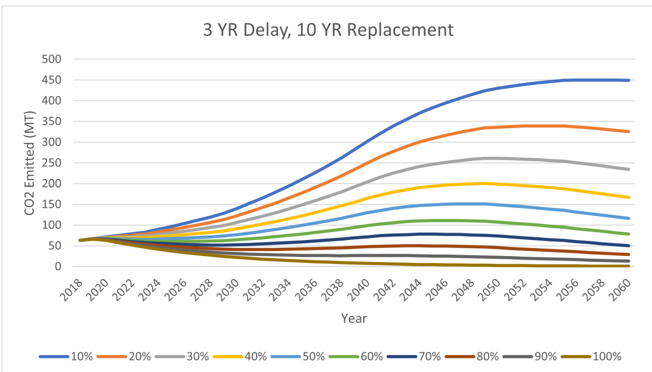
Figure 49: 20 years of service before replacement, different delay of implementation and market shares



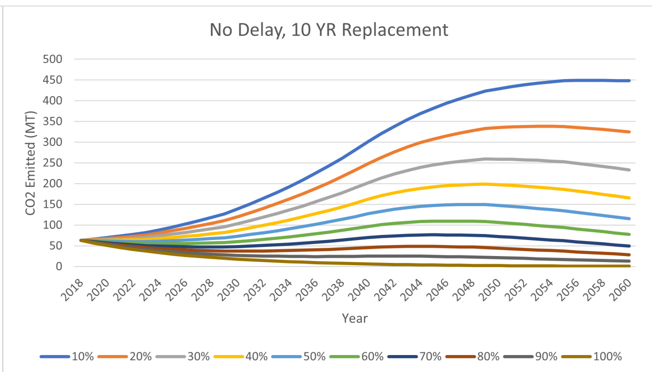
(a) 10 Year Delay



(b) 5 Year Delay



(c) 3 Year Delay



(d) No Delay

Figure 50: 10 years of service before replacement, different delay of implementation and market shares

Visually, only in the last graph, with no delay and 10 year replacement time and 100% market share reached, do the SETVs appear to reach 0 CO2 emissions. In reality, there is still an emission level of 0.7563 MT of CO2 in 2060 in this case. This level of CO2 emissions is due to the residual amount of combustion engine vehicles that have remained in service thus far. The number of combustion engine vehicles in this case has already dropped below 1 million in 2044, and has dropped to just under 200.000 vehicles in 2060. Faster removal of these vehicles could be accomplished by implementing policies that disincentivize keeping these vehicles in service.
For the creation of policies, it is imperative that the first policies introduced are 'pulling' individuals towards the purchase of SETVs, increasing the market share of these vehicles as fast as possible. The last policies should then be of the 'pushing' type, disincentivizing the use of old combustion engine vehicles, to decrease the residual amount of combustion engine vehicles as fast as possible.
This does not mean that vehicles in real life can be simulated with such long replacement times. Although up to 1990 an increase in lifetimes of vehicles has been observed, from 10 years up to 15 years, it cannot be expected that this trend will continue (Hamilton and MacAuley, 1998; Feeney and Cardebring, 1988) [8]. Rather, it can be argued that this trend is reversing, and that the lifetime of vehicles will return to roughly 10 years. While the increase in lifetime has been attibuted to increase in the quality of parts, service and infrastructure, a subsequent decrease in lifetime can also be attributed to these same indicators. Newer cars contain more expensive components, which increase the sunk cost of reparations compared to the purchase of newer vehicles. Even so, the lifetime of vehicles in Europe has been observed to have averaged to nearly 22 years, although with significant deviation and east-west divide, likely due to cultural and economical differences (Held et al., 2021). Whether or not Indonesia will follow this trend is unknown, and research into the lifetimes of vehicles in South East Asia is recommended.

Delay in implementation

The 2060 CO2 emission values for each delay and percentage of market share is given in the table 32 below in MT for a replacement time of 30 years.

Table 32: CO2 emissions per implementation delay and market share of SETVs

	Implementation Delay			
Market Share	10 Years	5 Years	3 Years	No Delay
0	616.09	616.09	616.09	616.09
10	523.15	521.09	520.45	519.87
20	439.92	436.27	435.16	434.15
30	365.42	360.61	358.29	357.83
40	298.8	293.14	291.44	289.91
50	239.26	233.03	231.18	229.5
60	186.09	179.51	177.57	175.82
70	138.66	131.91	129.92	128.15
80	96.39	89.6	87.62	85.85
90	58.75	52.03	50.09	48.36
100	25.28	18.72	16.84	15.17

It should be noted that only in the cases of high market share for the SETVs, the delay in implementation becomes noticible, making a difference of little over 10 MT for a market share of 100%. This small difference can further be illustrated if the total CO2 emissions are plotted against the market share per delay scenario. This is given in the figures below.

[8] Recent observations of lifetime of ICEVs is very rare, especially for non western countries, as the interest has shifted towards lifetime observations of renewable vehicles and components.

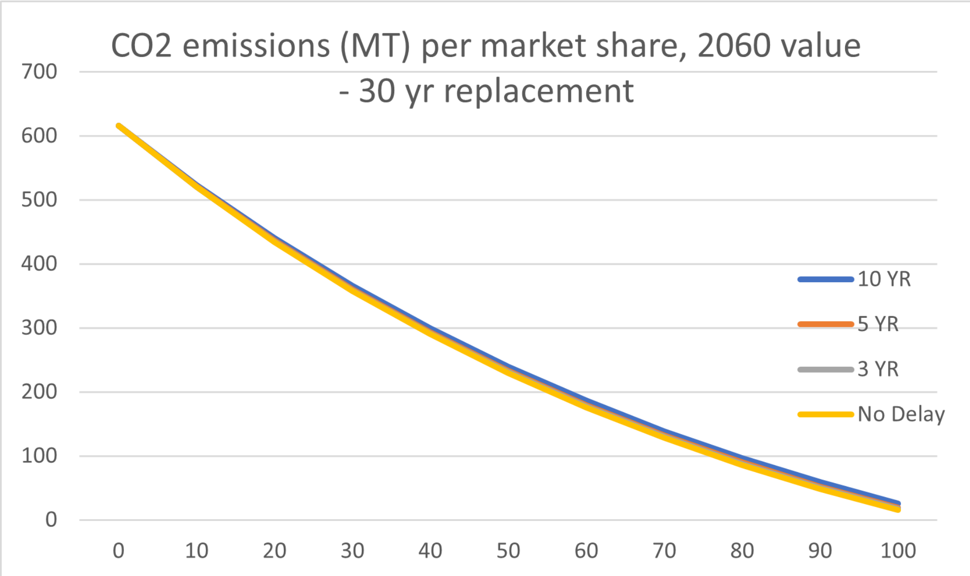


Figure 51: Change in CO2 emissions per change in market share percentage for 30 years as replacement time

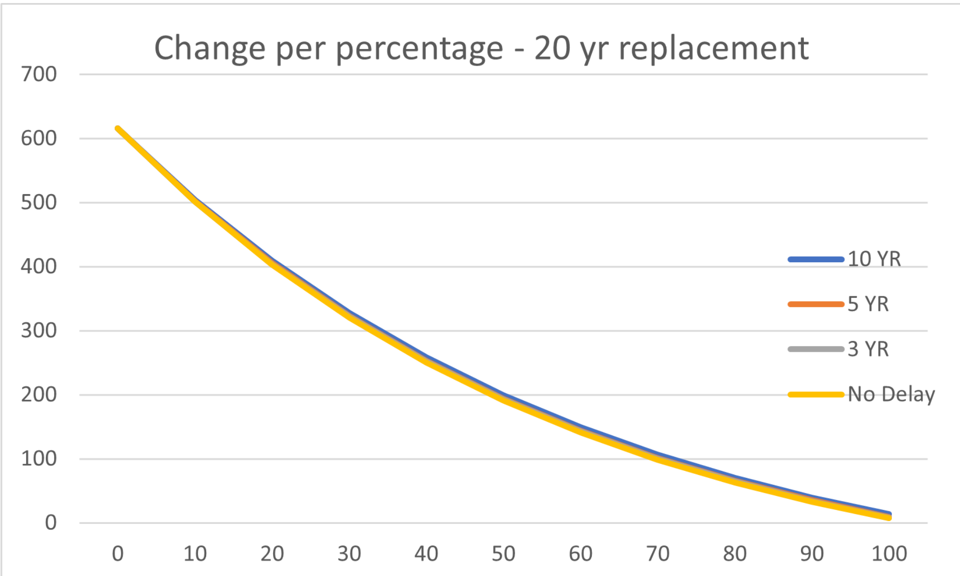


Figure 52: Change in CO2 emissions per change in market share percentage for 20 years as replacement time

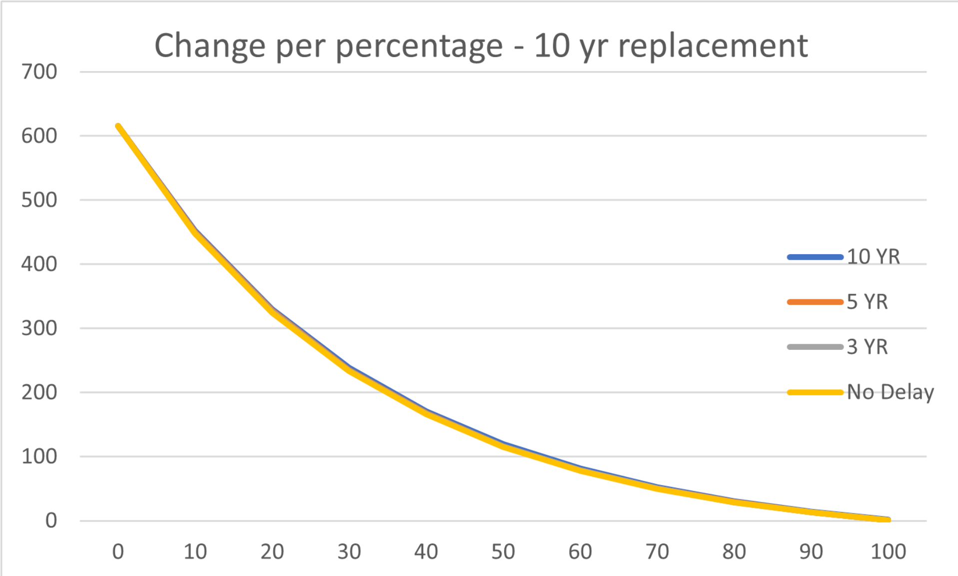


Figure 53: Change in CO2 emissions per change in market share percentage for 10 years as replacement time

There is significant overlap between each of the delays, indicating that the delay on the timescale chosen here does not matter significantly in terms of achieving the intended goal, regardless of the pursued market share. What does appear to be of interest is the shape of the curves observed. While for a 30 and 20 year service time the curves can to some degree still be viewed as linear regressions, in the case of 10 years this is clearly no longer the case. Starting from 60% market share and higher, the residual amount of combustion engine vehicles that remain appear to cause some CO2 emissions to remain up to 2060 that would likely not be present if a fixed number of vehicles were to be replaced each year. This comes back to the conclusion that was made in the previous section. While for low market shares the best solution for reducing CO2 emissions is to increase the market share, for high market shares, the best solution is to increase the replacement rate or the total number of vehicles replaced.

B.7 Raw data for the final scenario

Displayed here is the raw data for the market share of EVs, % of biofuel in the fuel mix, % of BAU CO2 emissions mitigated, yearly ICEVs and EVs bought, biofuel production in L and emissions mitigated per source used in the final scenario.

Year	EVs Market Share	% biofuels in fuel mix	% CO2 mitigated
2018	0	20	20%
2019	0	20	20%
2020	0	30	30%
2021	0	30	30%
2022	0	30	30%
2023	0	30	30%
2024	0	30	30%
2025	0	30	30%
2026	0	30	30%
2027	0	30	30%
2028	0	30	30%
2029	10	30	31%
2030	10	30	31%
2031	20	30	33%
2032	20	30	34%
2033	30	30	36%
2034	30	30	38%
2035	40	40	48%
2036	40	40	50%
2037	50	40	52%
2038	50	40	54%
2039	50	40	55%
2040	50	50	64%
2041	60	50	65%
2042	60	50	66%
2043	60	50	67%
2044	60	50	68%
2045	70	50	69%
2046	70	50	70%
2047	70	50	71%
2048	70	50	71%
2049	80	50	72%
2050	80	70	84%
2051	80	70	84%
2052	80	70	84%
2053	90	70	85%
2054	90	70	85%
2055	90	100	100%
2056	90	100	100%
2057	100	100	100%
2058	100	100	100%
2059	100	100	100%
2060	100	100	100%

Figure 54: Market share of EVs, % of biofuel in the fuel mix and % of BAU CO2 emissions mitigated for a combined future scenario

Year	ICEVs bought (million)	EVs bought (million)	Biofuel production billion L	EVs CO2 mitigated (MT)	Biofuel CO2 mitigated (MT)
2018	0	0	5.090909091	0	12.6
2019	2.185923	0	5.447036258	0	13.48141
2020	2.25594	0	8.738162123	0	21.62695
2021	2.330056	0	9.341143633	0	23.11933
2022	2.408525	0	9.981575846	0	24.7044
2023	2.491612	0	10.66166354	0	26.38762
2024	3.130647	0	11.64674528	0	28.82569
2025	3.254915	0	12.69113638	0	31.41056
2026	3.386557	0	13.79835671	0	34.15093
2027	3.526033	0	14.97214505	0	37.05606
2028	3.673831	0	16.21647332	0	40.13577
2029	3.447424	0.383047	17.35274382	1.508248	42.94804
2030	4.287614	0.476402	18.89001432	3.384079	46.75279
2031	3.987237	0.996809	20.28392286	7.309016	50.20271
2032	4.173878	1.043469	21.76690988	11.41768	53.8731
2033	3.82533	1.639427	23.08354445	17.87292	57.13177
2034	4.009018	1.718151	24.48784847	24.63814	60.60742
2035	3.603321	2.402214	34.26469936	34.09686	84.80513
2036	3.780524	2.520349	35.99169941	44.02073	89.07946
2037	3.307132	3.307132	37.41745033	57.04257	92.60819
2038	3.473433	3.473433	38.94902881	70.71921	96.39885
2039	3.649954	3.649954	40.59293907	85.0909	100.4675
2040	3.837354	3.837354	52.94512963	100.2005	131.0392
2041	2.919963	4.379945	54.41934291	117.4465	134.6879
2042	2.778746	4.168119	55.78122443	133.8585	138.0585
2043	2.645706	3.968559	57.03727838	149.4847	141.1673
2044	2.520349	3.780524	58.1936168	164.3705	144.0292
2045	1.718151	4.009018	58.71184261	180.156	145.3118
2046	1.639427	3.82533	59.16744739	195.2182	146.4394
2047	1.565204	3.652143	59.56401125	209.5986	147.4209
2048	1.495214	3.488832	59.90490106	223.3358	148.2646
2049	0.952803	3.811213	59.81432784	238.3425	148.0405
2050	0.766094	3.064377	83.40533055	250.4085	206.4282
2051	0.734766	2.939065	83.03571404	261.981	205.5134
2052	0.705207	2.820826	82.63317891	273.088	204.5171
2053	0.338656	3.047901	81.82243941	285.0891	202.5105
2054	0.325491	2.929423	80.99703976	296.6238	200.4677
2055	0.313065	2.817583	114.5111446	307.718	283.4151
2056	0.249161	2.242451	113.2105678	316.5476	280.1962
2057	0	2.408525	111.5135981	326.0312	275.9962
2058	0	2.330056	109.8166284	335.2058	271.7962
2059	0	2.25594	108.1196587	344.0886	267.5962
2060	0	2.185923	106.422689	352.6956	263.3962

Figure 55: Yearly ICEVs and EVs bought, biofuel production in litres and emissions mitigated per source for a combined future scenario

References

Abrahams, C. (2010). Transforming the region: Supermarkets and the local food economy. *African Affairs*, 109(434):115–134.

ACEA (2022). World motor vehicle production.

Acemoglu, D., Johnson, S., and Robinson, J. A. (2001). The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91(5):1369–1401.

Acevedo, J. C., Hernández, J. A., Valdés, C. F., and Khanal, S. K. (2015). Analysis of operating costs for producing biodiesel from palm oil at pilot-scale in Colombia. *Bioresource Technology*, 188:117–123.

Adaro (2022a). Adaro Mining.

Adaro (2022b). Adaro Power.

Adiatma, J. C., Marciano, I., and Institute for Essential Services Reform (2020). Electric Vehicles in De-Carbonizing Indonesia's Road Transport Sector. Technical report.

Agora Energiewende (2018). The Future Cost of Electricity-Based Synthetic Fuels. Technical report.

Agustina, C. D. R., Fengler, W., and Schulze, G. G. (2012). The regional effects of Indonesia's oil and gas policy: options for reform. *Bulletin of Indonesian Economic Studies*, 48(3):369–397.

AHK Indonesien (2021). Indonesian Electric Vehicles Industry Development Gains Momentum.

Åhman, M., Olsson, O., Vogl, V., Nyqvist, B., Maltais, A., Nilsson, L. J., Hallding, K., Skånberg, K., and Nilsson, M. (2018). Hydrogen steelmaking for a low-carbon economy.

Ahmed, A., Al-Amin, A. Q., Ambrose, A. F., and Saidur, R. (2016). Hydrogen fuel and transport system: A sustainable and environmental future. *International Journal of Hydrogen Energy*, 41(3):1369–1380.

Airgas (2020). Hydrogen Material Safety Data Sheet. Technical report.

Åkerman, J. and Höjer, M. (2006). How much transport can the climate stand?—Sweden on a sustainable path in 2050. *Energy Policy*, 34(14):1944–1957.

AKR Corporindo Retail (2018). Home – PT. AKR Corporindo Tbk.

Alazemi, J. and Andrews, J. (2015). Automotive hydrogen fuelling stations: An international review. *Renewable and Sustainable Energy Reviews*, 48:483–499.

Altarazi, Y. S., Abu Talib, A. R., Yu, J., Gires, E., Abdul Ghafir, M. F., Lucas, J., and Yusaf, T. (2022). Effects of biofuel on engines performance and emission characteristics: A review. *Energy*, 238:121910.

ANDRIYANTO, H. (2021). Indonesia Aims to Reach Net Zero Emissions by 2060 or Sooner.

Anitha, K., Verchot, L. V., Joseph, S., Herold, M., Manuri, S., and Avitabile, V. (2015). A review of forest and tree plantation biomass equations in Indonesia. *Annals of Forest Science*, 72(8):981–997.

AP News (2019). Indonesian capital hit by massive 8-hour power outage.

AP Worldstream (2005). 100 million Indonesians affected by power outage - Waybackmachine.

APROBI (2022). APROBI About Us.

Asian Development Bank (2012). Transport Sector Assessment, Strategy, and Road Map - Indonesia. Technical report.

Astra Agro Lestari (2022). Astra-Agro Company Profile.

Badan Pusat Statistik (2018). Perkembangan Jumlah Kendaraan Bermotor Menurut Jenis, 1949-2018.

Bakker, S., Dematera Contreras, K., Kappiantari, M., Tuan, N., Guillen, M., Gunthawong, G., Zuidgeest, M., Liefferink, D., and van Maarseveen, M. (2017). Low-Carbon Transport Policy in Four ASEAN Countries: Developments in Indonesia, the Philippines, Thailand and Vietnam. *Sustainability*, 9(7):1217.

Banerjee, A. V. and Newman, A. F. (1993). Occupational Choice and the Process of Development. *Journal of Political Economy*, 101(2):274–298.

Banpu (2022). Banpu Group Operation Map.

Bemelmans-Videc, M., Rist, R. C., and Vedung, E. (1998). *Carrots, sticks, and sermons: Policy instruments and their evaluation*. Transaction Publishers, New Brunswick, New Jersey, fifth edit edition.

Berg, C. N., Deichmann, U., Liu, Y., and Selod, H. (2017). Transport Policies and Development. *The Journal of Development Studies*, 53(4):465–480.

BIRO KOMUNIKASI DAN INFORMASI PUBLIK (2010). JAVA - SUMATERA SUSTAINABLE TRANSPORTATION TO BE REALIZED IN 2014.

Bloomberg (2022). Indonesia's Coal Miners Are Bracing For New Export Curbs.

Britannica (2022). path dependence — Definition and Facts — Britannica.

Brooks, T. and Kennedy, E. (2004). Biodiversity barometers. *Nature*, 431(7012):1046–1047.

Buchholz, K. (2020). Rising Sea Levels Will Threaten 200 Million People by 2100.

Burchell, R. W., Lowenstein, G., Dolphin, W. R., Galley, C. C., Downs, A., Seskin, S., Still, K. G., Moore, T., Transportation Research Board, and Rutgers University (2002). Costs of sprawl–2000. Technical report.

Burchell, R. W., Shad, N. A., Listokin, D., Phillips, H., Center for Urban Policy Research, Rutgers University, Downs, A., The Brookings Institution, Seskin, S., Davis, J. S., Parsons Brinckerhoff Quade and Douglas, I., Moore, T., Helton, D., Gall, M., and ECONorthwest (1998a). Public/Private Capital and Operating Costs. In *The costs of sprawl - revisited*, pages 45–60.

Burchell, R. W., Shad, N. A., Listokin, D., Phillips, H., Center for Urban Policy Research, Rutgers University, Downs, A., The Brookings Institution, Seskin, S., Davis, J. S., Parsons Brinckerhoff Quade and Douglas, I., Moore, T., Helton, D., Gall, M., and ECONorthwest (1998b). Transportation and Travel Costs. In *The costs of sprawl - revisited*, pages 61–72.

Camagni, R., Gibelli, M. C., and Rigamonti, P. (2002). Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion. *Ecological Economics*, 40(2):199–216.

Carmen (2021). Five largest coal mines in Indonesia in 2020.

Carmichael, J., Talwar, S., Tansey, J., and Robinson, J. (2017). Where Do We Want To Be? Making Sustainability Indicators Integrated, Dynamic and Participatory. In *Community Indicators Measuring Systems*, pages 178–204. Routledge.

Cawsey, D. C. and Mellon, P. (1983). A review of experimental weathering of basic igneous rocks. *Geological Society, London, Special Publications*, 11(1):19–24.

CEICData (2020). Indonesia Coal Production.

CEICData (2022). Indonesia - Trade Balance.

Center for Transportation and Logistics Studies (2022). Center for Transportation and Logistics Studies - Universitas Gadja Mada.

Cesprini, E., Resente, G., Causin, V., Urso, T., Cavalli, R., and Zanetti, M. (2020). Energy recovery of glued wood waste – A review. *Fuel*, 262:116520.

Chen, H., Pei, P., and Song, M. (2015). Lifetime prediction and the economic lifetime of Proton Exchange Membrane fuel cells. *Applied Energy*, 142:154–163.

Chesheva, E., Goller, E., Diez, T. H., Paterson, W. D., of Indonesia, M. o. F. o. t. R., and World Bank (2020). Indonesia Public Expenditure Review - Chapter 9: National Roads. Technical report.

China Dialogue (2022). Indonesia's coal gasification plans move forward, despite coal pledge.

ChinaPower (2022). How Well-off is China's Middle Class?

Christina, B. (2019). Indonesia launches B30 biodiesel to cut costs, boost palm oil.

Climate Action (2022). IBPA Company Details.

Climate Transparency, IESR, and Tumiwa, F. (2020). Climate Transparancy Report 2020 - Country profile; Indonesia. Technical report, Climate Transparency.

Climateactiontracker (2021). Indonesia Climate Action Tracker.

CNBC Indonesia (2020). Pemerintah Guyur Rp 2,5 T untuk Sawit, Buat Apa?

Comcar (2022). Kg CO2 per litre of diesel vehicles.

Commander, S., Nikoloski, Z., and Vagliasindi, M. (2015). Estimating the Size of External Effects of Energy Subsidies in Transport and Agriculture.

Cooper, R. N. (1992). CURRENCY DEVALUATION IN DEVELOPING COUNTRIES. In *International Economic Policies and their Theoretical Foundations*, pages 742–770. Elsevier.

Crundwell, F. K., Moats, M. S., Ramachandran, V., Robinson, T. G., and Davenport, W. G. (2011). Smelting Laterite Concentrates to Sulfide Matte. In *Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals*, pages 95–107. Elsevier.

Cullen, J. M. and Allwood, J. M. (2010). Theoretical efficiency limits for energy conversion devices. *Energy*, 35(5):2059–2069.

Darnoko, D. and Cheryan, M. (2000). Continuous production of palm methyl esters. *Journal of the American Oil Chemists' Society*, 77(12):1269–1272.

de Jesus Martínez-Roldán, A. and Ibarra-Berumen, J. (2019). Employment of Wastewater to Produce Microalgal Biomass as a Biorefinery Concept. In Alam, M. A. and Wang, Z., editors, *Microalgae Biotechnology for Development of Biofuel and Wastewater Treatment*, pages 487–505. Springer Singapore, Singapore.

Deendarlianto, Widyaparaga, A., Sopha, B. M., Budiman, A., Muthohar, I., Setiawan, I. C., Lindasista, A., Soemardjito, J., and Oka, K. (2017). Scenarios analysis of energy mix for road transportation sector in Indonesia. *Renewable and Sustainable Energy Reviews*, 70:13–23.

Deendarlianto, Widyaparaga, A., Widodo, T., Handika, I., Chandra Setiawan, I., and Lindasista, A. (2020). Modelling of Indonesian road transport energy sector in order to fulfill the national energy and oil reduction targets. *Renewable Energy*, 146:504–518.

Delta Dunia (2022). Delta Dunia Company Profile.

Demirbas, A. (2008). Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. *Energy Conversion and Management*, 49(8):2106–2116.

Deng, X. (2007). Private Car Ownership in China: How Important is the effect of Income? *Economic Society of Australia*, (May):1–22.

Destyanto, A. R., Silalahi, T. D., and Hidayatno, A. (2017). Exploration of government policy structure which support and block energy transition process in indonesia using system dynamics model. *IOP Conference Series: Earth and Environmental Science*, 94:012155.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (2014). Sustainable Urban Transport Programme Indonesia (NAMA SUTRI): An Overview. Technical report.

Devex (2022). PT SMART Tbk (SMART).

Dewita, Y., Yen, B. T., and Burke, M. (2018). The effect of transport cost on housing affordability: Experiences from the Bandung Metropolitan Area, Indonesia. *Land Use Policy*, 79:507–519.

Dhina, N. and Permana, T. (2021). Natural gas transportation business contribution to Indonesia's national energy policy and carbon emission offset by on-grid solar PV utilization: Surabaya, East Java, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 753(1):012022.

di Gropello, E., Kruse, A., and Tandon, P. (2011). Skills for the Labor Market in Indonesia Trends in Demand, Gaps and Supply. Technical report.

Dirgahayani, P. and Sutanto, H. (2020). The effect of transport demand management policy on the intention to use public transport: A case in Bandung, Indonesia. *Case Studies on Transport Policy*, 8(3):1062–1072.

Djohari, D. and Australian Road Federation (1992). ASPAC 92: IRF/ARF ASIA PACIFIC REGIONAL ROAD CONFERENCE, 1992, GOLD COAST, QUEENSLAND, AUSTRALIA. In *TOLL ROADS IN INDONESIA: POLICY, OPERATION AND FINANCING*, pages 1–9, Gold Coast.

Dreborg, K. H. (1996). Essence of backcasting. *Futures*, 28(9):813–828.

Durand-Lasserve, O., Campagnolo, L., Chateau, J., and Dellink, R. (2015). Modelling of Distributional Impacts of Energy Subsidy Reforms: An Illustration with Indonesia. *SSRN Electronic Journal*.

Easterly, W. (2001). The middle class consensus and economic development. *Journal of Economic Growth*, 6(4):317–335.

Eckstein, D., Künzel, V., and Schäfer, L. (2021). GLOBAL CLIMATE RISK INDEX 2021: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2019 and 2000-2019. Technical report.

Ecoscore (2022). How to calculate the CO2 emission from the fuel consumption?

EIA (2021). International Energy Outlook 2021. Technical report.

EIA (2022). Diesel fuel explained - Diesel prices and outlook.

El-Araby, R., Amin, A., El Morsi, A., El-Ibiari, N., and El-Diwani, G. (2018). Study on the characteristics of palm oil–biodiesel–diesel fuel blend. *Egyptian Journal of Petroleum*, 27(2):187–194.

Electric Vehicle Database (2022). Useable battery capacity of full electric vehicles.

Engerman, S. and Sokoloff, K. (1994). Factor Endowments: Institutions, and Differential Paths of Growth Among New World Economies: A View from Economic Historians of the United States. Technical report, National Bureau of Economic Research, Cambridge, MA.

Envirotech (2015). Which Countries are Most at Risk of Rising Sea Levels?

Erawan, M. and Karuniasa, M. (2020). Spatial Dynamics of Air Pollution in Tangerang City, Jabodetabek Metropolitan Area. In *Proceedings of the Proceedings of the 13th International Interdisciplinary Studies Seminar, IISS 2019, 30-31 October 2019, Malang, Indonesia*. EAI.

Erdiwansyah, Mamat, R., Sani, M., and Sudhakar, K. (2019). Renewable energy in Southeast Asia: Policies and recommendations. *Science of The Total Environment*, 670:1095–1102.

Eurostat (2019). Passenger cars per 1 000 inhabitants.

Ewing, R. and Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association*, 76(3):265–294.

F and I Tools (2022). Car Sales by Country - 2021.

Famoso, F., Prestipino, M., Brusca, S., and Galvagno, A. (2020). Designing sustainable bioenergy from residual biomass: Site allocation criteria and energy/exergy performance indicators. *Applied Energy*, 274:115315.

FAO (2008). The state of Food and Agriculture, Biofuels: Prospects, Risks and Opportunities. Technical report.

FAOLEX (2000). Government Regulation No. 25/2000 concerning central and provincial government authorities as an autonomous region. Technical report.

Feeney, B. P. and Cardebring, P. (1988). Car longevity in Sweden: A revised estimate. *Transportation Research Part A: General*, 22(6):455–465.

Feng, X., Fujiwara, A., Zhang, J. Y., Niu, X. J., and Hayashi, Y. (2010). Backcasting Assessment of Strategies for Efficiently Sustainable Urban Transport Developments of Developing Cities. In *Traffic and Transportation Studies 2010*, pages 13–26, Reston, VA. American Society of Civil Engineers.

Food and Agriculture Organization of the United Nations (2020). Land Use and Oil Production Data.

Forkenbrock, D. J. (2001). Comparison of external costs of rail and truck freight transportation. *Transportation Research Part A: Policy and Practice*, 35(4):321–337.

Fragkos, P., Laura van Soest, H., Schaeffer, R., Reedman, L., Köberle, A. C., Macaluso, N., Evangelopoulou, S., De Vita, A., Sha, F., Qimin, C., Kejun, J., Mathur, R., Shekhar, S., Dewi, R. G., Diego, S. H., Oshiro, K., Fujimori, S., Park, C., Safonov, G., and Iyer, G. (2021). Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States. *Energy*, 216:119385.

FuelCellsWorks (2021). Australia Indonesia to Cooperate on Green Economy, Energy Transition and Green Hydrogen.

Fukuda, H., Kondo, A., and Noda, H. (2001). Biodiesel fuel production by transesterification of oils. *Journal of Bioscience and Bioengineering*, 92(5):405–416.

Fulton, L., Mejia, A., Arioli, M., Dematera, K., and Lah, O. (2017). Climate Change Mitigation Pathways for Southeast Asia: CO2 Emissions Reduction Policies for the Energy and Transport Sectors. *Sustainability*, 9(7):1160.

G20 (2021). G20 Presidency of Indonesia.

Gad, M., El-Araby, R., Abed, K., El-Ibiari, N., El Morsi, A., and El-Diwani, G. (2018). Performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel. *Egyptian Journal of Petroleum*, 27(2):215–219.

Gallup, J. L., Sachs, J., and Mellinger, A. (1998). Geography and Economic Development. Technical report, National Bureau of Economic Research, Cambridge, MA.

Gandoman, F. H., Jaguemont, J., Goutam, S., Gopalakrishnan, R., Firouz, Y., Kalogiannis, T., Omar, N., and Van Mierlo, J. (2019). Concept of reliability and safety assessment of lithium-ion batteries in electric vehicles: Basics, progress, and challenges. *Applied Energy*, 251:113343.

Gasik, M. I. (2013). Technology of Chromium and Its Ferroalloys. In *Handbook of Ferroalloys*, pages 267–316. Elsevier.

Geffen, C. A., Edmonds, J. A., and Kim, S. H. (2004). Transportation and Climate Change: The Potential for Hydrogen Systems.

Germer, J. and Sauerborn, J. (2008). Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. *Environment, Development and Sustainability*, 10(6):697–716.

Geurs, K. and Van Wee, B. (2000). Backcasting as a Tool to Develop a Sustainable Transport Scenario Assuming Emission Reductions of 80-90 *Innovation: The European Journal of Social Science Research*, 13(1):47–62.

Givoni, M., Macmillen, J., Banister, D., and Feitelson, E. (2013). From Policy Measures to Policy Packages. *Transport Reviews*, 33(1):1–20.

GlobalData (2022a). Coal mining in Indonesia to 2022.

GlobalData (2022b). Mining.

Goverment of Indonesia (2004). REGULATION OF GOVERNMENT OF THE REPUBLIC OF INDONESIA NO. 36/2004 ON OIL AND GAS DOWNSTREAM BUSINESS. Technical report.

Greenwell, H. C., Laurens, L. M. L., Shields, R. J., Lovitt, R. W., and Flynn, K. J. (2010). Placing microalgae on the biofuels priority list: a review of the technological challenges. *Journal of The Royal Society Interface*, 7(46):703–726.

Gudmundsson, H., Sorensen, C., Akerman, J., Fearnley, N., Hoff, A., Givoni, M., and Macmillen, J. (2010). Limits to and unintended effects of transport policies. page 14.

Gunawan, H., Bressers, H., Megantara, E. N., Kurnani, T. B. A., Hoppe, T., Mohlakoana, N., and Parikesit (2019). A governance of climate change mitigation in transport sector and selected co-benefits in Indonesia: the case of Bandung City. *IOP Conference Series: Earth and Environmental Science*, 306(1):012015.

Gylfason, T. (2001). Natural resources, education, and economic development. *European Economic Review*, 45(4-6):847–859.

Hall, R. E. and Jones, C. I. (1999). Why do Some Countries Produce So Much More Output Per Worker than Others? *The Quarterly Journal of Economics*, 114(1):83–116.

Hamilton, B. W. and MacAuley, M. K. (1998). Competition and Car Longevity.

Handy, S., Cao, X., and Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment*, 10(6):427–444.

Hao, X., Lin, Z., Wang, H., Ou, S., and Ouyang, M. (2020). Range cost-effectiveness of plug-in electric vehicle for heterogeneous consumers: An expanded total ownership cost approach. *Applied Energy*, 275:115394.

Harahap, F., Silveira, S., and Khatiwada, D. (2019). Cost competitiveness of palm oil biodiesel production in Indonesia. *Energy*, 170:62–72.

Harberger, A. C. (1950). Currency Depreciation, Income, and the Balance of Trade. *Journal of Political Economy*, 58(1):47–60.

Havlík, P., Schneider, U. A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., Aoki, K., Cara, S. D., Kindermann, G., Kraxner, F., Leduc, S., McCallum, I., Mosnier, A., Sauer, T., and Obersteiner, M. (2011). Global land-use implications of first and second generation biofuel targets. *Energy Policy*, 39(10):5690–5702.

Held, M., Rosat, N., Georges, G., Pengg, H., and Boulouchos, K. (2021). Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics. *European Transport Research Review*, 13(1):9.

Henrici-Olivé, G. and Olivé, S. (1984). Methanol from CO + H2. In *The Chemistry of the Catalyzed Hydrogenation of Carbon Monoxide*, pages 131–142. Springer Berlin Heidelberg, Berlin, Heidelberg.

Hickman, R., Ashiru, O., and Banister, D. (2009). Achieving Carbon-Efficient Transportation. *Transportation Research Record: Journal of the Transportation Research Board*, 2139(1):172–182.

Hickman, R. and Banister, D. (2007). Looking over the horizon: Transport and reduced CO2 emissions in the UK by 2030. *Transport Policy*, 14(5):377–387.

Hidayati, I., Yamu, C., and Tan, W. (2019). The Emergence of Mobility Inequality in Greater Jakarta, Indonesia: A Socio-Spatial Analysis of Path Dependencies in Transport–Land Use Policies. *Sustainability*, 11(18):5115.

Hill, M. and Hupe, P. (2002). *Implementing Public Policy: Governance in Theory and in Practice*. SAGE Publications Ltd., London.

Hirani, A. H., Javed, N., Asif, M., Basu, S. K., and Kumar, A. (2018). A Review on First- and Second-Generation Biofuel Productions. In *Biofuels: Greenhouse Gas Mitigation and Global Warming*, pages 141–154. Springer India, New Delhi.

Hosseini, S. E. and Butler, B. (2020). An overview of development and challenges in hydrogen powered vehicles. *International Journal of Green Energy*, 17(1):13–37.

Hu, Q., Sommerfeld, M., Jarvis, E., Ghirardi, M., Posewitz, M., Seibert, M., and Darzins, A. (2008). Microalgal triacylglycerols as feedstocks for biofuel production: perspectives and advances. *The Plant Journal*, 54(4):621–639.

HumanCities (2017). Jakarta and Manila - Urban Challenges Overview. Technical report.

HydrogenTools (2022). Hydrogen Embrittlement.

Hyundai (2021). Hyundai Motor Group and LG Energy Solution Begin Construction of EV Battery Cell Plant in Indonesia.

Ichsan, M., Martak, Y., Ramadhani, M., Septyandrica, C., and Yusgiantoro, P. (2021). Is cheap fuel policy a (short-term) remedy for costly transportation in rural Indonesia? *IOP Conference Series: Earth and Environmental Science*, 753(1):012030.

IDN Financials (2021). Indonesia is in need of 2,500 electric vehicle charging stations per year.

IEA (2019). IEA Key Energy Statistics 2019.

IEA (2020a). Coal exports: Overview.

IEA (2020b). Tracking Transport 2020.

IEA (2021a). Greenhouse Gas Emissions from Energy Data Explorer.

IEA (2021b). Hydrogen - tracking report. Technical report.

IEA (2022). Transport sector CO2 emissions by mode in the Sustainable Development Scenario, 2000-2030.

IESR, Adiatma, J. C., and Marciano, I. (2020). The Role of Electric Vehicles in Decarbonizing Indonesia's Road Transport Sector. Technical report.

Inalum (2022). PT Indonesia Asahan Aluminium (Persero) — Home.

Inchauste, G. and Victor, D. G. (2017). *The Political Economy of Energy Subsidy Reform.* Washington, DC: World Bank.

Indika Energy (2022a). Indika Energy Energy Resources.

Indika Energy (2022b). Indika Energy Services and Infrastructures.

Indonesia-Investments (2022). Trade Balance Indonesia: Exports Soar Thanks to Coal Palm Oil Shipments, Imports Rebound.

Indonesia Water Portal (2022). Ministry of Public Works and Housing.

Institute for Transportation and Development Policy (2022). ITDP - About.

International Institute for Sustainable Development (2022). Mission and Goals.

International Road Federation (2017). IRF World Road Statistics 2017. Technical report, Geneva.

International Road Federation (2022). Mission.

Ismiyati, I. and Hermawan, F. (2018). Lifestyle as an Influential Factor to Urban Mobility Transport: a Case Study of Semarang City, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 123:012020.

Jahirul, M., Rasul, M., Chowdhury, A., and Ashwath, N. (2012). Biofuels Production through Biomass Pyrolysis —A Technological Review. *Energies*, 5(12):4952–5001.

Karmee, S. K. (2016). Liquid biofuels from food waste: Current trends, prospect and limitation. *Renewable and Sustainable Energy Reviews*, 53:945–953.

Kharas, H. and Gertz, G. (2010). The new global middle class. *Brookings Institution Press*, pages 32–52.

Kharel, S. and Shabani, B. (2018). Hydrogen as a Long-Term Large-Scale Energy Storage Solution to Support Renewables. *Energies*, 11(10):2825.

Kharina, A., Malins, C., and Searle, S. (2016). BIOFUELS POLICY IN INDONESIA: OVERVIEW AND STATUS REPORT.

Kharina, A. and Searle, S. (2016). INDONESIA'S DELUSIONAL STRATEGY FOR REDUCING GHG EMISSIONS.

Kim, U.-H., Kuo, L.-Y., Kaghazchi, P., Yoon, C. S., and Sun, Y.-K. (2019). Quaternary Layered Ni-Rich NCMA Cathode for Lithium-Ion Batteries. *ACS Energy Letters*, 4(2):576–582.

KIMURA, H. S. and SWINDALE, L. D. (1967). A DISCRIMINANT FUNCTION USING ZIRCONIUM AND NICKEL FOR PARENT ROCKS OF STRONGLY WEATHERED HAWAIIAN SOILS. *Soil Science*, 104(1):69–76.

Knothe, G. (2011). A technical evaluation of biodiesel from vegetable oils vs. algae. Will algae-derived biodiesel perform? *Green Chemistry*, 13(11):3048.

Ko, C. H., Park, S. H., Jeon, J.-K., Suh, D. J., Jeong, K.-E., and Park, Y.-K. (2012). Upgrading of biofuel by the catalytic deoxygenation of biomass. *Korean Journal of Chemical Engineering*, 29(12):1657–1665.

Koh, L. P. and Wilcove, D. S. (2008). Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters*, 1(2):60–64.

König, A., Nicoletti, L., Schröder, D., Wolff, S., Waclaw, A., and Lienkamp, M. (2021). An Overview of Parameter and Cost for Battery Electric Vehicles. *World Electric Vehicle Journal*, 12(1):21.

Krishnamurti, I. (2004a). Diesel Locomotive Roster.

Krishnamurti, I. (2004b). History of Railways in Indonesia.

Kröger, M. and Müller-Langer, F. (2012). Review on possible algal-biofuel production processes. *Biofuels*, 3(3):333–349.

Kyle, J. (2018). Local Corruption and Popular Support for Fuel Subsidy Reform in Indonesia. *Comparative Political Studies*, 51(11):1472–1503.

Lam, M. K. and Lee, K. T. (2012). Microalgae biofuels: A critical review of issues, problems and the way forward. *Biotechnology Advances*, 30(3):673–690.

Lean Green Europe (2019). Introduction to the calculation of CO2 emissions for participation in Lean Green. Technical report.

Leung, K. H. (2016). INDONESIA's SUMMARY TRANSPORT ASSESSMENT. *ADB Papers on Indonesia*, (15):20.

Li, W., Erickson, E. M., and Manthiram, A. (2020). High-nickel layered oxide cathodes for lithium-based automotive batteries. *Nature Energy*, 5(1):26–34.

Li, Y. and Chang, Y. (2019). Road transport electrification and energy security in the Association of Southeast Asian Nations: Quantitative analysis and policy implications. *Energy Policy*, 129:805–815.

Liu, Z., Song, J., Kubal, J., Susarla, N., Knehr, K. W., Islam, E., Nelson, P., and Ahmed, S. (2021). Comparing total cost of ownership of battery electric vehicles and internal combustion engine vehicles. *Energy Policy*, 158:112564.

Lototskyy, M. V., Tolj, I., Pickering, L., Sita, C., Barbir, F., and Yartys, V. (2017). The use of metal hydrides in fuel cell applications. *Progress in Natural Science: Materials International*, 27(1):3–20.

Lubis, H., Armijaya, H., and Dharmowijoyo, D. (2005). THE COMPETITION OF PASSENGER TRANSPORT MODES ALONG JAKARTA-BANDUNG CORRIDOR. *Proceedings of the Eastern Asia Society for Transportation Studies*, 5(1):75–89.

Lubis, H. and Nurullah, P. (2007). RECENT DEVELOPMENT OF INDONESIAN RAILWAY INSTITUTION. *Journal of the Eastern Asia Society for transportation Studies*, 7(13):1886–1901.

Marsden, G. and Reardon, L. (2017). Questions of governance: Rethinking the study of transportation policy. *Transportation Research Part A: Policy and Practice*, 101:238–251.

Marubeni (2021). Commencement of PoC for Green Hydrogen Production, Transportation and Utilization in Australia and Indonesia.

Marwasta, D. (2019). Spatial Trends of Urban Physical Growth of Cities in Java, Indonesia, 1975–2015. *ASEAN Journal on Science and Technology for Development*, 36(2).

Masters, W. and Wiebe, K. (2000). Climate and Agricultural Productivity. *Center for International Development*, pages 1–38.

Masyarakat Transportasi Indonesia (MTI) (2022). About - Masyarakat Transportasi Indonesia (MTI).

Mayer, I. (1999). Debating technologies: A methodological contribution to the design and evaluation of participatory policy analysis. *Journal of Policy Analysis and Management*, 18(2):339–343.

MCDOWALL, W. and EAMES, M. (2007). Towards a sustainable hydrogen economy: A multi-criteria sustainability appraisal of competing hydrogen futures. *International Journal of Hydrogen Energy*, 32(18):4611–4626.

Meira, M., Quintella, C. M., Ribeiro, E. M. O., Silva, H. R. G., and Guimarães, A. K. (2015). Overview of the challenges in the production of biodiesel. *Biomass Conversion and Biorefinery*, 5:321–329.

Mekhilef, S., Saidur, R., and Safari, A. (2012). Comparative study of different fuel cell technologies. *Renewable and Sustainable Energy Reviews*, 16(1):981–989.

Michaels, G. (2011). The Long Term Consequences of Resource-Based Specialisation. *The Economic Journal*, 121(551):31–57.

Milenko, Y. Y., Sibileva, R. M., and Strzhemechny, M. A. (1997). Natural ortho-para conversion rate in liquid and gaseous hydrogen. *Journal of Low Temperature Physics*, 107(1-2):77–92.

Mining Technology (2020). Five Largest nickel mines in Indonesia in 2020.

Ministry of Energy and Mineral Resources of Indonesia (2020a). 20 BBN Business Entities to Distribute 9.2 Million KL of Biodiesel in 2021.

Ministry of Energy and Mineral Resources of Indonesia (2020b). Stipulation of Fuel Oil Business Entities And Biodiesl Type Biofuel Business Entities As Well As Allocation Of Volume For Solar Type Fuel Oil Mixing For The Period Of January-December 2021.

Ministry of Energy and Mineral Resources of Indonesia (2022). Kementerian ESDM.

Ministry of Environment and Forestry of Indonesia (2017). FIRST NATIONALLY DETERMINED CONTRIBUTION REPUBLIC OF INDONESIA. Technical report.

Ministry of Environment and Forestry of Indonesia (2021a). Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050). Technical report.

Ministry of Environment and Forestry of Indonesia (2021b). UPDATED NATIONALLY DETERMINED CONTRIBUTION REPUBLIC OF INDONESIA. Technical report.

Ministry of Industry of Indonesia (2015). INDONESIA: National Industry Development Master Plan (RIPIN) 2015-2035 (Government Regulation No. 14/2015 of 2015).

Ministry of State-Owned Enterprises of Indonesia (2022). Principal Tasks and Functions.

Ministry of Transportation of Indonesia (2022). Ministry of Transportation - Tugas dan Fungsi.

Mitropoulos, L. K., Prevedouros, P. D., and Kopelias, P. (2017). Total cost of ownership and externalities of conventional, hybrid and electric vehicle. *Transportation Research Procedia*, 24:267–274.

Mohd Azhar, S. H., Abdulla, R., Jambo, S. A., Marbawi, H., Gansau, J. A., Mohd Faik, A. A., and Rodrigues, K. F. (2017). Yeasts in sustainable bioethanol production: A review. *Biochemistry and Biophysics Reports*, 10:52–61.

Mojovic, L., Pejin, D., Grujic, O., Markov, S., Pejin, J., Rakin, M., Vukasinovic, M., Nikolic, S., and Savic, D. (2009). Progress in the production of bioethanol on starch-based feedstocks. *Chemical Industry and Chemical Engineering Quarterly*, 15(4):211–226.

Murugan, A., de Huu, M., Bacquart, T., van Wijk, J., Arrhenius, K., te Ronde, I., and Hemfrey, D. (2019). Measurement challenges for hydrogen vehicles. *International Journal of Hydrogen Energy*, 44(35):19326–19333.

Muzakir, A. Z., Yap, E. H., and Mahlia, T. M. I. (2021). The Way towards an Energy Efficient Transportation by Implementation of Fuel Economy Standards: Fuel Savings and Emissions Mitigation. *Sustainability*, 13(13):7348.

NAMA Facility (2017). Sustainable Urban Transport Programme in Indonesia (SUTRI NAMA). Technical report.

Nathan, R. (2021). Indonesia's Pertamina eyes hydrogen to meet 2026 goal.

National Council on Climate Change of Indonesia (2010). Peluang dan Kebijakan Pengurangan Emisi - Opportunities and Policies Emission Reduction. Technical report.

Ndayishimiye, P. and Tazerout, M. (2011). Use of palm oil-based biofuel in the internal combustion engines: Performance and emissions characteristics. *Energy*, 36(3):1790–1796.

Negara, S. D. and Hidayat, A. S. (2021). Indonesia's Automotive Industry: Recent Trends and Challenges. *Southeast Asian Economies*, 38(2):166–186.

Neofytou, H., Nikas, A., and Doukas, H. (2020). Sustainable energy transition readiness: A multicriteria assessment index. *Renewable and Sustainable Energy Reviews*, 131:109988.

Ney, S. (2012). *Resolving Messy Policy Problems*. Routledge.

Nhuchhen, D. R., Sit, S. P., and Layzell, D. B. (2022). Decarbonization of cement production in a hydrogen economy. *Applied Energy*, 317:119180.

Nicita, A., Maggio, G., Andaloro, A., and Squadrito, G. (2020). Green hydrogen as feedstock: Financial analysis of a photovoltaic-powered electrolysis plant. *International Journal of Hydrogen Energy*, 45(20):11395–11408.

Nukman and Sipahutar, R. (2015). The Potential of Biomass from Wood, Leaves, and Grass as Renewable Energy Sources in South Sumatera, Indonesia. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 37(24):2710–2715.

OEC (2020a). Ferroalloys in Indonesia.

OEC (2020b). Indonesia Country Profile: Trade, Complexity and Rankings.

OEE Project (2022). The cost of electricity. In *Open Electricity Economics*.

Office of Energy Efficiency Renewable Energy - U.S. Department of Energy (2022). Hydrogen Storage - Hydrogen and Fuel Cell Technologies Office.

OICA (2021). 2021 PRODUCTION STATISTICS.

Ourworldindata (2018). Oil yield by crop type, 2018.

Pate, R. C. (2013). Resource requirements for the large-scale production of algal biofuels. *Biofuels*, 4(4):409–435.

Peng, L., Fu, D., Chu, H., Wang, Z., and Qi, H. (2020). Biofuel production from microalgae: a review. *Environmental Chemistry Letters*, 18(2):285–297.

Peper, B. (1970). Population Growth in Java in the 19th Century: A New Interpretation. *Population Studies*, 24(1):71.

Pers, S. (2021). Go Green, Pertamina Patra Niaga Prepares Charging Station and Battery Swapping Station for Electric Vehicles.

Petchmala, A., Yujaroen, D., Shotipruk, A., Goto, M., and Sasaki, M. (2008). Production Methyl Esters from Palm Fatty Acids in Supercritical Methanol. *Chiang Mai Journal of Science*, 35(1):23–28.

Pickrell, D. and The DOT Center for Climate Change Environmental Forecasting (2003). Fuel Options for Reducing Greenhouse Gas Emissions from Motor Vehicles. Technical report, U.S Department of Transportation DOT-VNTSC-RSPA-03-03.

Pradhan, P., Mahajani, S. M., and Arora, A. (2018). Production and utilization of fuel pellets from biomass: A review. *Fuel Processing Technology*, 181:215–232.

Prastowo, B. (2015). BAHAN BAKAR NABATI ASAL TANAMAN PERKEBUNAN SEBAGAI ALTERNATIF PENGGANTI MINYAK TANAH UNTUK RUMAH TANGGA. *Perspektif*, 6(1):10–18.

Pt. Bayan Resources, T. (2022). Bayan Coal Overview.

PT. BUMI RESOURCES Tbk. (2022). PT. BUMI ResourceS Tbk.

PT. Jasa Marga (2019). Jasa Marga in Brief.

PT. Pertamina (2017). Moving Further: 2017 Pertamina annual report. Technical report.

PT. Pertamina (2019a). Pertamina Tetapkan RKAP 2019.

PT. Pertamina (2019b). PT Pertamina (Persero) and its subsidiaries - Consolidated Financial Statements as of December 31, 2019 and for the year then ended with independent auditors' report. Technical report.

PT. Pertamina (2019c). Strengthening commitment, securing energy: Pertamina annual report 2018. Technical report.

PT. Pertamina Power Indonesia (2022a). Indonesia Power - Home Page.

PT. Pertamina Power Indonesia (2022b). Indonesia Power - Home Page.

Pt. Salim Ivomas Pratama Tbk. (2022). SIMP Divisi Perkebunan.

PT. Yiwan Mining (2012). SELAMAT DATANG DI WEBSITE PT.YIWAN MINING.

Putra, Z. D. W. and van der Knaap, W. G. (2020). Pasikola. *International Journal of E-Planning Research*, 9(3):24–46.

Quist, J., Rammelt, C., Overschie, M., and de Werk, G. (2006). Backcasting for sustainability in engineering education: the case of Delft University of Technology. *Journal of Cleaner Production*, 14(9-11):868–876.

Quist, J. and Vergragt, P. (2006). Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. *Futures*, 38(9):1027–1045.

Quist, J. and Vergragt, P. J. (2003). Backcasting for Industrial Transformations and System Innovations Towards Sustainability: Relevance for Governance? In Jacob, K., Binder, M., and Wieczorek, A., editors, *Berlin Conference on the Human Dimensions of Global Environmental Change*, pages 409–437.

Rahayu, D. E., Nasarani, D., Hadi, W., and Wrjodirjo, B. (2018). Potential of biomass residues from oil palm agroindustry in Indonesia. *MATEC Web of Conferences*, 197:13008.

Rahmawati, S. S., Sudrajat, S., and Giyarsih, S. R. (2020). Analysis of Settlements along Abandoned Railway Tracks in Majalaya Subdistrict, Bandung Regency, Indonesia. *Forum Geografi*, 34(1).

Ramadhani, N. (2022). Indonesia pushes use of electric vehicles for green energy transition.

Ramanathan, C. S. (2021). NMCA - a new high-performance cathode for Lithium-ion batteries used in EVs.

Rashid, M., Mesfer, M., Naseem, H., and Danish, M. (2015). Hydrogen Production by Water Electrolysis: A Review of Alkaline Water Electrolysis, PEM Water Electrolysis and High Temperature Water Electrolysis. *International Journal of Engineering and Advanced Technology*, 4(3):80–93.

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., and Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, 90(5):1933–1949.

Rentschler, J. and Bazilian, M. (2017). Reforming fossil fuel subsidies: drivers, barriers and the state of progress. *Climate Policy*, 17(7):891–914.

Reuters (2020). Indonesia's Pertamina to start production of B100 biodiesel next year: CEO.

Ricklefs, M. C. (1993). *A History of Modern Indonesia since c. 1300*. Macmillan Education UK, London.

Robinson, J. (2003). Future subjunctive: backcasting as social learning. *Futures*, 35(8):839–856.

Robinson, J., Burch, S., Talwar, S., O'Shea, M., and Walsh, M. (2011). Envisioning sustainability: Recent progress in the use of participatory backcasting approaches for sustainability research. *Technological Forecasting and Social Change*, 78(5):756–768.

Robinson, J. B. (1982). Energy backcasting A proposed method of policy analysis. *Energy Policy*, 10(4):337–344.

Rodionova, M., Poudyal, R., Tiwari, I., Voloshin, R., Zharmukhamedov, S., Nam, H., Zayadan, B., Bruce, B., Hou, H., and Allakhverdiev, S. (2017). Biofuel production: Challenges and opportunities. *International Journal of Hydrogen Energy*, 42(12):8450–8461.

Romm, J. (2006). The car and fuel of the future. *Energy Policy*, 34(17):2609–2614.

Roth, A. and Kåberger, T. (2002). Making transport systems sustainable. *Journal of Cleaner Production*, 10(4):361–371.

Roy, M. M., Wang, W., and Bujold, J. (2013). Biodiesel production and comparison of emissions of a DI diesel engine fueled by biodiesel–diesel and canola oil–diesel blends at high idling operations. *Applied Energy*, 106:198–208.

Ruamsuke, K., Dhakal, S., and Marpaung, C. O. (2015). Energy and economic impacts of the global climate change policy on Southeast Asian countries: A general equilibrium analysis. *Energy*, 81:446–461.

Sachs, J. (2001). Tropical Underdevelopment. Technical report, National Bureau of Economic Research, Cambridge, MA.

Saha, A. and Basak, B. (2020). Scope of value addition and utilization of residual biomass from medicinal and aromatic plants. *Industrial Crops and Products*, 145:111979.

SAKINTUNA, B., LAMARIDARKRIM, F., and HIRSCHER, M. (2007). Metal hydride materials for solid hydrogen storage: A review. *International Journal of Hydrogen Energy*, 32(9):1121–1140.

Saputra, G. and Jati, G. (2021). Indonesia Needs Specific Strategy to Develop Hydrogen For Decarbonization.

Saputro, S. P., Godang, S., Priadi, B., Basuki, N. I., and Himawan, B. (2022). Geochemical study of Al–Fe–Ti enrichment in rock weathering: Implications for the recognizing of igneous protolith and the enrichment of REE in soil profile. *Applied Geochemistry*, 140:105259.

Sarkar, N., Ghosh, S. K., Bannerjee, S., and Aikat, K. (2012). Bioethanol production from agricultural wastes: An overview. *Renewable Energy*, 37(1):19–27.

Satya, S., Kolakoti, A., B., N. R., R., S. S., and Rao, R. (2019). Optimization of palm methyl ester and its effect on fatty acid compositions and cetane number. *Mathematical Models in Engineering*, 5(1):25–34.

Schillhorn van Veen, T. W. (2005). International trade and food safety in developing countries. *Food Control*, 16(6):491–496.

ScienceAgri (2022). 15 Biggest Indonesian Oil Palm Owners.

Setiawan, I. C., Indarto, and Deendarlianto (2019). System Dynamics Modeling of Indonesia Road Transportation Energy Demand and Scenario Analysis to achieve National Energy Policy Target. *IOP Conference Series: Materials Science and Engineering*, 546(5):052070.

Shao, Z., Miller, J., and Jin, L. (2020). Soot-free road transport in Indonesia: A cost-benefit analysis and implications for fuel policy.

Shell Indonesia (2020). EKSPANSI SPBU SHELL: SHELL JALIN KERJA SAMA DENGAN KADIN JAWA BARAT.

Shiva Kumar, S. and Himabindu, V. (2019). Hydrogen production by PEM water electrolysis – A review. *Materials Science for Energy Technologies*, 2(3):442–454.

Sia-Toolbox (2022). INDONESIA STATE MINISTRY OF ENVIRONMENT AND FORESTRY.

Sikarwar, V. S., Zhao, M., Fennell, P. S., Shah, N., and Anthony, E. J. (2017). Progress in biofuel production from gasification. *Progress in Energy and Combustion Science*, 61:189–248.

Situmeang, H., Lubis, S., Prasetijo, D., Sugiyanto, A., Munzinger, P., Rosenberg, A., Laksmi, A., Jinca, A., P., N., Sakamoto, K., Dore, C., Sari, N., Wulan, Y., Lupke, H., Haeruman, H., Guizol, P., and Faulwetter, M. (2012). Development of the Indonesian NAMAs Framework. Technical report.

Skovgaard, J. and van Asselt, H. (2018). Fossil Fuel Subsidy Reform in Indonesia The struggle for Successful Reform. In *The Politics of Fossil Fuel Subsidies and Their Reform*, pages 193–211.

Skuld and Katsoula, P. (2022). Indonesia: Coal Export Ban.

Smith, D. D., Cousins, P., Westerberg, S., Jesus-Tabajonda, R. D., Aniero, G., and Shen, Y.-C. (2014). Toward the Practical Limits of Silicon Solar Cells. *IEEE Journal of Photovoltaics*, 4(6):1465–1469.

Soesastro, H., Smith, A. L., and Han, M. L. (2003). *Governance in Indonesia: Challenges Facing the Megawati Presidency.*

SOLARGIS (2022). Solar resource maps of Indonesia.

Solway (2017). Aquila Project Indonesia.

Statista (2019). Total diesel consumption in Indonesia from from 2011 to 2019 and forecast for 2020.

Statista (2021). Total land area of oil palm plantations in Indonesia from 2011 to 2020 (in million hectares).

Statista (2022a). Coal production in Indonesia from 2011 to 2020.

Statista (2022b). Number of state university students in Indonesia from 2013 to 2021(in millions).

Statista (2022c). Production of major vegetable oils worldwide from 2012/13 to 2021/2022, by type.

Statista (2022d). Production volume of palm oil in Indonesia from 2012 to 2021.

Statista (2022e). U.S. car sales from 1951 to 2021.

Statistics Indonesia and Badan Pusat Statistik (2022). EXPORT AND IMPORT.

Strakhov, V. M., Gaiduchenko, N. S., Nesterenko, A. M., Podskrebaev, B. G., Serov, G. V., Melchanov, N. E., Mizin, V. G., Minaev, V. M., Men'shenin, V. M., and Ukanakov, P. M. (1978). Use of lean Kuznets coals in sintering and ferroalloy production. *USSR koks i khimiya*, 9.

Thamrin, S. (2011). Indonesia's National Mitigation Actions: Paving the Way towards NAMAs. In *Global Forum on Environment: Seminar on MRV and Carbon Markets*, pages 1–13, Paris.

The Jakarta post (2018). Indonesia's proven oil reserves to last just 12 years: Arcandra.

Tight, M., Timms, P., Banister, D., Bowmaker, J., Copas, J., Day, A., Drinkwater, D., Givoni, M., Gühnemann, A., Lawler, M., Macmillen, J., Miles, A., Moore, N., Newton, R., Ngoduy, D., Ormerod, M., O'Sullivan, M., and Watling, D. (2011). Visions for a walking and cycling focussed urban transport system. *Journal of Transport Geography*, 19(6):1580–1589.

Tiwari, A. K. (2012). Are trade deficits sustainable? Evidence from the ASEAN-five. *International Journal of Social Economics*, 40(1):68–82.

Toulouevski, Y. N. and Zinurov, I. Y. (2013). *Innovation in Electric Arc Furnaces.* Springer Berlin Heidelberg, Berlin, Heidelberg.

Tran, M. K., Dunn-Rankin, D., and Pham, T. K. (2012). Characterizing sooting propensity in biofuel–diesel flames. *Combustion and Flame*, 159(6):2181–2191.

TransJakarta (2022). TransJakarta - SMART mobility for SMART city.

Ugolini, F. and Dahlgren, R. (2002). Soil development in volcanic ash. *Global Environmental Research*, 6:69–81.

UIC and International Union of Railways (2019). Railisa UIC statistics - length of electrified lines.

Ullah, K., Ahmad, M., Sofia, Sharma, V. K., Lu, P., Harvey, A., Zafar, M., Sultana, S., and Anyanwu, C. (2014). Algal biomass as a global source of transport fuels: Overview and development perspectives. *Progress in Natural Science: Materials International*, 24(4):329–339.

United States Department of Agriculture and Foreign Agricultural Service (2021). Oilseeds: World Markets and Trade. Technical report, USDA.

United States Environmental Protection Agency (2002). A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions Draft Technical Report. Technical report.

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, 28(12):817–830.

U.S. Department of Energy (2022). Tools - Fuel Properties Comparison. Technical report.

USDA (2022). Biofuels Annual. Technical report.

van der Ent, A., Baker, A., van Balgooy, M., and Tjoa, A. (2013). Ultramafic nickel laterites in Indonesia (Sulawesi, Halmahera): Mining, nickel hyperaccumulators and opportunities for phytomining. *Journal of Geochemical Exploration*, 128:72–79.

Vergragt, P. J. (2005). Back-Casting for Environmental Sustainability: From STD and SusHouse towards Implementation. In *Towards Environmental Innovation Systems*, pages 301–318. Springer-Verlag, Berlin/Heidelberg.

Vergragt, P. J. and Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue. *Technological Forecasting and Social Change*, 78(5):747–755.

Vogl, V., Åhman, M., and Nilsson, L. J. (2018). Assessment of hydrogen direct reduction for fossil-free steelmaking. *Journal of Cleaner Production*, 203:736–745.

Wagner, N. J., Coertzen, M., Matjie, R., and van Dyk, J. (2008). Coal Gasification. In *Applied Coal Petrology*, pages 119–144. Elsevier.

Whitten, A. J., Whitten, T., Soeriaatmadja, R. S., Soeriaatmadja, R. E., and Afiff, S. A. (1997a). *Ecology of Java Bali*. Periplus Editions (HK) Ltd.

Whitten, A. J., Whitten, T., Soeriaatmadja, R. S., Soeriaatmadja, R. E., and Afiff, S. A. (1997b). Ecology of Java Bali - Part B, Chapter 3 Physical Conditions. In *Ecology of Java Bali*, pages 87–147. Periplus Editions (HK) Ltd.

Widyanto, U. and Malkhama, S. (2013). RESTRUCTURING INDONESIAN RAILWAY – INTEGRATION OR SEPARATION. *Civil Engineering Forum*, 22(3):1–10.

Wijaya, A., Chrysolite, H., Ge, M., Wibowo, C., Pradana, A., Utami, A., and Austin, K. (2017). HOW CAN INDONESIA ACHIEVE ITS CLIMATE CHANGE MITIGATION GOAL? AN ANALYSIS OF POTENTIAL EMISSIONS REDUCTIONS FROM ENERGY AND LAND-USE POLICIES.

Wijayanta, A. T., Oda, T., Purnomo, C. W., Kashiwagi, T., and Aziz, M. (2019). Liquid hydrogen, methylcyclohexane, and ammonia as potential hydrogen storage: Comparison review. *International Journal of Hydrogen Energy*, 44(29):15026–15044.

World Bank (2014). Indonesia: Avoiding the Trap Development Policy Review 2014. Technical report.

World Bank (2022). The World Bank in Indonesia.

World Bank and Australian Government (2019). Aspiring Indonesia: Expanding the middle class. Technical report.

World Bank Group (2020). Poverty Equity Brief - Indonesia 2020. Technical report.

World Population Review (2022). Indonesia Population.

WorldoMeter (2016a). CO2 Emissions per Capita.

WorldoMeter (2016b). Indonesia Oil Reserves.

WorldoMeter (2017). Indonesia Natural Gas Reserves.

WorldoMeter (2019). CO2 Emissions by Country.

Worldstopexports (2020). Top nickel exporters by country.

Wright, J., Taylor, I., and Philp, D. (1991). A review of progress of the development of new ironmaking technologies. *Minerals Engineering*, 4(7-11):983–1001.

Wu, F., Wang, J., Chen, W., and Shuai, S. (2009). A study on emission performance of a diesel engine fueled with five typical methyl ester biodiesels. *Atmospheric Environment*, 43(7):1481–1485.

Xenias, D. and Whitmarsh, L. (2013). Dimensions and determinants of expert and public attitudes to sustainable transport policies and technologies. *Transportation Research Part A: Policy and Practice*, 48:75–85.

Xie, Y. and Harjono, M. (2020). A review of motor vehicle fuel demand and supply in Indonesia.

Yanxing, Z., Maoqiong, G., Yuan, Z., Xueqiang, D., and Jun, S. (2019). Thermodynamics analysis of hydrogen storage based on compressed gaseous hydrogen, liquid hydrogen and cryo-compressed hydrogen. *International Journal of Hydrogen Energy*, 44(31):16833–16840.

Yeong, S. K., Idris, Z., and Hassan, H. A. (2012). Palm Oleochemicals in Non-Food Applications. In *Palm Oil: Production, Processing, Characterization and Uses*, chapter 20, pages 587–625.

Yue, D., You, F., and Snyder, S. W. (2014). Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges. *Computers Chemical Engineering*, 66:36–56.

Yuksel, T. and Michalek, J. J. (2015). Effects of Regional Temperature on Electric Vehicle Efficiency, Range, and Emissions in the United States. *Environmental Science Technology*, 49(6):3974–3980.

Zhang, X., Yang, D., Luo, M., and Dong, Z. (2017). Load profile based empirical model for the lifetime prediction of an automotive PEM fuel cell. *International Journal of Hydrogen Energy*, 42(16):11868–11878.

Zheng, C. (2021). Indonesia sets 2060 net-zero ambition, but the power sector does not appear strongly committed yet.