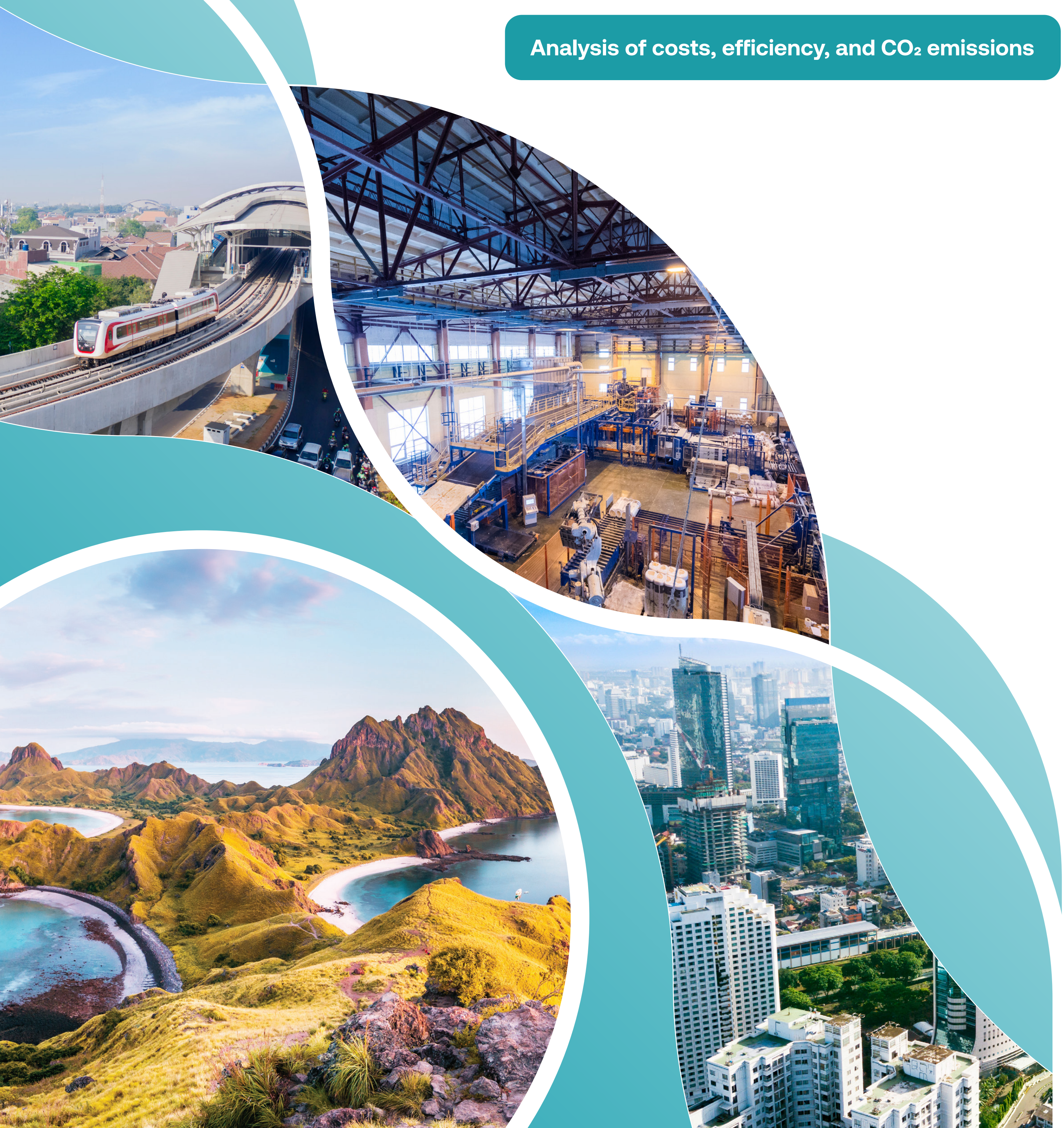
Danish Energy Agency

Ministry of Energy and Mineral Resources
Republic of Indonesia

TECHNO-ECONOMIC ANALYSIS OF DECARBONIZATION TECHNOLOGY OPTIONS FOR ENERGY END-USE SECTORS IN INDONESIA

Analysis of costs, efficiency, and CO_2 emissions



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Analysis of costs, efficiency, and CO_2 emissions

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Republic of Indonesia

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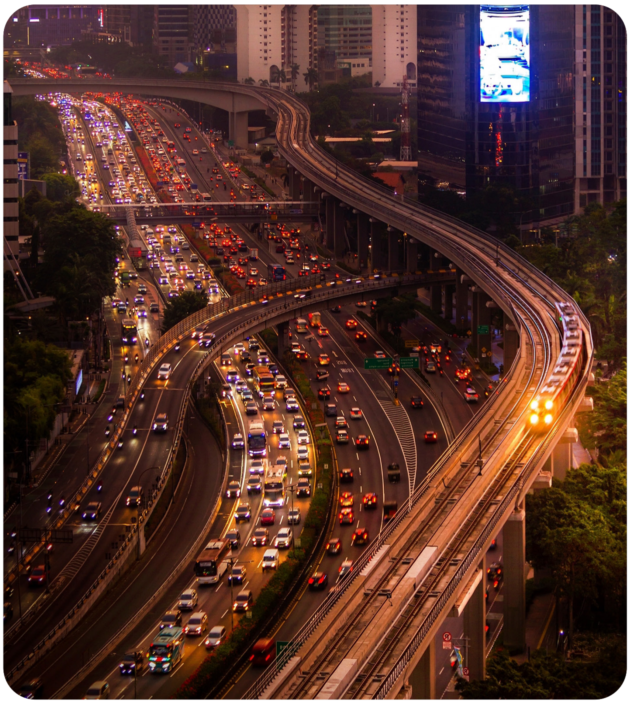

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LIST OF ABBREVIATIONS

BET	Battery electric truck
BEV	Battery electric vehicle
CNG	Compressed Natural Gas
COP	Coefficient of Permormance
CRT TV	Cathode ray tube television
DEA	Danish Energy Agency
DIY	*Daerah Istimewa Yogyakarta*/Special Region of Yogyakarta
DKI	*Daerah Khusus Ibukota*/Special Capital Region
DLUC	Direct land-use change
E2W	Electric two-wheeler
ERIA	Economic Research Institute for ASEAN and East Asia
EV	Electric vehicle
FCET	Fuel cell electric truck
GHG	Greenhouse gas
GVW	Gross vehicle weight
HP	Heat Pump
HEV	Hybrid electric vehicle
ICCT	International Council on Clean Transportation
ICE	Internal combustion engine
ICE2W	Internal combustion engine two-wheeler
ICEV	Internal combustion engine vehicle
KEN	Kebijakan Energi Nasional/National Energy Policy
KRL	Kereta Rel Listrik/Electric rail train
LCC	Life Cycle Cost
LCOH	Levelized Cost of Heating
LNG	Liquid Natural Gas
LPG	Liquified Petroleum Gas
LRT	Light rail transit
MEPS	Minimum Energy Performance Standards
MPV	Multi-purpose vehicle
O&M	Operations and maintenance
PLN	*Perusahaan Listrik Negara*/National Electricity Company
PV	Photovoltaics
Samsat	Sistem Administrasi Manunggal Satu Atap/One-stop Administrative System
SUV	Sport utility vehicle
TCO	Total cost of ownership
UK	United Kingdom
WTT	Well-to-tank
WTW	Well-to-wheels

FOREWORD

As part of Indonesia's commitment to achieve Net Zero Emissions (NZE) by 2060, the Government of Indonesia has determined to develop a comprehensive and measurable roadmap. The NZE roadmap will be an important guide in directing efforts to transition to cleaner, more sustainable energy, and in line with national greenhouse gas emission reduction targets. The development of the NZE roadmap will require careful modeling, the right approach, and good policy making to make the results relevant and applicable. Achieving this goal requires verified data and information, involving input from various stakeholders.

The Energy Demand Side Sector Technology Catalogue report has been developed as a comprehensive data source, encompassing aspects like energy efficiency, emissions impacts, energy consumption, and cost analysis of various decarbonization technologies on the demand side. This catalogue is anticipated to be a valuable resource for multiple stakeholders. Governments can leverage this data to formulate relevant policies and regulations that support the energy transition, thereby promoting a sustainable energy future. Investors and industry players can identify investment opportunities within this resource, helping them to adopt more efficient and environmentally friendly technologies. Additionally, academics and research institutions can use this catalogue as a foundational basis for further studies and research in the fields of energy and environmental science.

In conclusion, this catalog aims to realize a cleaner and more sustainable Indonesian demand side sector. We appreciate the cooperation of all stakeholders, especially the Danish Energy Agency, which has contributed data, input, and support in the preparation of this report. May this report be a foundation to accelerate Indonesia's steps in achieving NZE commitments and realizing a more advanced and sustainable energy future.

Dr. Ir. Hendra Iswahyudi
Director, Directorate General of New Renewable Energy and Energy Conservation

Indonesia is at a pivotal moment in its efforts to combat climate change and transition to a sustainable future with a commitment to achieve net-zero emissions by 2060. The path ahead requires smart decisions across all sectors. Denmark, through the Indonesia-Denmark Energy Partnership Programme (INDODEEP), strives to support Indonesia on this course, having undergone a 50-year long energy transition. Denmark has learnt many lessons on how to decarbonize key sectors such as the power sector by taking advantage of the wind energy resources we are endowed with. However, decarbonization of the power sector alone is not enough. Therefore, we have along the way also learnt how to take advantage of energy efficient technologies to decarbonize industry, transport and our buildings sectors with a binding political goal to reach climate neutrality by 2050.

The industrial, building, and transportation sectors are also key contributors to Indonesia's greenhouse gas emissions, making them central to the country's decarbonization efforts. This priority aligns with the anticipated tripling of Indonesia's electricity demand by 2040, creating a window of opportunity for decarbonization of different hard-to-abate sectors.

This report therefore serves the purpose of identifying the technologies currently available in the Indonesian market, i.e. conventional technologies and applications for mobility, process heating and building appliances specifically and analyzes the techno-economic data of these technologies in comparison to the unconventional decarbonization options to meet these very same energy end uses. In understanding how these technologies perform techno-economically, informed decision making on the required regulatory frameworks to realize Net-Zero by 2060 targets can be achieved. Innovation and investment in cleaner technologies will be important and Indonesia can become an example for sustainable growth in Southeast Asia, showing that economic development and decarbonization can go hand in hand.

Going forward, the INDODEPP programme remains committed to supporting the Indonesian government in its transformative journey through continued knowledge sharing. Together, we can achieve our respective decarbonization targets and ensure a better quality of life for future generations.

Mr. Ole Emmik Sørensen
Director, Global Cooperation, Danish Energy Agency

PREFACE

This report provides comprehensive technology data, including efficiency, greenhouse gas (GHG) emissions impacts, energy consumption, and cost analyses for various convectional and unconventional (decarbonization) technologies across traditional energy demand sectors, namely, industry, transport, and residential buildings. The data is shared for the primary objective of establishing a uniform, commonly accepted and up-to-date basis for energy planning activities, such as future outlooks, evaluations of security of supply and environmental impacts, climate change evaluations. The scope of this report, extends to include various techno-economic analyses to support decision making in Indonesia as the Ministry of Energy and Mineral Resources (MEMR) works towards achieving net-zero emissions by 2060 in the energy sector.

The data presented here is intended to facilitate engagement and data sharing among various ministries, governments, academia, and other stakeholders. Furthermore, the data gathered can be used to update model input/baseline data, refine technology details, and assess the impacts of technology shifts, fuel transitions, and potential energy efficiency policy. Local expert reviews have been solicited to verify the data.

Achieving net-zero emissions will require a balanced approach, integrating diverse technological options, effective regulatory frameworks, infrastructure capabilities, and extensive expertise and collaboration across markets and between governments, thus report is a tool to that can be used to evaluate the interconnections between conventional and unconventional technologies required to advance the energy transition.

In future, updates can be made as new information becomes available.

EXECUTIVE SUMMARY

Indonesia is the 4th largest country in the world with a GDP growth rate of approximately 5% in 2023, thereby making it the largest economy in South East Asia as of 2023 and the 7th largest economy in the world (World Bank, 2023)(IEA, 2022). The country is endowed with a population of over 270 million people thus presented by a large need for various energy sources to meet growing energy demands. Indonesia, has seen a growing electricity consumption that has doubled from 129 TWh in 2008 to more than 256 TWh in 2018 (CLASP, 2020) with 75 % of the electricity consumption being concentrated in its main island, Java, which is densely populated. Two decades ago, the country saw a shift from being a net oil exporter to a net oil importer as of 2003. While between 2017 and 2022, coal and natural gas represented about 25% of the total net goods exports. Emissions in the energy sector have also seen a more than double increase in the last two decades making Indonesia the 9th largest emitter of CO_2 emissions however its per capita emissions remain around the global average (2 tonnes per capita) (IEA, 2022).

As part of a long standing partnership between Indonesia and Denmark at governmental to governmental level, the Ministry of Energy and Mineral Resources (MEMR), in its Directorate General of New Renewable Energy and Energy Conservation (EBTKE) partnered with the Danish Energy Agency, an agency under Ministry of Energy, Climate and Utilities in Denmark, as part of the Indonesia - Denmark Energy Partnership Programme (INDOEDEPP) to develop this body of work. This in effort to support the Government of Indonesia ambitious targets to reach net zero in the energy sectors by 2060. The technology data and analyses provided here is intended to support the decision makers to assess key trends for identified key technologies; conventional and unconventional for industry, transport and residential building end use sectors as they develop regulatory instruments that enhance the government's ability to meet the ambitious targets to reach net zero emissions in the energy sector by 2060.

The analyses is conducted to assess how the identified technologies perform techno-economically, comparing decarbonization technology options to conventional technologies. Thus representative technologies are selected for analysis for the road transport sector, industrial process heating, and residential buildings with an emphasis on electrification of each of these end use sectors. As such, Total Cost of Ownership (TCO) is conducted for various vehicle classes and categories in the road transport segment to analyze how the total cost of ownership of internal combustion engine vehicles (gasoline or diesel powered) compares to that of electric vehicles. For industrial process heating; Levelized Cost of Heating (LCoH) is performed for key process heating equipment in industry, allowing for comparison of the total costs of heat generation of these heat provision technologies during their operational lifetime. Lastly, Life Cycle Cost (LCC) is performed for household appliances to evaluate the total cost of owning and operating a household appliance over its lifetime to understand the impact of the purchasing decisions on the environment and economically.

The analyses allows the decision maker to identify potential gaps and where there is need for e.g. economic incentives such as subsidies, grants, tax breaks, rebates etc. requirement to support certain technologies, or how they perform on a technical basis and the CO_2 emissions associated each technology in an effort to understand the contribution or lack thereof in supporting the goal to reach net zero by 2060 in the energy sectors.

Findings by end use sector and chapter, are summarized below:

1. ROAD TRANSPORT SECTOR

The transport analysis evaluates the Total Cost of Ownership (TCO), efficiencies, and well-to-wheel greenhouse gas emissions (WTW GHG) for different representative archetype vehicle models across different categories. The following emerges the analysis by road transport category:

TWO-WHEELERS

- **Electric two wheelers (E2W) are significantly more energy efficienct** and have nearly 73% less emissions per km than conventional internal combustion engine models (ICE2W).
- **Emissions of E2W decline to almost zero towards 2050** and remain lower than ICE2W's, assuming increasing renewable mix in the power grid.
- **E2W are already more cost-competitive than similar-sized ICE2W,** with a 15% lower TCO, mainly due to their lower energy cost. The difference increases to around 25% in 2050.

PASSENGER VEHICLES

- **In 2024, Battery Electric vehicles (BEVs) are the lowest well-to-wheel GHG emitters in all car categories**, while internal combustion engine and hybrid electric models are the highest emitters depending on categories.
- **WTW GHG emissions from BEVs are expected to decline as the share of renewable energy** in the grid increases and as their fuel economy improves.
- **Without any fiscal policies introduced, one of the two BEV models in each small and medium car categories have already achieved cost parity** with its respective ICE counterpart in 2024.
- **Whereas large BEV models as of 2024 have not reached cost parity** and would therefore require policy support to become competitive.
- **Both small BEV models analyzed achieve cost parity** with small ICEV only by 2030.
- **Depreciation is a significant contributor to the current high TCO of BEV** in all categories.

BUSES

- **Electric buses have the lowest WTW GHG emissions in 2024 due to their high efficiency.** Assuming the declining power grid's emission factor, electric bus's emissions will drop significantly by 2050.
- **Biodiesel buses produce the highest WTW GHG emissions (more than diesel buses)** due to biodiesel's high well-to-tank and direct land-use change emissions.
- **Despite its much lower energy cost, the TCO of electric bus is still 5% higher than that of diesel buses in 2024** due to their much higher purchase price.
- **As prices decline, electric bus will be more cost competitive than diesel bus** around 2030.

TRUCKS

- **Battery Electric Trucks (BETs) have the lowest final energy intensity (MJ/ton-100 km)** in both large and small categories.
- **Diesel and biodiesel trucks are the least energy efficient in the small category**, while Fuel Cell Electric Truck is the least energy efficient in the large category.
- **With WTT and Land Use Change emissions considered, biodiesel trucks (B35) produce the highest WTW emissions** in both large and small categories.
- **Large BETs achieve cost parity with their diesel counterparts around 2030**, while in the small category, BETs only achieve cost parity around 2040 based on the representative models
- **Large FCETs will achieve cost parity with diesel trucks in 2030 while small FCETs will only achieve around 2040**, however, this is assuming a 50% decline in hydrogen production by 2030 compared to current cost.
- **FCETs and BETs are promising alternatives in terms of emission and cost reduction potentials**. However, there are strong uncertainties around:
  - o Reliability of solar PV powered green hydrogen production
  - o TCO calculation of FCETs does not include distribution infrastructure cost, of which the development depends on the economies of scale, transport cost, etc.
  - o Future BET and FCET price projections used are taken from European case
  - o Uptake of BETs is highly interdependent on the development of charging infrastructure

2. INDUSTRIAL PROCESS HEATING SECTOR

Within industry, Levelized Cost of Heat (LCOH) is used as a measure to compare different technologies based on the total costs of heat generation, considering typical operation over their lifetime. The following emerging trends are observed:

- **Heat pumps present among the lowest costs of heating** after coal and biomass boilers. This is mainly due to their high efficiency compensating for the upfront investment costs being the highest.
- **Low temperature heat pumps are a commercially viable option**. Furthermore, the LCOH for heat pumps is expected to decline by 10-15% from today's prices towards 2050 as the technology develops.
- **Coal boilers present the ultimate lowest cost per unit of heat produced** when considering fuel prices for low quality coal and absence of any carbon costs. Considering higher quality coal prices or moderate carbon costs (15 USD/ton CO_2), costs would rise above those of heat pumps and biomass boilers.
- **Electric boilers are more than double the cost of coal boilers** and low temperature heat pumps, due to the high fuel cost (electricity price) thus not competitive purely from a cost perspective. However, remain important to achieve decarbonization targets.
- **Oil and gas boilers are the most expensive sources of heat** due to their very high fuel costs. Although they have low investment costs, they are more expensive to run over time and are not expected to develop much in the future as they are already very mature technologies.
- **Biomass and gas boilers are influenced by high uncertainty for their fuel prices**, thereby affecting their total cost.
- **There is significant potential to reduce emissions and improve energy efficiency** with current technologies, especially for low and medium temperature heating where electrification with heat pumps is a relevant option.
- **However electrification of higher temperatures (above 90 °C hot water and steam) still poses higher costs than most alternatives** but are expected to have a positive development and will be a key tool to decarbonize as the electricity generation develops towards net zero emissions.
- **Generally, fuel costs are the largest contributor generally to the LCOH analysis and therefore important to evaluate as e.g. price of biomass** can have a very wide range from around 600 Rp/kg for agricultural waste (e.g., rice husk) to around 2800 Rp/kg for wood pellets in the international market (high level in end of 2022 for export to South Korea and Japan).

3. RESIDENTIAL BUILDINGS SECTOR

In residential buildings, Life Cycle Cost (LCC) analysis for household appliances is conducted to assess the total expenses associated with owning and operating these appliances throughout their lifespan and the analysis highlights the following key points:

- **Residential buildings represent more than 75% of the energy consumption in buildings**, thus, ensuring improved efficiency of electrical appliances and cooking is important, with Minimum Energy Performance Standards (MEPS) being an important tool.
- **Electricity is already a dominant source of energy which means more emissions are upstream in the electricity generation mix**, thus greening of the electricity mix remains a key priority to see less emissions.
- Life cycle costs of the various household appliances analyzed in this study, namely, rice cookers, refrigerators, televisions, air conditioners, cooking stoves, lights and water heaters, decrease towards 2060 in a scenario with continuous revisions of MEPS due to the energy savings from improved energy efficiency.
- **The cost for lighting is expected to decrease by 65% in a MEPS vs No MEPS scenario due to energy savings from operating the light.** This although the upfront cost for LED is double the cost of the incandescent light per unit, as it has 16 times longer lifetime and consumes 8 times less in energy to provide the same lighting.
- **Electrification still has a role to play within cooking, as LPG remains the primary source of energy yet electrified cooking is more efficient**, ranging from 75-90% depending on technology whilst LPG stoves have 55% efficiency. The total annual costs are also significantly lower for electric stoves.
- **Cost of abatement declines towards 2060 for all household appliances, assuming a goal to reach Net Zero in 2060 and a changing electricity mix**. Many appliances have “negative” abatement costs as they provide lower costs as well as reduced emissions already today.
- **MEPS are key tools to drive the penetration of more efficient appliances in the market** but their implementation should be carefully considered to ensure domestic manufacturers’ ability to comply and minimize potential negative impacts on local supply chains.

In conclusion, this report highlights the significant potential of available technologies to decarbonize the above identified energy end-use subsectors. By analyzing the costs, efficiencies, and CO_2 emission reductions associated with these options, it underscores the critical need for strategic decision making and public choice awareness. Accelerating the adoption of clean energy solutions will contribute to achieving Indonesia's climate goals while fostering a sustainable energy future. Strategic planning and tailored technology deployment will be essential to balancing economic and environmental objectives in Indonesia's transition to a sustainable energy future.

INTRODUCTION

This report provides information about technology, economy and environment for a number of identified technologies within industry, transport and residential buildings end use sectors in Indonesia, specifically looking at process heating, road and residential subsectors respectively. The data gathered can be used as input for energy planning activities, such as future outlooks, climate change evaluations, and technical and economic analyses e.g. on the framework conditions for the development and deployment of certain classes of technologies.

The scope of this document includes data and analyses to provide insights for energy planners. Furthermore, the analyses is conducted. The analysis is conducted to enable policy makers, regulators, and other decision makers to compare the performance of technologies on a fair basis. With the purpose to energy planning activities, such as future outlooks, evaluations of security of supply and environmental impacts, climate change evaluations, as well as technical and economic analyses, e.g. on the framework conditions for the development and deployment of certain classes of technologies.

Representative technologies are analyzed in each end use sector on a fair basis. Here Levelized Cost of Heating (LCoH) is performed for process heating in industry, Total Cost of Ownership (TCO) is conducted for various vehicles classes and categories in the road transport segment and Life Cycle Cost (LCC) is performed for household appliances to evaluate the total cost of owning and operating a household appliance over its lifetime to understand the impact of the purchasing decisions on the environment and economically.

Chapter 1 **assesses techno-economic data of the transport sector with a particular focus on the road transport category**, assessing two wheelers, passenger cars, buses and truck technologies comparing the conventional internal combustion engine vehicles (ICEVs) to electric vehicles and in the case of truck both battery electric and fuel cell electric trucks are analyzed. The TCO is used to depict a more accurate representation of the financial commitment as it pertains to ownership of the various vehicle classes by technology type, assessing the maintenance costs, depreciation, and resale value.

Chapter 2 **provides overview of industrial processing heating which accounts for the largest share of industrial energy needs.** Here various heat generating equipment such as boilers (coal, gas, biomass or oil fueled), and heat pumps, are compared using a key metric, the LCoH, to evaluate the performance of these technologies by analyzing the economic competiveness over their technical lifetime. By so doing, decision makers are better equipped to identify the most cost effective technologies, the technologies that offer the most emission abatement potentials and depending on the ministry's objectives, then identify gaps in policy frameworks required to develop chosen technologies further. This could range from tariffs, subsidies and other required incentives to ensure the energy efficiency goals and targets are realized. Furthermore, to put the risks faced by industry e.g. capital costs or operational expenses required to meet desired targets. Ensuring that regulators engage with the market to develop techno-economically optimal pathways.

Chapter 3 **assesses the household sector, were there is a need for informed consumer decisions to enable consumers to opt for appliances** that result in lower cost over the lifetime of the appliance. In some cases policy support is required to ensure identified devise are incentivized to allow them to compete economically with their less efficient and sometimes cheaper alternatives that consumers may opt for due to purchasing power reasons. The analysis conducted in this report indicate thus to reach net zero by 2060, the energy consumption of the various appliances must be kept to a minimum, thus as penetration rate continues to grow, the role of MEPS becomes even more paramount.

In all cases, the GHG emissions from the conventional and unconventional technologies are presented and a summary by chapter are presented. The data in the have been obtained from public sources and expert advice. Assumptions and expert projections are used in cases where data is difficult to obtain. Consistency is maintained within a chapter however the chapters by their inherent nature have been structured in the most suitable way to show the information by chapter. Investors may have different views on economic attractiveness and different preferences. Assumptions are applied when computing expectations for the future economic trends, as well as on penetration of certain technologies, which may result in differences approximations. However there is a high degree of confidence on the base year data applied. It is paramount to note that the real world is ambiguous thus data may vary from source to source, thus in all cases data that aligns with multiple other sources is used as reference. Where uncertainties lay, this has been communicated to ensure data quality, availability and usability. Thus it is encouraged that new data be shared with the authors for future updates.

"In all cases, the GHG emissions from the conventional and unconventional technologies are presented and a summary by chapter are presented. The data in the have been obtained from public sources and expert advice."

Road Transport Sector

1. Road Transport Sector

Among other sectors, transportation accounted for 25% of Indonesia's total energy-related GHG emissions in 2021[1], it is currently experiencing a rebound after the effects of the COVID-19 pandemic in 2020. This huge number of emissions is due to the high share of fossil fuel consumed (86.66%) in 2021's transport energy mix[2].

ROAD

Decarbonization Technology Measures / Technology data

The use of decarbonized electricity in road transport was set as one of Indonesian guiding pillars in low carbon strategy in energy sector, alongside three other efforts: implementation of energy efficiency measures; fuel shift from coal to gas and renewables in industry; and enhancement of renewable energy in power, transport, and industry. Indonesian government has also encouraged the acceleration of battery electric vehicles (EVs) adoption for road transport through Presidential Regulation No. 79/2023, has been changed by Presidential Regulation 79/2023, with some derivatives regulations implemented by various government bodies (Ministry of Finance, Ministry of Transport, Central Bank, Ministry of Energy and Mineral Resources, Ministry of Industry, Indonesian Police, etc.).

1.1 Passenger cars

In 2022 there were around 17.18 million units of passenger car in Indonesia. Battery and hybrid electric car sales comprise only 1.3% and 0.6% of the total passenger car sales in 2022 (796,563 units)[3]. This is still far-fetched from Government of Indonesia's target of 100% EV sales in 2040.

The tables below compare energy consumption and WTW (well-to-wheels) emissions of various ICEV (internal combustion engine vehicle). HEV (hybrid electric vehicle), and BEV (battery electric vehicle) categories. WTW emissions of fossil-fuelled cars are calculated as a total of WTT (well-to-tank) and tailpipe emissions. On the other hand, the BEV models' WTW emissions are calculated based on the lifecycle WTW emissions of the power grid including transmission and distribution losses. Each category is represented by one vehicle model, except small and medium BEVs where two models are chosen for each to provide variety in the cost and performance for consumers. A 10,000 km of annual mileage is assumed for all car categories. Fuel economy data are gathered from multiple sources, such as automotive review websites and the manufacturer's claim. Fuel economy value obtained from manufacturer's claim is adjusted with correction factor, to reflect real world driving pattern.

1 Climate Transparency. (2022). Climate Transparency Report 2022: Indonesia
2 Ministry of Energy and Mineral Resources. (2022). Handbook of Energy and Economics Statistics Indonesia 2021
3 https://www.gaikindo.or.id/indonesian-automobile-industry-data/

Table 1. Energy consumption and emission of various categories of fossil-fueled cars

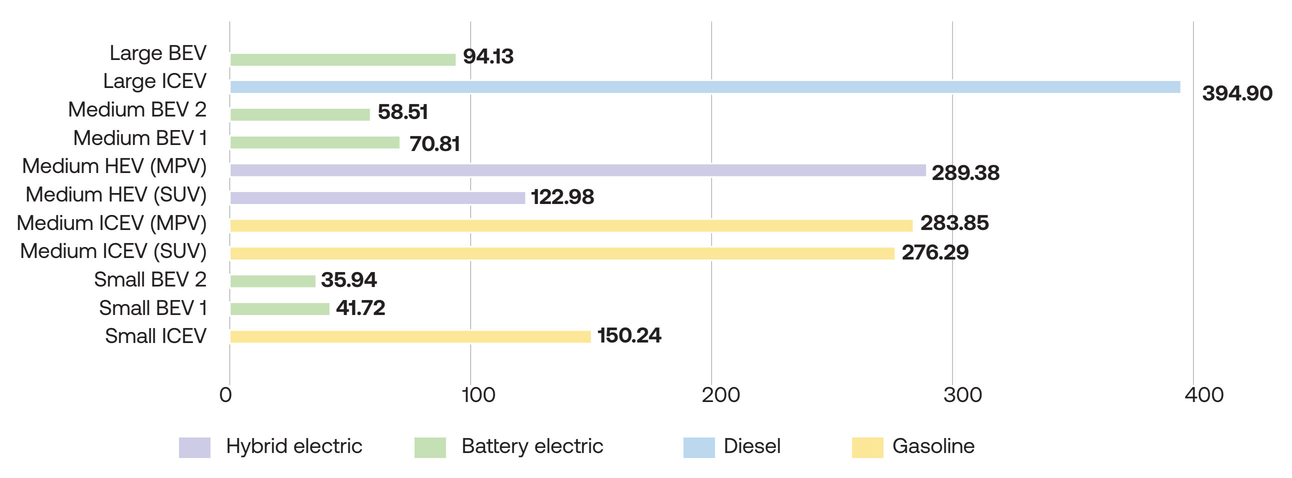
Fuel	Category	Engine capaczity (liter)	Energy consumption		WTW GHG emissions			
			On-road fuel economy (km/l)	Annual fuel consumption (liter)	WTT emissions (g CO_2e/km)	Tailpipe emissions (g CO_2e/km)	Total WTW emissions (g CO_2e/km)	Annual WTW emissions (kg CO_2e)
Gasoline	**Small ICEV**	1.2	23.7	421	29.90	109.07	138.97	1,390
	Medium ICEV (SUV)	2.0	12.9	775	54.98	200.58	255.56	2,556
	Medium ICEV (MPV)	1.5	12.6	796	56.49	206.08	262.56	2,626
	Medium HEV (SUV)	1.5	29.0	345	24.47	89.28	113.76	1,138
	Medium HEV (MPV)	1.5	12.3	812	57.59	210.09	267.68	2,677
Diesel	**Large ICEV (SUV)**	2.7	10.1	995	86.48	293.93	380.42	3,804

Table 2. Energy consumption and emission of various categories of electric cars

Category	Maximum engine power (kW)	Maximum battery range (km)	Energy consumption		WTW GHG emissions	
			On-road electricity consumption (kWh/km)	Annual electricity consumption (kWh)	WTW emissions (g CO_2e/km)	Annual WTW emissions (kg CO_2e)
Small BEV 1	30	300	0.111	1,113	86.08	861
Small BEV 2	25	180	0.096	958	74.15	742
Medium BEV 1	110	384	0.189	146.09	146.09	1,461
Medium BEV 2	132	403	0.156	1,560	120.72	1,207
Large BEV	283	497	0.251	2,510	194.22	1,942

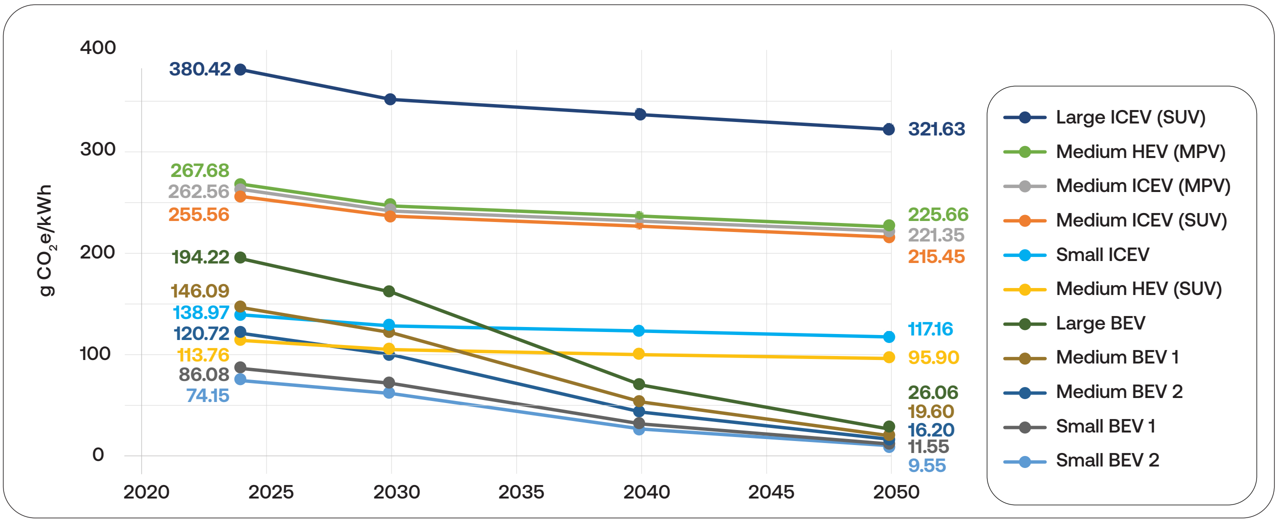
Electrification of road transport also means improvement of energy efficiency. Figure 1 shows that BEVs have much lower energy consumption than all HEV and ICEV in each category for the same distance travelled. Electrification will also contribute to the reduction of fuel imports. If 10,000 km of annual distance is assumed, every ICEV replaced by BEV is expected to avoid 421–995 liter of fuel import per year (see **Table 1**).

Figure 1. Final energy intensity of various car categories



Ultimately, the electrification of road transport is expected to reduce GHG emissions. WTW emissions per km from ICE cars are compared with power generation emissions from EV cars. WTW emissions are assumed as the total of WTT (well-to-tank) and tailpipe emissions. The emissions can be seen in Figure 2. Given the high current emission factor of PLN grid (774 g CO_2e/kWh[4]), in 2024 a large ICE SUV produces the highest emissions per km at 380 g CO_2e/km. Medium hybrid models, in this case, have far different emissions per km. Hybrid MPV (268 g CO_2e/km) produces higher emissions than medium ICE SUV and MPV (256 and 262 g CO_2e/km), while hybrid SUV (114 g CO_2e/km) emits less than small ICEV (139 g CO_2e/km) and large and medium BEVs. The current lowest emitting car model is a small BEV with 74 g CO_2e.

Figure 2. Projection of WTW GHG emissions of various fossil and electric car models until 2050



As power system emissions and engine efficiency improve over time, the vehicles' tailpipe emissions are expected to decline in the future. With constant WTT emissions assumed, the total WTW emissions are projected until 2050. In this calculation, a 9% fuel economy improvement by 2050 is assumed for BEVs, while 20% is assumed for HEVs and ICEVs. The result shows that large ICEV will stay as the top emitter in 2050 with 321.63 g CO_2e/km in 2050, followed by the medium models ranging from 215.45–225.66 g CO_2e/km. Due to assumed decreasing power grid lifecycle emission factor to 114 g CO_2e/kWh[5], all BEV models will experience significant emission decline, beating the medium hybrid SUV emissions (95 g CO_2e/km). Emissions from the BEVs in 2050 will range from 10 g CO_2e/km (small BEV 2) to 26 g CO_2e/km (large BEV).

4 Meira, Z. & Bieker, G. (2023). Comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars and two-wheelers in Indonesia. ICCT.
5 Idem.

Figure 3. Total cost of operation without tax and subsidy of various car categories purchased in 2024, for 10 years of use

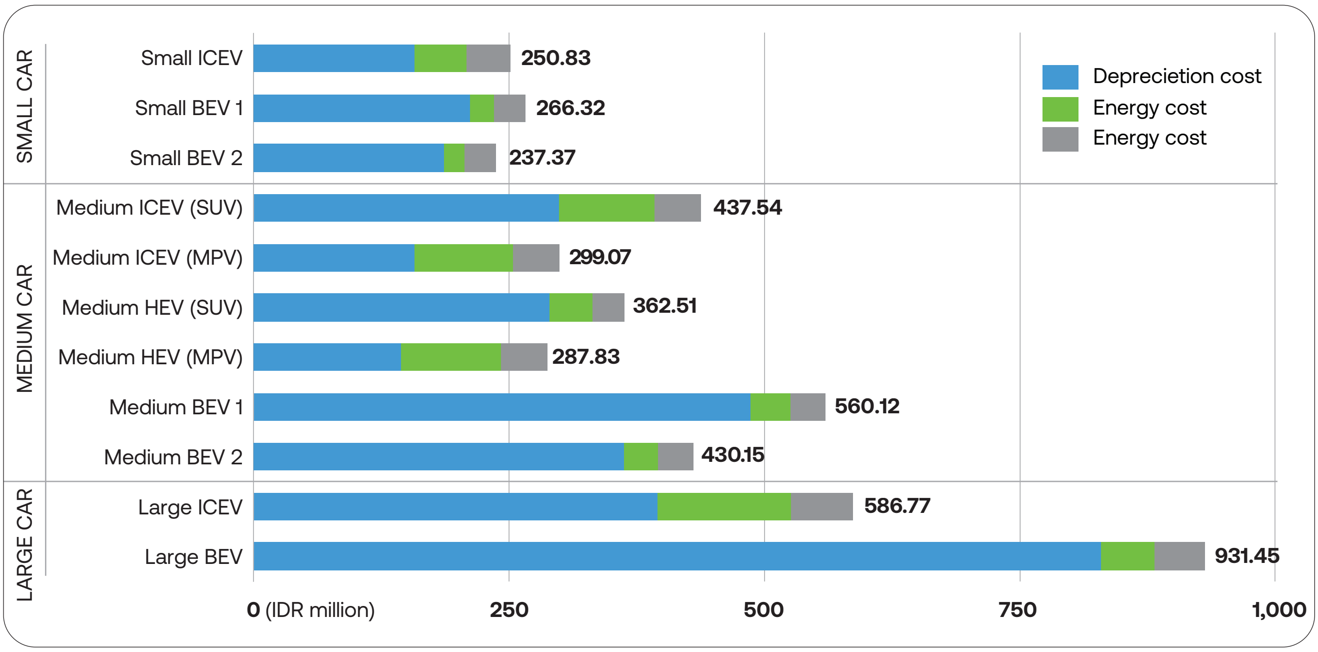


Table 3. TCO of various categories of fossil-fueled cars purchased in 2024, for 10 years of ownership

Fuel	Category	Average off-the-road price (IDR million)	TCO (IDR million)			
			Depreciationcost	Energy cost	Maintenance cost	Total
Gasoline	Small ICEV	177	157.53	50.99	42.31	250.83
	Medium ICEV (SUV)	364	298.48	93.77	45.30	437.55
	Medium ICEV (MPV)	192	157.44	96.34	45.30	299.08
	Medium HEV (SUV)	353.4	289.80	41.74	30.98	362.51
	Medium HEV (MPV)	176	144.32	98.21	45.30	287.83
Diesel	Large ICEV (SUV)	482	395.24	130.85	60.69	586.78

Table 4. TCO of various categories of electric cars purchased in 2024, for 10 years of ownership

Category	Average off-the-road price (IDR million)	TCO (IDR million)			
		Depreciation cost	Energy cost	Maintenance cost	Total
Small BEV 1	200	212.17	23.18	30.98	266.33
Small BEV 2	171	186.43	19.96	30.98	237.37
Medium BEV 1	565	486.17	39.33	34.62	560.12
Medium BEV 2	411	363.03	32.50	34.62	430.15
Large BEV	994	829.37	52.29	49.79	931.45

Cost will be one important factor that could influence the success of the electrification policy in the transport sector. Currently, from the user's perspective, replacing an ICEV with a BEV is not yet favorable. In average, price of a BEV is currently 2–3 times more expensive than its ICEV counterpart. However, in terms of energy cost, BEVs are much more economical with the current fuel and electricity price. To estimate the overall expense paid by consumers during a vehicle's lifetime, the total cost of ownership (TCO) is calculated for each category.

TCO is calculated for 10 years of operation and consists of depreciation cost, energy cost, and maintenance cost. The depreciation cost is assumed as the summation of a vehicle's off-the-road price, a 7-kW home charger installation and cost for home load capacity upgrade to 7.7 kVA for BEV models, and finally reduced by its resale value. The off-the-road price of each representative model is collected from Samsat DKI Jakarta's website, while its resale value after 10 years of ownership is assumed as a percentage of its purchase price with different percentage assumed for each vehicle category. The energy cost is calculated assuming 10,000 km of annual mileage for cars, 2024 energy prices with 50-50 home-to-commercial charging ratio for the BEVs, and each vehicle's fuel economy. Lastly, the maintenance cost is assumed to be a constant annual cost, specified for each vehicle category, across 10 years of ownership. No battery replacement is assumed for the BEVs.

The 2024 TCOs are shown in **Table 3 and Table 4** above. Without taxes and fees considered, it is shown that TCO of medium HEVs are already lower than their ICE counterparts in each SUV and MPV category. Medium BEV 2 also shows lower TCO compared with medium ICE SUV. In the small category, TCO of BEV 2 is 5.4% lower than its ICE counterpart, while BEV 1 is still less cost competitive.

As the battery cost declines, the TCO of BEVs is also expected to drop in the future. TCO projections are conducted here for small and medium car categories, comparing cost competitiveness of BEVs and ICEVs until 2050. All costs are discounted to 2024 Indonesian Rupiah (IDR). Constant prices are assumed for the ICEVs, while BEV prices are projected using 7% decline rate for battery-pack cost per kWh until 2040 and 4% afterwards. BEV prices are calculated as a total of its cost components: battery-pack cost, powertrain and electronics, and other direct costs. Battery capacities (kWh) of the BEVs are assumed to increase up to 195% of the current capacity. The energy prices are assumed to increase. Fossil fuel prices are assumed to increase 1% per year, while electricity price projection trend follows the Low Carbon cost scenario in RUPTL 2021–2030. The energy consumption of BEVs and ICEVs are assumed to improve up to 9% and 20% by 2050.

Figure 4 and Figure 5 below show projected TCO comparison of BEV and ICEV for small and medium car models. As described above small BEV 2[6] already achieved its cost parity with small ICEV[7] in 2024. In 2030, small BEV 1[8] will also achieve its cost parity with its ICE counterpart, with TCO of IDR2024 247 million and IDR2024 248.6 million, respectively. In the medium category, TCO of medium BEV 2[9] will continue to decline reaching IDR2024 350.4 million, which is 20.5% lower than medium ICEV's TCO (IDR2024 440.9 million) in 2050. On the other hand, medium BEV 1[10] will remain less cost competitive compared with its ICE counterpart by 2050.

> **“In all these categories, the depreciation cost of the ICEV is still lower than that of the BEVs, which is compensated for by the BEVs' lower energy and maintenance costs.”**

6 Represented by DFSK Seres E1
7 Represented by Honda Brio RS CVT
8 *Represented by Wuling Air ev - Long*
9 *Represented by MG ZS EV*
10 *Represented by Hyundai Ioniq Signature Standard*

Figure 4. Projection of annual total cost of ownership of small BEV and ICEV until 2050

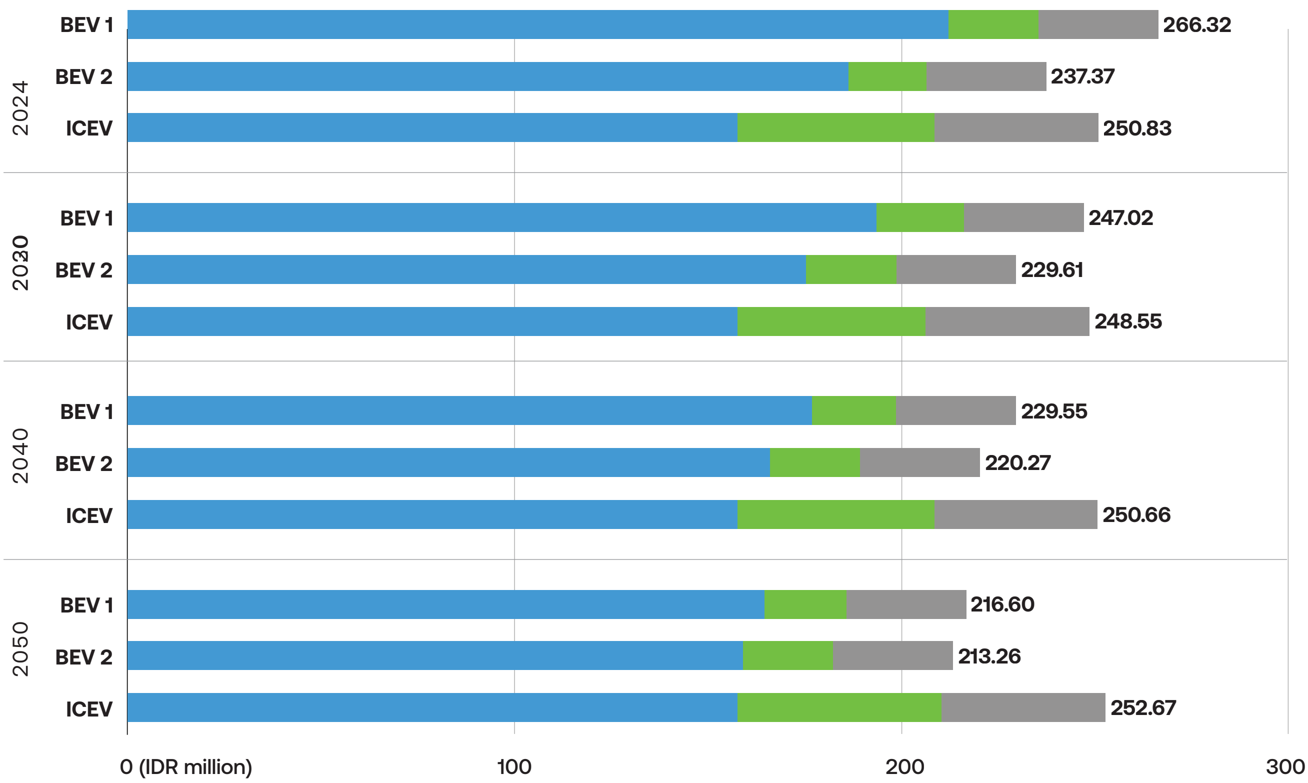
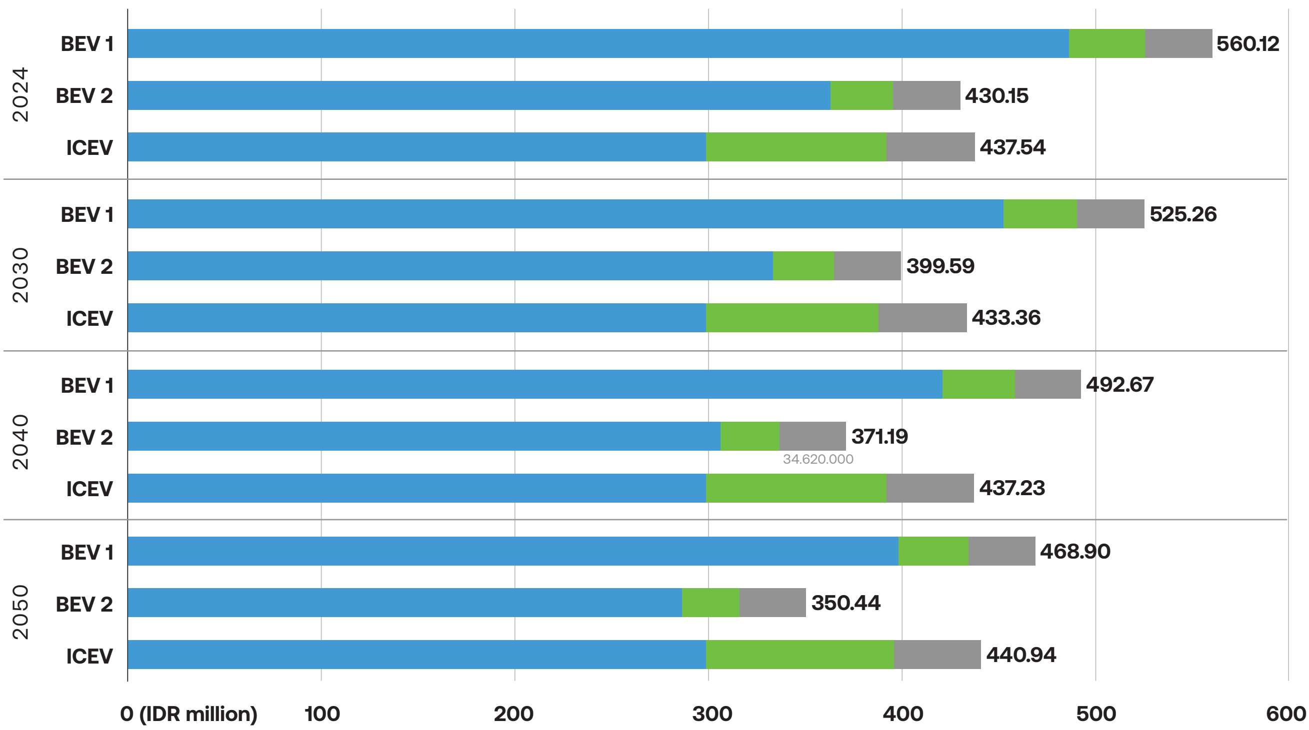


Figure 5. Projection of annual total cost of ownership of medium BEV and ICEV until 2050



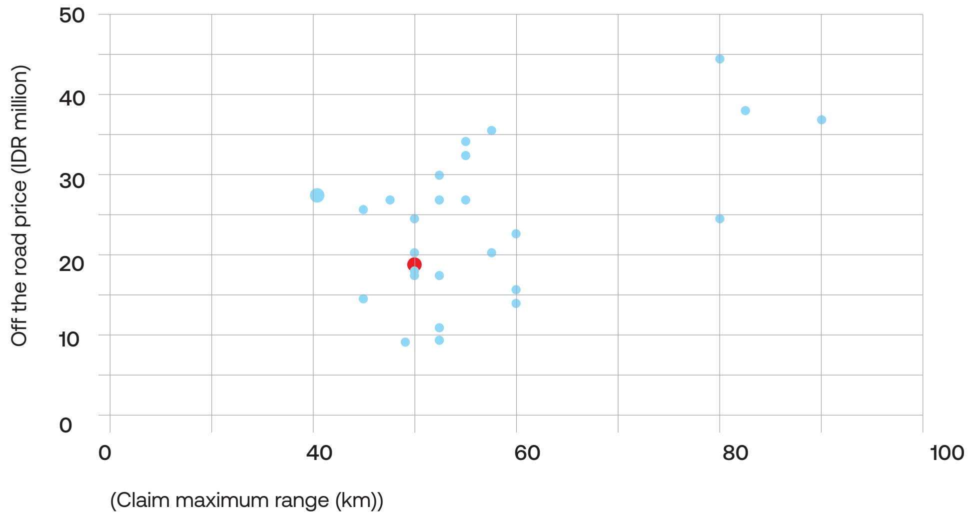
1.2 Two-wheelers

As the most popular type of vehicle in Indonesia, with a total of 132.4 million units recorded in 2023[11], internal combustion engine two-wheelers (ICE2Ws) have been contributing largely to Indonesia's GHG emissions. In 2018, ICE2Ws comprise 41% of fuel consumption in transportation sector or around 160 million BOE of gasoline[12], which is equivalent to 64.9 Mton CO_2e of GHG emissions or 10.9% of total estimated energy sector GHG emissions in 2018 (596 Mton CO_2e[13]).

The transition from the internal combustion engine (ICE) to the battery electric two-wheelers (E2W) has been slowly happening in Indonesia for the last few years. Since 2019, there were only 75 thousand units of E2W sold in Indonesia[14]. In 2023 alone, E2W sales only reached 41.8 thousand units. It is very small compared to ICE2W sales in the same year, which was 6.2 million units[15]. This E2W uptake is supported by Indonesian ride hailing companies which has been using some local-brand fleets, some of which are equipped with swappable battery.

With a similar method to the cars above, WTW GHG emissions from ICE2W and E2W models are compared in this analysis. An 8,000 km annual mileage is assumed in this analysis.

Figure 6. Price and maximum range of E2W models in Indonesian market. The red dot shows the representative small e-scooter model.



This analysis compares small ICE and e-scooter models. One representative model is picked for each side. Viar Q1 is chosen as the representative e-scooter model and Figure 6 shows its position relative to other models in the Indonesian market. On the other hand, ICE scooter is represented by Honda Beat. These two models are not actually comparable in terms of performance, i.e. maximum engine power, but these two are amongst two most popular models in each category.

11 BPS. (2024). Motorised Vehicle Stocks by Province and Type. https://www.bps.go.id/id/statistics-table/3/VjJ3NGRGa3dkRk5MTlU1bVNFOTVVbmQyVURSTVFUMDkjMw==/jumlah-kendaraan-bermotor-menurut-provinsi-dan-jenis-kendaraan--unit---2022.html?year=2023
12 Secretariat General of National Energy Council. (2019). Indonesia Energy Outlook 2019.
13 Ministry of Environment and Forestry. (2021). Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050).
14 Aismoli. (2024). Statistic. https://aismoli.or.id/statistic?type=yearly
15 AISI. (2024). Statistic Distribution. https://www.aisi.or.id/statistic/

Table 5. Energy consumption and emissions of fossil-fueled two-wheeler by size

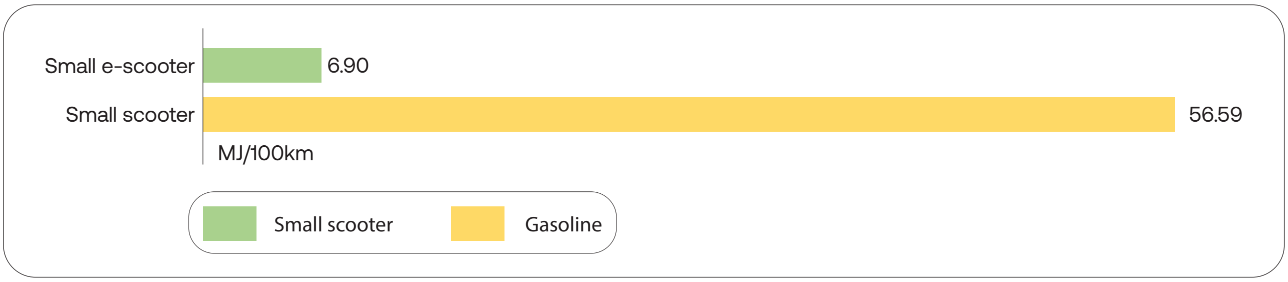
Category	Engine capacity (cc)	Energy consumption		WTW GHG emissions			
		On-road fuel economy (km/l)	Annual fuel consumption (liter)	WTT emissions (g CO_2e/km)	Tailpipe emissions (g CO_2e/km)	Total WTW emissions (g CO_2e/km)	Annual WTW emissions (kg CO_2e)
Small scooter	110	63.0	127	11.26	41.08	52.35	419

The energy consumption and emissions data of the ICE2W and E2W models are shown in Table 5 and Table 6 respectively. It is shown that if 8,000 km of annual distance is assumed, every ICE2W replaced with E2W could avoid around 127 liter of fuel import per year.

Table 6. Energy consumption and emissions of e-scooter model

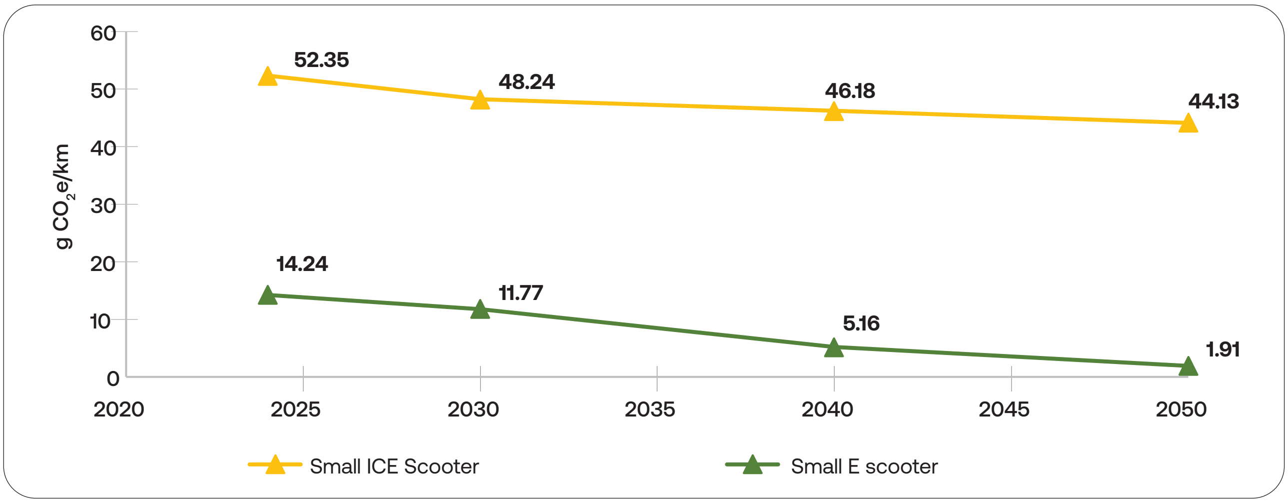
Category	Maximum battery range (km)	Energy consumption		WTW GHG emissions	
		On-road electricity consumption (kWh/km)	Annual electricity consumption (kWh)	WTW emissions (g CO_2e/km)	Annual WTW emissions (kg CO_2e)
Small e-scooter	60	0.0184	147	14.24	114

Figure 7. Final energy intensity of various two-wheeler categories



WTW GHG emissions of the e-scooter model (14.24 g CO_2e/km) are currently already lower than that of its ICE counterpart (52.35 g CO_2e/km). Although an electric scooter has 8 times better energy efficiency than fossil-fueled scooters (Figure 7), its WTW GHG emission per km is only around 3.7 times lower than its ICE counterparts. This is due to the high emission factor of the power grid, which is dominated by coal power plants. In 2050, improved fuel economy and power grid's emission factor are expected to reduce the e-scooter's emissions to only 1.91 g CO_2e/km, while improved fuel economy of the ICE scooter reduce its emissions to 44.13 g CO_2e/km.

Figure 8. Projection of WTW GHG emissions of various fossil and electric two-wheeler models until 2050



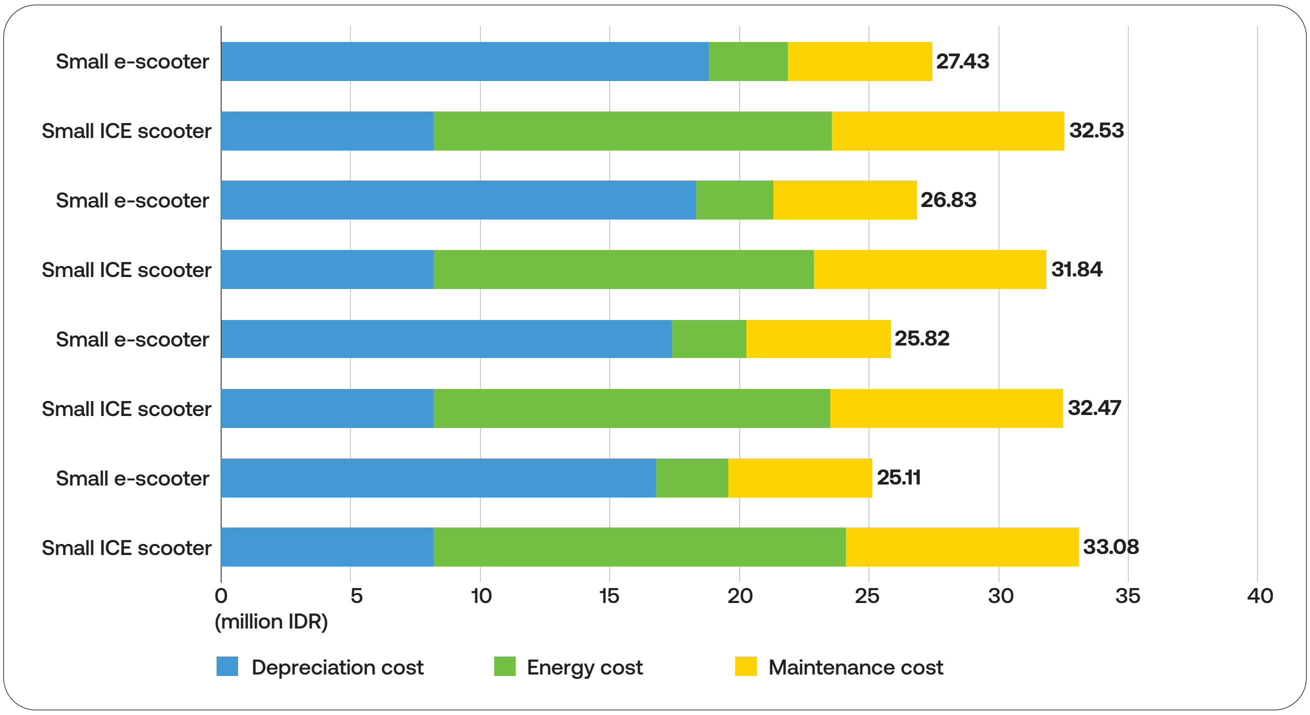
The price and TCO components of the ICE2W and E2W models in 2024 are shown in **Table 7.** In this example, the depreciation cost of the e-scooter is much higher than its ICE counterpart. In terms of energy cost, the e-scooter requires only IDR 3.07 million during 10 years of ownership or 20% of the fuel cost of a small ICE scooter. In total, the e-scooter's TCO in 2024 is already 15.7% lower than the ICE's.

Table 7. TCO of various categories of fossil-fueled two-wheelers purchased in 2024, for 10 years of ownership

Category	Off-the-road price (IDR million)	TCO (IDR million)			
		Depreciation cost	Energy cost	Maintenance cost	Total
Small scooter	13	8.19	15.37	8.98	32.53
Small e-scooter	18.9	18.81	3.07	5.56	27.43

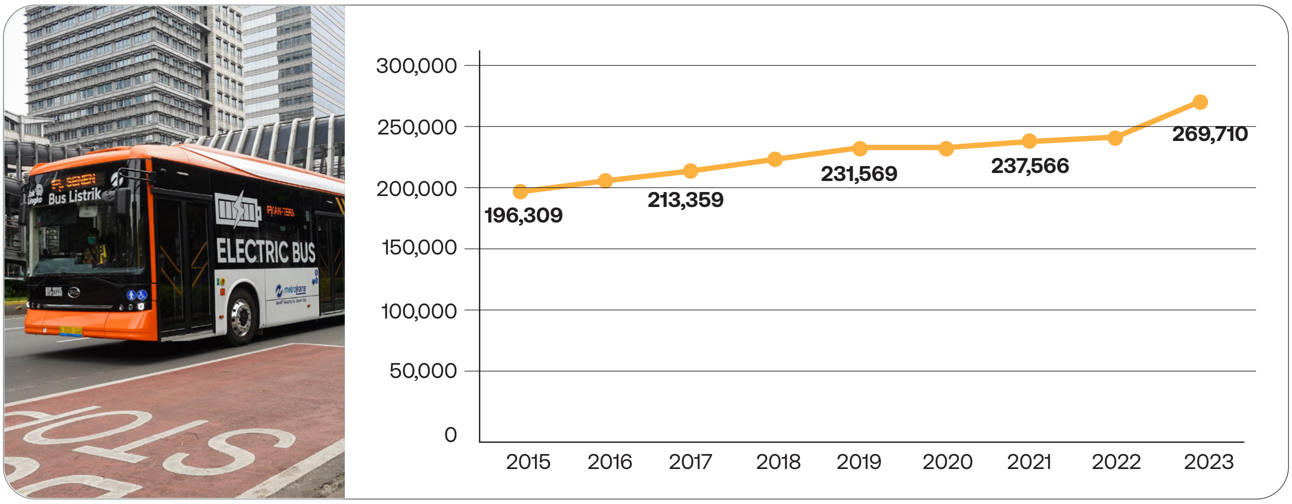
With all costs discounted to 2024 rupiah values, TCO of two-wheelers is projected until 2050. The currently low TCO of the e-scooter is expected to decline further in the future. Its price will fall from IDR2024 18.9 million in 2024 to IDR2024 16.8 million in 2050. On the other hand, the ICE scooters' prices are assumed to be constant in this analysis. This will widen the TCO gap in 2050, with e-scooter's TCO 24.8% lower than its ICE counterpart.

Figure 9. Projection of total cost of ownership of E2Ws and ICE2Ws until 2050



1.3 BUSES

Figure 10. Bus stocks in Indonesia (2015–2023)[16]



Due to its limited range, electric buses have been optimised for urban public transport uses. The uptake of electric buses has been happening in Jakarta. TransJakarta started to adopt electric bus back in 2022 with 30 units[17]. By 2024, TransJakarta already has 100 electric bus fleets, and is adding another 200 by the end of the year[18]. Nationally, only 124 electric buses are being used in urban public transport systems across three cities[19]. On the other hand, the Ministry of Transport has set an ambitious target to electrify 90% of all urban public transport fleets in 2030 and 100% in 2040.

With a similar method to the cars above, WTW GHG emissions from diesel and electric bus models are compared in this analysis. The tables below show energy consumption and emission of 12-meter diesel bus and an example of TransJakarta's electric bus fleet, assuming 192 km/day of distance travelled or 70,080 km of annual mileage. The WTW GHG emissions of the biodiesel bus also consider direct land-use change (DLUC) emissions alongside the WTT and tailpipe emissions.

Table 8. Energy consumption and WTW GHG emissions of ICE bus consuming B35 biodiesel and diesel fuels

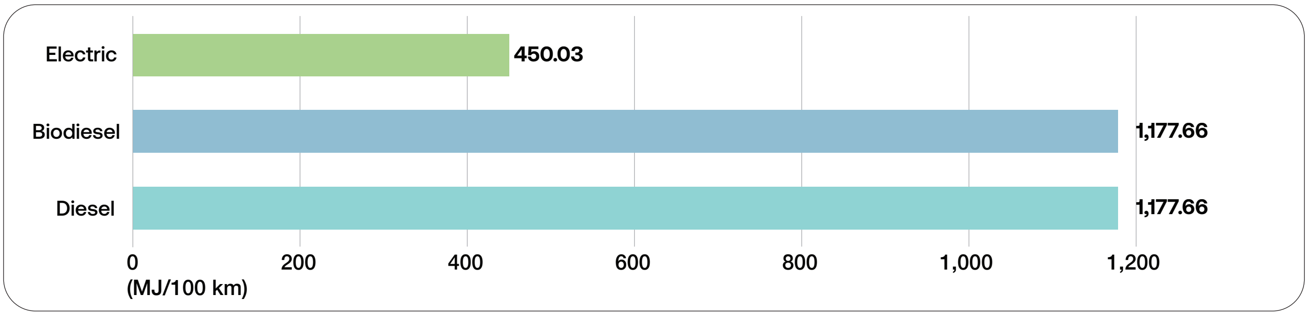
Fuel	Length (m)	Energy consumption		WTW GHG emissions			
		On-road fuel economy (km/l)	Annual fuel consumption (liter)	WTT & DLUC emissions (g CO_2e/km)	Tailpipe emissions (g CO_2e/km)	Total WTW emissions (g CO_2e/km)	Annual WTW emission (kg CO_2e)
Biodiesel (B35)	12	3.37	20,795	781.97	569.77	1,351.74	94,730
Diesel	12	3.37	20,795	257.91	876.57	1,134.48	79,504

Table 9. Energy consumption and emission of an electric bus

Fuel	Length (m)	Maximum battery range (km)	Energy consumption		WTW GHG emissions	
			On-road electricity consumption (kWh/km)	Annual electricity consumption (kWh)	WTW emissions (g CO_2e/km)	Annual WTW emissions (kg CO_2e)
Electric	12	300	1.2	84,096	929.51	65,070

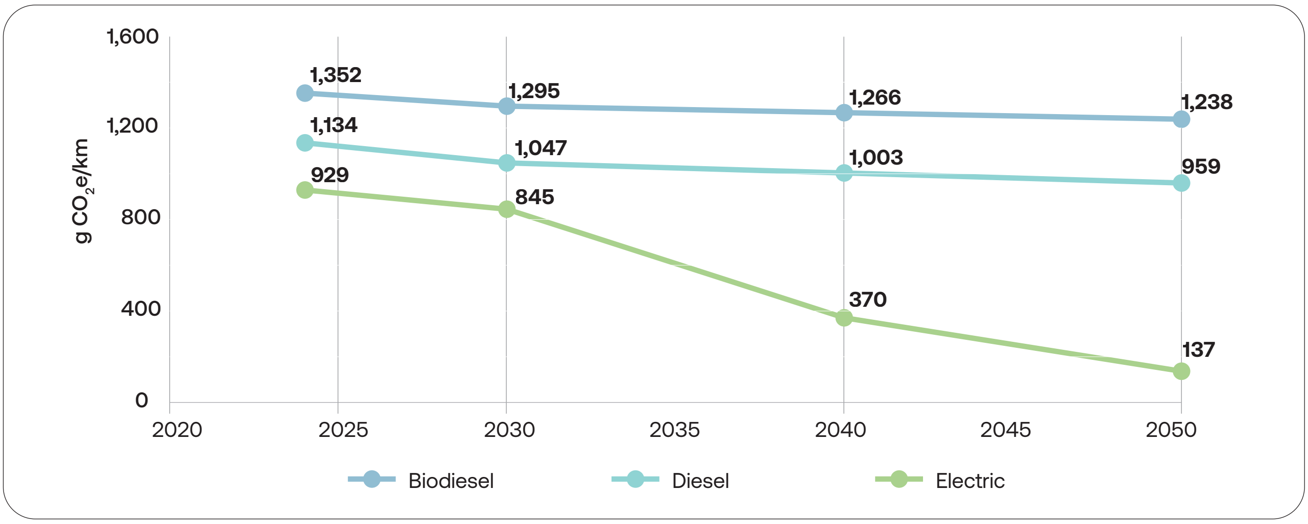
16 BPS. (2024). Motorised Vehicle Stocks by Province and Type. https://www.bps.go.id/id/statistics-table/3/VjJ3NGRGa3dkRk5MTlU1bVNFOTVVbmQyVURSTVFUMDkjMw==/jumlah-kendaraan-bermotor-menurut-provinsi-dan-jenis-kendaraan--unit---2022.html?year=2023
17 Antara. (2022). 30 electric buses start rolling in Jakarta. https://en.antaranews.com/news/218977/30-electric-buses-start-rolling-in-jakarta
18 Antara. (2024). Transjakarta sebut sebanyak 200 bus listrik segera masuk koridor. *https://en.antaranews.com/news/217869/jakarta-targets-electrifying-50-pct-of-transjakartas-fleet-by-2025*
19 ITDP. (2024). Building the Momentum for Transport Electrification in Indonesia. https://itdp.org/2024/07/15/building-momentum-for-transport-electrification-in-indonesia/

Figure 11. Final energy intensity of B35 biodiesel, diesel and electric buses



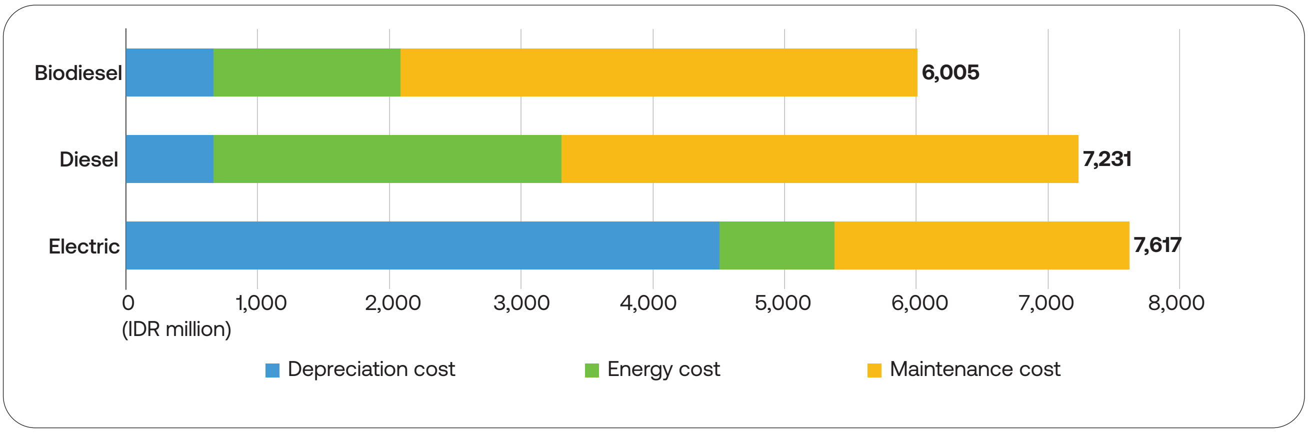
An electric bus is almost 3 times more energy efficient than a similar size diesel bus (Figure 12). Diesel and biodiesel-fuelled bus have similar final energy intensity. Despite its lower tailpipe emissions, the high emissions from DLUC make B35 biodiesel-fuelled bus the highest WTW emitter with 1,351.74 g CO_2e/km compared to the other two models in 2024. It is followed by diesel-fuelled bus (1,134.48 g CO_2e/km) and electric bus (928.51 g CO_2e/km) being the lowest emitter.

Figure 12. Projection of WTW GHG emissions of B35 biodiesel, diesel, and electric bus models until 2050



Biodiesel and diesel bus will remain the two highest emitters in 2050 with 1,237.78 g CO_2e/km and 959.16 g CO_2e/km respectively. Electric bus will experience significant decline in its WTW emissions with 137.02 g CO_2e/km in 2050.

Figure 13. TCO without tax and subsidy of B35 biodiesel, diesel, and electric buses, for 10 years of use



Currently, in 2024, the price of an electric bus (IDR 5 billion) is almost 6 times higher than a diesel bus (IDR 876 million). If a company decides to invest in a bus depot charger (150 kW), an additional IDR 703.33 million upfront cost is required for one electric bus fleet. The depreciation cost of an electric bus in 2024 (consisting of purchase price, depot charger cost, and resale value reduction) is almost 7 times higher than that of a diesel bus. In return, an electric bus has a much lower energy cost (IDR 871.23 million) compared to a diesel bus (IDR 2.64 billion) over 10 years of ownership. The maintenance cost of a TransJakarta bus is currently 0.2 USD/km or around 3,194 IDR/km, which is much lower than that of a diesel bus with 5,600 IDR/km. In total, the TCO of electric bus is 5% and 27% higher than that of diesel and biodiesel buses in 2024.

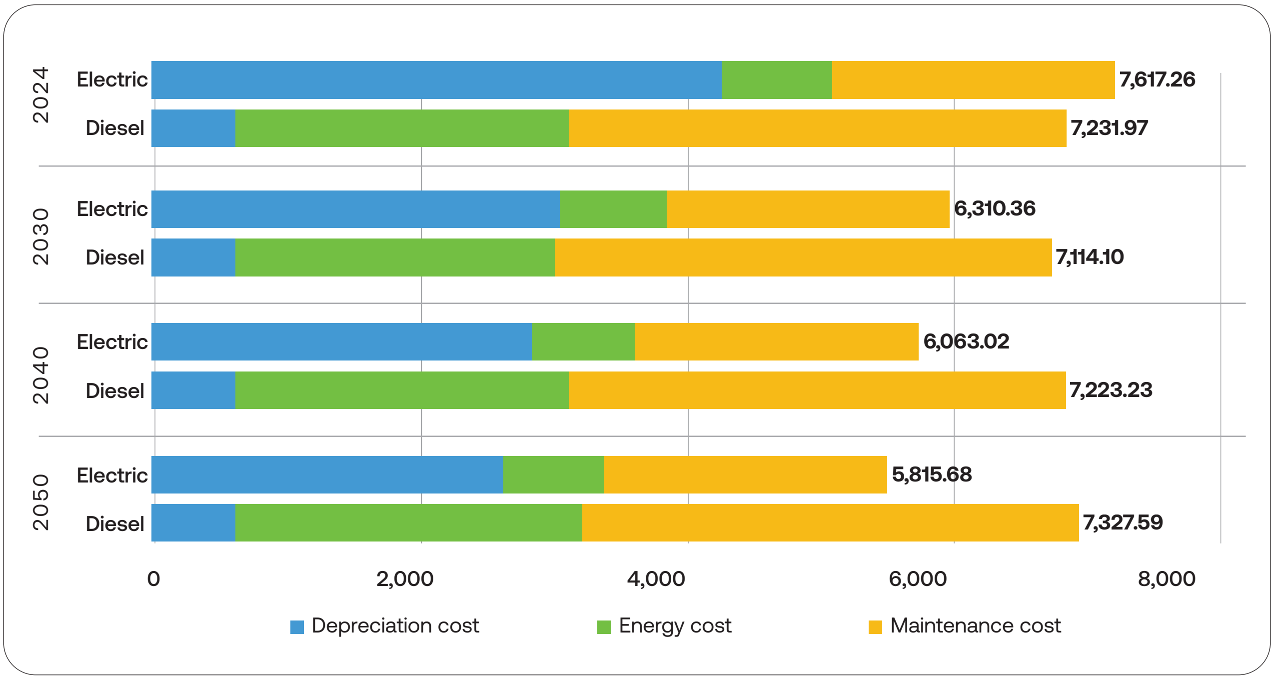
Table 10. TCO of ICE buses consuming B35 biodiesel and diesel purchased in 2024, for 10 years of ownership

Fuel	Off-the-road price (IDR million)	TCO (IDR million)			
		Depreciation cost	Energy cost	Maintenance cost	Total
Biodiesel (B35)	876	666.50	1,414.08	3,924.48	6,005.05
Diesel	876	666.50	2,640.99	3,924.48	7,231.97

Table 11. TCO of electric bus purchased in 2024, for 10 years of ownership

Fuel	Off-the-road price (IDR million)	Depot charger upfront cost (IDR million)	TCO (IDR million)			
			Depreciation cost	Energy cost	Maintenance cost	Total
Electric	5,000	703.33	4,507.53	871.23	2,238.49	7,617.26

Figure 14. Current (2024) and 2030 projection of TCO of diesel and electric buses



With all costs discounted to 2024 rupiah values, TCO of buses is projected until 2050. With assumed declining price, charger infrastructure costs, and increasing energy efficiency, electric bus would achieve its TCO parity by 2030. Furthermore, the 2050 projection shows that electric bus could be much cheaper reaching IDR2024 2.92 billion. This reduces its depreciation cost to IDR2024 2.78 billion, which is still 4.2 times higher than a diesel bus. However, the electric bus' TCO (IDR 5.82 billion) will be 20.6% lower than a diesel bus (IDR2024 7.33 billion), due to its much lower energy cost (IDR2024 792.8 million) compared with diesel's (IDR2024 2.74 billion)

1.4 TRUCKS

Decarbonization of on-road freight transports are expected by shifting demand away from diesel vehicles. In this case, battery electric trucks (BET) and fuel-cell electric trucks (FCET) are suggested to replace the diesel trucks.

Technoeconomic analysis is conducted to compare various sized diesel trucks, BETs, and FCETs. The diesel trucks are based off three different models available in Indonesian market (small truck: Mitsubishi Fuso Canter FE 74 HDS, medium truck: Mitsubishi Fighter X FM 65 240PS, large truck: Hino FM 340 TH). BET and FCET both consist of small and large sizes. The small BET model is based off Mitsubishi Fuso eCanter, a newcomer to Indonesian market, while the small FCET model is taken from ICCT study for China[20]. Both large BET and FCET models are based off DEA's report[21] for European case.

Firstly, energy consumption and emissions are shown, assuming 100,000 km of annual mileage for all truck models. As conducted before in the bus section, the WTW GHG emissions of the biodiesel trucks consider direct land-use change (DLUC) emissions alongside the WTT and tailpipe emissions. The FCETs are assumed to use green hydrogen fuel, generated from solar PV electrolyzer, producing very low WTW emissions.

Table 12. Energy consumption and emissions of various diesel truck sizes

Category	Fuel	Specifications		Energy consumption		WTW GHG emissions (a)			
		GVW (ton)	Max. payload (ton)	On-road fuel economy (km/l)	Annual fuel consumption (liter)	WTT & DLUC emissions (g CO_2e/ ton-km)	Tailpipe emissions (g CO_2e/ ton-km)	Total WTW emissions (g CO_2e/ ton-km)	Annual WTW emission (kg CO_2e)
Small	Biodiesel B35	5–10	5.68	5.33	18,750	164.70	120.01	284.71	85,413
	Diesel	5–10	5.68	5.33	18,750	54.32	184.63	238.95	71,685
Large	Biodiesel B35	>24	37.61	1.20	83,333	123.37	89.89	213.27	379,613
	Diesel	>24	37.61	1.20	83,333	40.69	138.30	178.99	318,599

Small and large FCETs are assumed to carry 3 and 17.8 tons of payload, respectively.

Table 13. Energy consumption and emissions of battery electric trucks

Category	Specifications			Energy consumption		WTW GHG emissions	
	GVW (ton)	Max. payload (ton)	Max. battery range (km)	On-road fuel economy (kWh/km)	Annual electricity consumption (kWh)	WTW emissions (g CO_2e/ton-km) (a)	Annual WTW emissions (kg CO_2e)
Small	6	3	140	0.741	74,107	191.14	57,341
Large	28	17.8	313	1.147	114,659	49.84	88,719

Small and large FCETs are assumed to carry 3 and 17.8 tons of payload, respectively.

Table 14. Energy consumption and emissions of a fuel-cell electric trucks

Category	Specifications			Energy consumption		WTW GHG emissions	
	GVW (ton)	Max. payload (ton)	Max. battery range (km)	On-road fuel economy (kWh/km)	Annual electricity consumption (kWh)	WTW emissions (g CO_2e/ton-km) (a)	Annual WTW emissions (kg CO_2e)
Small	8.6	9.4	18	0.3806	3,806	24.10	7,231
Large	28	18.4	34	0.0654	6.542	6.98	12,429

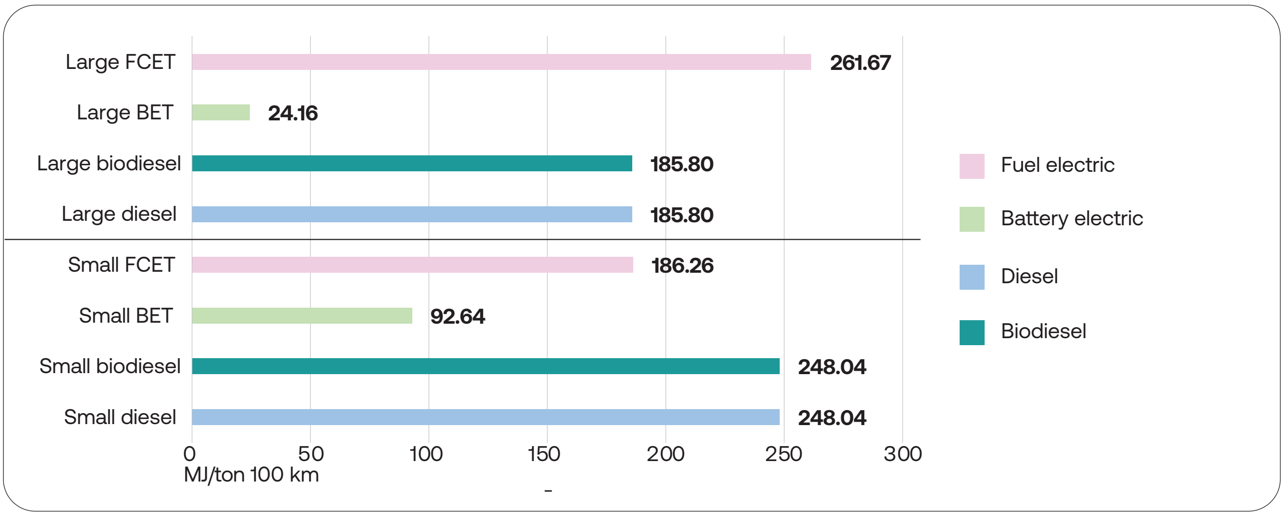
Small and large FCETs are assumed to carry 3 and 17.8 tons of payload, respectively.

20 ICCT. (2021). Total cost of ownership for heavy trucks in China: battery electric, fuel cell electric, and diesel trucks.
21 DEA. (2023). Technology data – Commercial freight- and passenger transport

The final energy intensities of the trucks are compared to each other, showing the energy consumption in MJ unit per ton of load and 100 km of distance travelled. In this analysis, small and large trucks are assumed to carry 3 tons and 17.8 tons of payload, respectively.

The result shows that diesel truck gets more energy efficient as the size increases. Among the small trucks, the BET model has the lowest final energy intensity (92.64 MJ/ton-100 km) followed by the diesel models (186.26 MJ/ton-100 km) and the diesel model (248.04 MJ/ton-100 km). On the other hand, in the large categories, FCET is the least energy efficient model (261.67 MJ/ton-100 km), with BET being the most energy efficient (24.16 MJ/ton-100 km).

Figure 15. Final energy intensity of various sized biodiesel B35, diesel, and electric trucks



As seen before in the bus section, B35 biodiesel fuel produces higher WTW emission intensity compared with fossil diesel fuel due to its high DLUC emissions. Currently in 2024, electrification is still ineffective in reducing emissions of small trucks. In small and large categories, FCET produced the lowest WTW emission intensity in 2024 with 24.10 and 6.98 g CO_2e/ton-km. The highest emission intensities with are produced by biodiesel trucks with 284.71 and 213.27 g CO_2e/ton-km in small and large models, respectively.

BETs produce the second lowest emission intensity in 2024 with 191.14 and 24.10 g CO_2e/ton-km in small and large models, respectively. Assuming increasing energy efficiency and decreasing power grid emission factor in the future, WTW emission intensity of BETs will drop significantly to 25.64 and 15.43 g CO_2e/ton-km. This result depends highly on renewable mix increase in Indonesian power grid.

Figure 16. Projection of WTW GHG emissions of small diesel, B35 biodiesel, battery electric, and fuel cell electric truck models until 2050

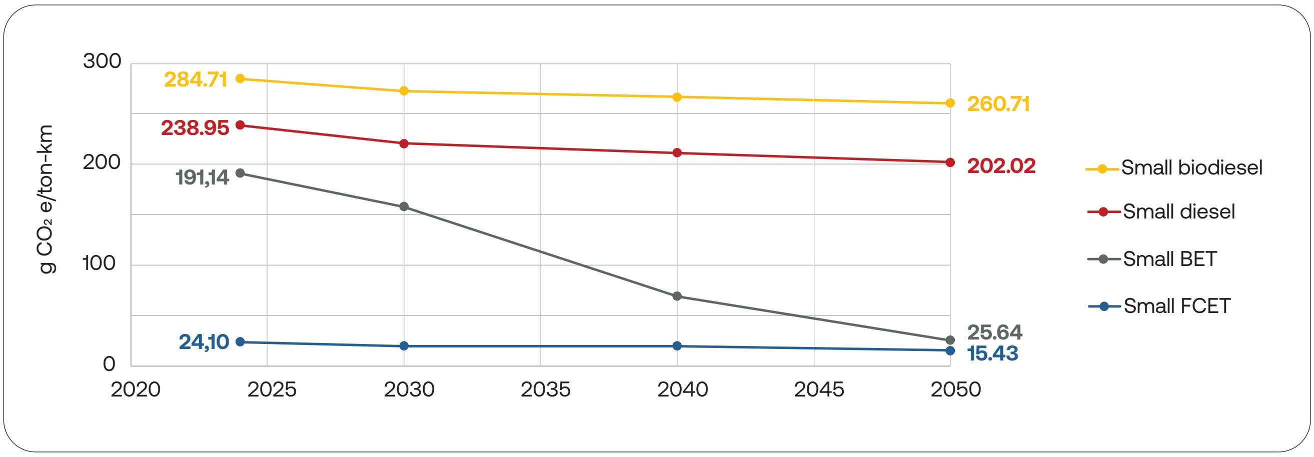
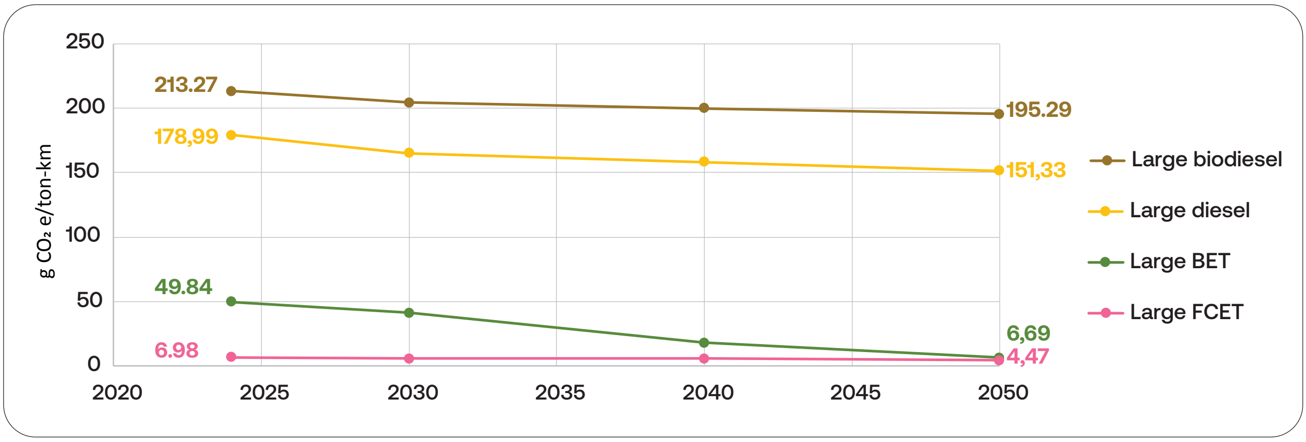


Figure 17. Projection of WTW GHG emissions of large diesel, B35 biodiesel, battery electric, and fuel cell electric truck models until 2050



The total cost of ownership of trucks purchased in 2024 is compared among the technologies. In the small category, a BET still costs slightly higher than a diesel truck. In the large category, a BET has already achieved its TCO parity with diesel and biodiesel. In both categories, FCETs still cost much higher than the other technologies.

Figure 18. TCO without tax and subsidy 10 years of operation

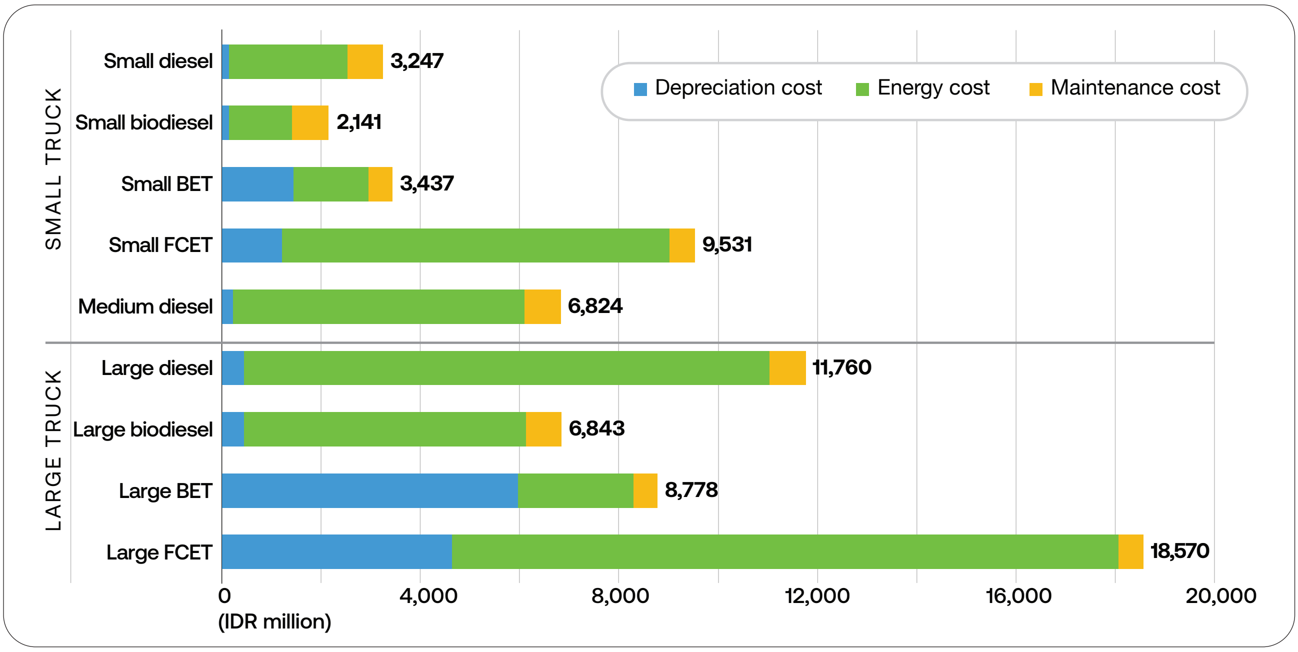


Table 15. Current TCO of various diesel, battery electric, and fuel cell electric trucks

Category	Technology	Off-the-road price (IDR million)	Depot charger upfront cost (IDR million)	TCO (IDR million)			
				Depreciation cost	Energy cost	Maintenance cost	Total
Small	Biodiesel B35	192		146.08	1,275.00	720.66	2,141.75
	Diesel	192		146.08	2,381.25	720.66	3,248.00
	BET	974	703.33	1,444.39	1,509.97	493.40	3,437.76
	FCET	1,597.37		1,215.35	7,810.95	505.57	9,531.87
Large	Biodiesel B35	600		456.50	5,666.67	720.66	6,843.84
	Diesel	600		456.50	10,583.33	720.66	11,760.50
	BET	6,907.10	703.33	5,958.54	2,336.23	483.40	8,778.17
	FCET	6,908.61		4,640.07	13,425.29	505.57	18,570.93

Figure 19. TCO projection of small diesel, battery electric, and fuel cell electric trucks until 2050

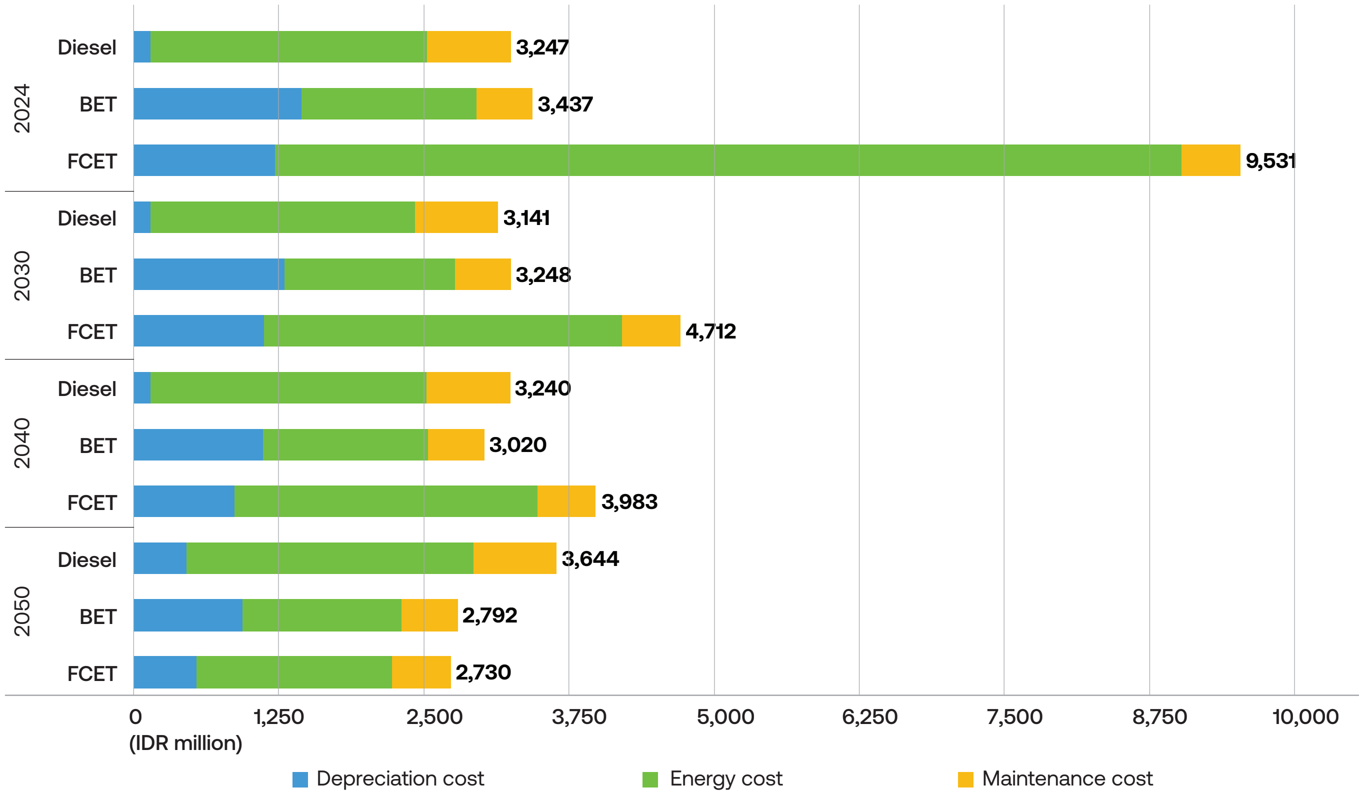
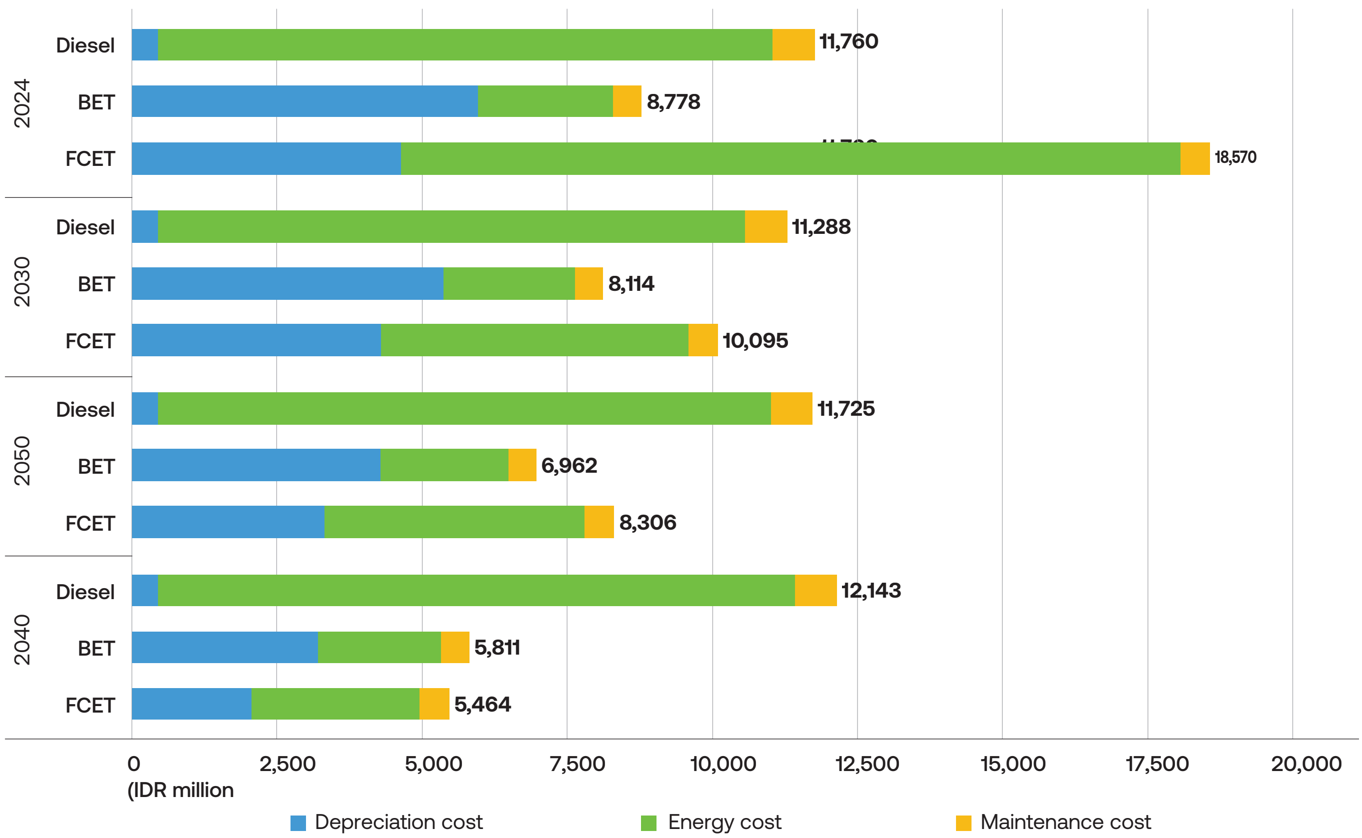


Figure 20. TCO projection of large diesel, battery electric, and fuel cell electric trucks until 2050



With all costs discounted to 2024 rupiah value, TCO of trucks is projected until 2050. It assumes constant price for diesel truck. Prices of BET and FCET are assumed to follow price decline trend from ICCT's Chinese study. In 2050, prices of a BET and an FCET are expected to decline by 49.7% and 37.8% of their current prices. For the FCET, according to ERIA's study[22], green hydrogen production cost using solar PV electrolyzer in Indonesia will decline by 66.3% in 2050. However, this does not include the distribution cost and other supporting infrastructure.

In the small category, BET will achieve its TCO parity with diesel truck in 2040, while FCET will follow by 2050. In the large category, FCET will achieve its TCO parity with diesel truck in 2030, following BET which has achieved it earlier in 2024. However, this favorable result for FCET depends highly on the hydrogen price in Indonesia, especially the development of its distribution infrastructure. Moreover, FCET has not reached market viability, particularly in Indonesia. On the other hand, BET already entered Indonesian market with charging infrastructure already available. Decarbonization could start with setting targets for BET uptake for certain industries, complemented with incentives such as tax exemptions.

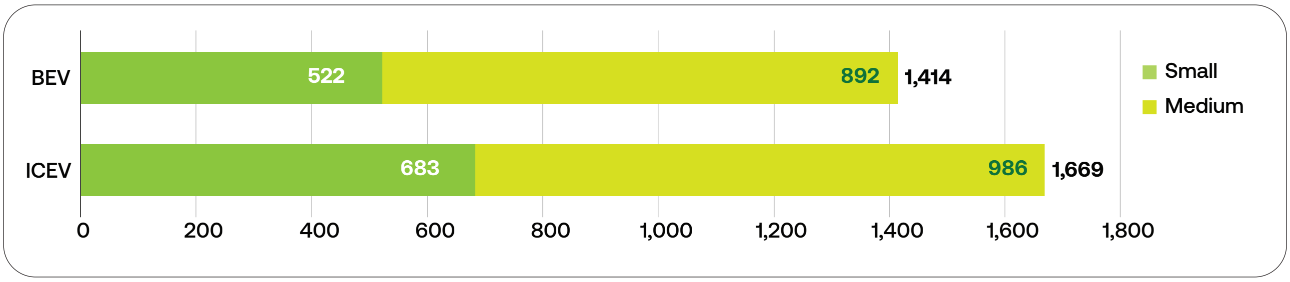
1.5 CONSUMER COST TO ACHIEVE NATIONAL TARGET OF BEV SALES

Based on NZE Roadmap, the Government of Indonesia has set a target to achieve 2 million units of BEV by 2030. Total BEV sales during the 2019–2023 period were only 28,188 units[23]. This means there are 1.97 million BEV units left to achieve the 2030 target or on average 184.9 thousand units per year from 2024 until 2030.

Assuming annual sales consist of 50% small and 50% medium-sized cars, the total consumer costs are calculated to achieve 2 million units of BEV in 2030. The cost is calculated by adding upfront costs (purchase price and, for BEVs, charger installation costs) and operating and maintenance costs from the vehicle's purchase year until 2030. The cost reduction projected in the previous section is also considered.

In total, small BEVs will cost IDR 522 trillion, while medium BEVs will require IDR 892 trillion by 2030. A similar calculation is also done to achieve the same number of ICEV sales by 2030. The result shows that small ICEVs will cost IDR 683 trillion, while medium ICEVs will require IDR 986 trillion. In total, the cost for BEV cars (IDR 1,415 trillion) is 15.2% lower than for ICEVs (IDR 1,669 trillion).

Figure 21. Total user's upfront investment and O&M costs to achieve 2 million units of BEV vs ICEV in 2023–2030



CHARGING INFRASTRUCTURE

Table 16 below shows the financial model of a 25-kW commercial EV charging station, which calculates cost, revenue, and profit of its yearly operation.The unit and installation upfront cost shown here is the price published by PLN to open an EV charging franchise in 2022. Another part of the upfront cost is the land cost for 42 m^2 area in Jakarta. Total upfront cost is IDR 1.4 billion or IDR 88.58 million per year for 30 years of operation.

22 Rusli, R.D., Purwanto, A.J., Setyawati, C.E.N., Elsye, V., Bhaskara, R.W., & Pranindita, N. (2024), 'Hydrogen Economics for Southeast Asian Industries' in Purwanto, A.J. and R.D.Rusli (eds.) Hydrogen Demand and Supply in ASEAN's Industry Sector. Jakarta: ERIA, pp. 132-145.
23 Gaikindo. (2024). Indonesian Automobile Industry Data. https://www.gaikindo.or.id/indonesian-automobile-industry-data/

The electricity cost is calculated to serve an equivalent of one-year charging for 10 units of E2W and 20 units of BEV. The total annual charging consumption is 459.7 MWh which costs IDR 513.37 million, while operational & maintenance costs are assumed to be 10% of the electricity cost. The resell electricity price is IDR 2,466.78/kWh which generates IDR 2.1 billion revenue per year. Estimated annual profit will be IDR 480.74 million.

Table 16. Costs and revenue for 25 kW commercial electric vehicle charging station

1. UPFRONT COST			
Unit & installation upfront cost (25 kW outdoor)	389,000,000	IDR	PLN franchise
Annualised charger cost	33,774,952	IDR	15-year lifetime
Land cost (42 m^2 - DKI Jakarta)	1,008,000,000	IDR	IDR 24 million per m2 - DKI Jakarta median price
Annualised land cost	54,806,302	IDR	30-year
Total upfront costs	**1,397,000,000**	**IDR**	
Total annualised upfront costs	**88,581,254**	**IDR**	
2. ELECTRICITY COST			
Car			
No. EV cars served per charger	20	units	1:20 ratio
Annual mileage per EV car	10,000	km	ICCT (2023)
Fuel economy	0.1113	kWh/km	Wuling Air ev
Annual electricity consumption per EV car	22,250	kWh	
Total annual charging consumption for 1 charger	459,720	kWh	
Electricity price bought from PLN	1,116.71	IDR/kWh	
Total annual electricity cost for 1 charger	**496,935,950**	**IDR**	
Total annual other variable O&M costs	**49,693,595**	**IDR**	**10% of electricity cost per year**
3. REVENUE			
Electricity selling price	2,466.78	IDR/kWh	
Total annual revenue	**1,097,717,100**	**IDR**	
4. PROFIT			
Total annual profit	**462,506,301**	**IDR**	

In support of the increasing BEV population, charging infrastructure should be developed much faster than the current rate. Assuming one charging station serves 20 BEV cars, a total of 100,000 charging stations will need to be built by 2030. This is equivalent to 16,666 per year during 2025 until 2030 period. The total investment cost required is IDR2024 139.7 trillion.

Table 17. Total upfront investment costs for charging infrastructure until 2030

Target of BEV car units in 2030	**2 million**
Assumed BEV car-to-charging station ratio	**20 : 1**
Number of charging stations required tobuild per year until 2030	**16,666**
Total upfront investment until 2030	**IDR 139.7 trillion**

Industrial Process Heating Sector

2. Industrial Process Heating Sector

Industry sectors accounted for 45% of the total final energy consumption in Indonesia in 2023. The energy consumption is currently dominated by fossil fuels, with coal, natural gas, and oil fuels (incl. LPG) taking up around 57%, 21%, and 5% respectively, and the remaining consumption covered by industrial biomass (4%) and electricity (12%) (MEMR, 2024*a*).

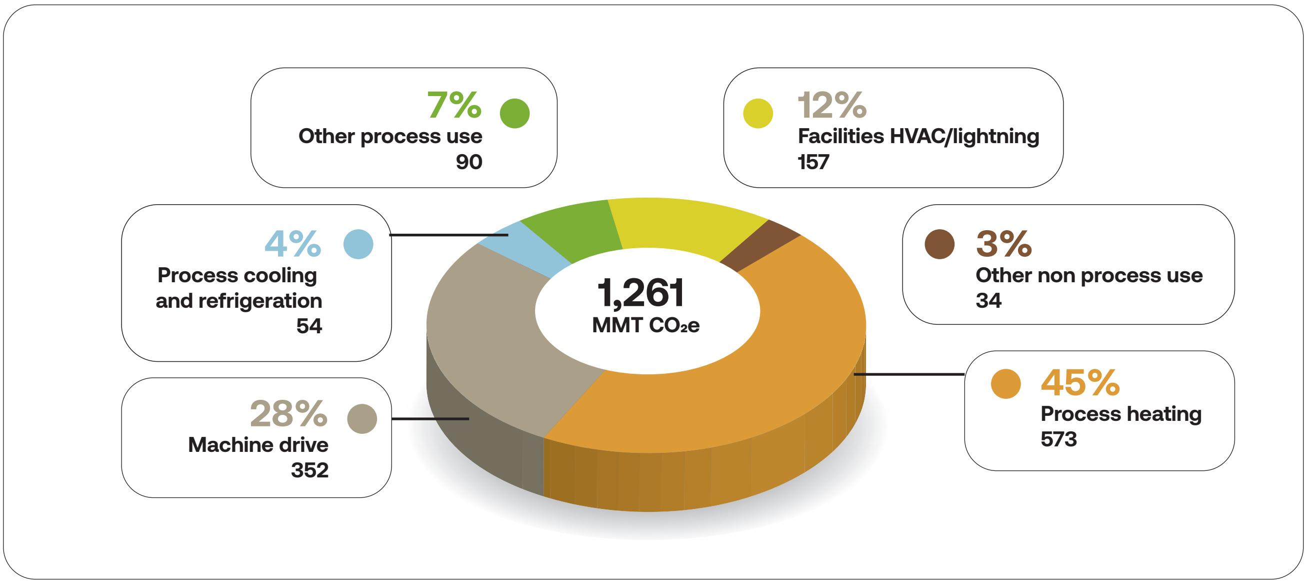
The industry sectors are expected to be a key element in the economic growth of Indonesia, and energy demand is therefor expected to increase significantly in both short and long term, whereby decarbonization efforts are important to meet the declared target of reaching net zero emission by 2060.

The energy consumption in industry primarily serves two key needs:

1. **Process heating:** is split between direct heating and indirect heating. Direct heating processes across most sectors heavily depend on fossil fuels, especially for high-temperature operations above 500°C, where low-carbon alternatives remain limited. In contrast, indirect heating, also predominantly fossil-fuel-based, offers greater potential for electrification, particularly if renewable energy sources are integrated into the electricity supply (Rightor et.al, 2022). As an example, Figure 2 shows how most of the energy demand in the food and beverage sector can be met by indirect heating below 130 °C, based on a series of energy audits.

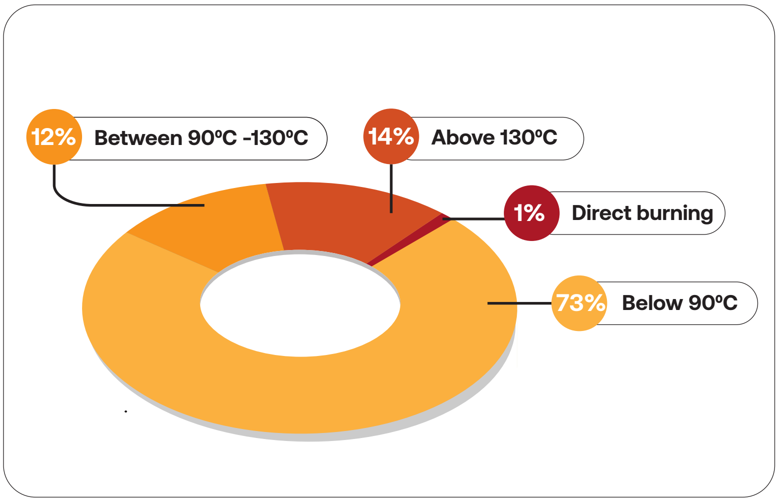
2. **Machine drives**: electricity is used to power machine drives, which are systems that convert electrical energy into mechanical energy to power machines and equipment. They typically consists of a motor, control systems, and associated mechanical components to regulate speed, torque, and direction of movement. Machine drives are primarily electric motors, pumps, and fans (EIA, 2013).

Figure 22 : Process heating and machine drives generally account for the majority of energy-related emissions in the industry sector, as observed for the case of the US based on extensive surveys (US Department of Energy, 2022).



This report primarily focuses on process heating to demonstrate the potential of electrifying the industrial sector in an effort to reduce reliance on fossil fuels. This section, therefore, examines how different technologies within the sector interact and evaluates them in comparison to electrification options. Electrification would enable industry to capture cost savings as electricity prices decrease with the integration of more renewables into the grid and on potential future avoided CO_2 taxes. In turn, this shift also results in CO_2 reductions, enhancing the industry's potential for GHG mitigation (McKinsey, 2024). This raises the opportunity for policy makers to support plans to adopt electric technologies.

Figure 23. Example of observed process heating temperature requirements in selected enterprises within the food and beverage sector in Indonesia. (INDODEPP, 2023).



2.1 Process Heating: Decarbonization Technology Descriptions

This report provides an overview of various heating technologies used in industrial and commercial applications, highlighting their operational principles and energy efficiencies. It covers heat pumps, electric boilers, biomass boilers, coal boilers, oil boilers, natural gas boilers, natural gas condensing boilers, and biomass condensing boilers. Each technology is examined in terms of its description, energy efficiency, and CO_2-emissions, offering insights into their effectiveness as heat sources in different temperature ranges and operational contexts. This comparative analysis serves as a resource for understanding the options available for achieving efficient and sustainable process heating solutions.

There is a chance to electrify heating process within a lower temperature range, below 100°C and a large share of medium temperature processes between 100°C to 500°C, especially in sub sectors such as chemical, petrochemicals, food and beverages, tobacco, machinery and transport manufacturing as well other industry (agriculture, mining and construction) (Hasanbeigi et.al, 2021). Higher temperature heat required for sectors such as cement and steel production is much more difficult to electrify with currently available technology and therefore continues to rely heavily on combustion of fossil fuels, which then leads to significant greenhouse gas emissions. Transitioning to low-carbon alternatives, such as electric or renewable energy-based heat sources, can help mitigate these emissions while supporting the industry's energy demands (Gross and Mai, 2021).To assess the cost of producing heat across different technologies, we conducted a Levelized Cost of Heating (LCOH) analysis, to analyze the average cost of heat generation per unit of heat supplied. To ensure clarity in comparing these technologies, the following tables provide descriptions and technical data, including cost and efficiency information where available. The LCOH analysis is then represented in subsequent sections.

The technology descriptions and data have been collected by combining information from international and domestic sources such as the Danish technology catalogue for industry process heat (Danish Energy Agency, 2024), desk research and stakeholder consultations via organized workshops and individual interviews. Stakeholders include experts within energy efficiency in industry sectors and knowledge from performed energy audits, as well as industry associations, think tanks and academia. The resulting data is therefore an estimate of the expected status of process heating technologies in Indonesia formed by a broad view across the various inputs. Priority has been given to inputs from Indonesian experts, and where no clear data has been available specifically for Indonesia, (Danish Energy Agency, 2024) has been used as reference. This especially for technologies not commonly deployed in Indonesia (heat pumps and condensing boilers) and expected future development trends.

Compressor driven heat pumps

Technology description	• A compressor driven heat pump draws heat from a heat source (input heat) and converts it to a higher temperature (output heat) using electricity. Utilizing the energy available in the heat source, the need for electricity compared to the heat output is low, making the heat pump very efficient compared to conventional boilers. • Heat Pumps have very high efficiency and no direct emissions but are also more dependent on the specific process they are integrated in, compared to conventional boilers. • Heat Pumps are not currently considered a widely common technology in Indonesia, but is proven and commercially available for lower temperature heating up to 90 °C. Due to significant development in recent years, various types of heat pumps are now available to deliver heat up to 150 °C. • Heat pumps are best suited to deliver hot water, but there are available options to deliver steam as well, although generally with lower efficiency and higher costs. • Heat pumps can also be utilized for cooling which is co-generated with the heat, providing a broader range of functionalities and potential for reducing the cooling need within an industrial facility. This is again dependent on the specific industrial processes and not covered further in this study. • Heat pumps are expected to improve in the future as a function of the technology maturing and getting deployed more widely leading to learning effects and reduced costs, as well as improved technical performance. • Further descriptions and overview of available heat pump technologies can be found in (Danish Energy Agency, 2024) and (Sawe et. al, 2024).
Energy efficiency	• The efficiency of a heat pump is described with a Coefficient of Performance (COP) which is expressed as the useful heat output divided by the electricity used. The COP is primarily defined by the difference between the heat source (where the heat pump extracts heat) and the heat sink (where the heat is delivered. The lower the temperature difference is, the higher the COP, and vice versa. The temperature difference is often referred to as the temperature lift the heat pump has to deliver. • Heat pump COPs are typically in the range of 3-4 when delivering low temperature heat (70-80 °C supply) – which can be considered the same as 300-400% efficiency compared to other heating technologies. • COPs will range depending on the temperature lift, from around 2.0 if delivering up to 150 °C to above 5 for lower than 30 °C. The actual heat delivery that can be reached depends on the heat source temperature. • For the purpose of this study, two archetypes of heat pumps for different applications are chosen. • Low temperature: utilizing a source at 30 °C (e.g., low temperature water or ambient air) and delivering hot water at 80 °C, resulting in a COP of 3.83 • Medium temperature: utilizing a heat source at 80 °C (e.g. internal waste heat or other cooling water) and delivering hot water at up to 150 °C, resulting in a COP of 2.95. • In both cases, technology improvements are expected leading to COP values in 2050 of 4.07 and 3.20 respectively.

Electric Boilers

Technology description	• Electric boilers are simply pressurized vessels which rely on resistance elements that are affixed inside the boiler to heat the water and create steam or domestic hot water. Electric boilers have no built in complex components and are therefore very dependable and easy to maintain, electricity prices thus constitute the major part of the operational costs.
Energy efficiency	• Conversion from electrical energy to thermal energy takes place at almost 99-100 % efficiency

Biomass Boilers

Technology description	• Biomass boilers are a renewable energy technology that use organic materials—such as wood, agricultural residues, or dedicated energy crops—to generate heat or steam for industrial processes. Due to the nature of the fuel and combustion, there is a higher need for ongoing maintenance compared with gas fired or electric boilers. • Unlike fossil fuel boilers, biomass systems rely on carbon-neutral fuel sources, assuming the carbon dioxide released during combustion is balanced by the carbon absorbed during the growth of the biomass.
Energy efficiency	Conversion to thermal energy takes place at around 82%-85% efficiency

Coal Boilers

Technology description	• A coal boiler burns coal in a furnace to generate heat, producing steam or hot water for heating or power. Key components include the furnace, heat exchanger, and flue gas system, which manage combustion and heat transfer. The system often features devices like economizers and air preheaters to enhance efficiency in larger units.
Energy efficiency	Conversion to thermal energy takes place at almost 86%-90% efficiency

Oil Boilers

Technology description	• An oil boiler burns oil to generate heat, producing steam or hot water for heating purposes. Key components include the burner, heat exchanger, and flue gas system, which handle combustion and heat transfer. Oil is fed into the burner, where it is atomized and ignited. The heat generated is transferred to water or steam in the heat exchanger. Oil boilers are efficient but can have environmental impacts due to emissions and oil consumption.
Energy efficiency	Conversion to thermal energy takes place at almost 87%-90% efficiency

Natural Gas Boilers

Technology description	• A natural gas boiler burns natural gas to produce heat, generating steam or hot water for heating. Key components include the burner, heat exchanger, and flue gas system, which manage combustion and heat transfer. Natural gas is ignited in the burner, and the resulting heat is transferred to water or steam. These boilers are known for their efficiency and lower emissions compared to coal or oil boilers. They are commonly used due to their relatively clean operation and ease of use.
Energy efficiency	• Conversion to thermal energy takes place at 87%-90% efficiency

Natural Gas Condensing Boilers

Technology description	• Condensing gas boilers are high-efficiency heating systems that extract maximum heat from combustion by condensing water vapor present in the exhaust gases. They thereby achieve efficiencies over 100% (based on the lower heating value of the fuel) and typically feature two heat exchangers and modulating burners. Their compact design and ability to lower energy bills make them environmentally friendly options industrial applications. • While installation costs may be higher (in the European market only around 10%) than non-condensing ones, the long-term energy savings and reduced greenhouse gas emissions often offset this expense. Regular maintenance is essential due to the acidic condensate produced during operation.
Energy efficiency	Conversion to thermal energy typically takes place at 101-103% efficiency

Biomass Condensing Boilers

Technology description	• Biomass condensing boilers are high-efficiency heating systems that use renewable biomass fuels, such as wood pellets or chips, to produce heat. They operate similarly to gas condensing boilers, capturing heat from the combustion process and condensing water vapor in the exhaust to achieve efficiencies exceeding 100%.. Although their initial costs may be higher than traditional systems (in the European market only around 10%), the long-term savings and sustainability benefits often justify the investment.
Energy efficiency	• The conversion efficiency is approximately 116% to 120%. • However, it's important to clarify that this efficiency can vary significantly depending on the type of biomass used, as different biomass materials have different moisture contents and energy densities. The stated efficiency values are based on the lower heating value (LHV) of wood chips with a water content of 50%, which accounts for the energy content available for useful work.

Table 18 summarises the costs, efficiencies and representative capacities of the described technologies, both current and future development used for the LCOH analysis.

Table 18. Summary of financial and technical data for heating technology options in the industry sector

Variable	Year	HeatPump Low temp	Heat Pump Medium temp	Electric Boiler	Biomass Boiler	Coal Boiler	Oil Boiler	Gas Boiler	Gas Cond.	Biomass Cond.
Investment M$2022 / MWth	2020	0.60	1.26	0.19	0.12	0.20	0.04	0.04	0.05	0.13
	2030	0.54	1.13	0.16	0.11	0.20	0.04	0.04	0.05	0.12
	2040	0.51	1.08	0.16	0.11	0.20	0.04	0.04	0.05	0.12
	2050	0.49	1.02	0.16	0.10	0.20	0.04	0.04	0.05	0.11
Fixed O&M 1000$2022 /MWth/ year	2020	2.4	1.18	1.3	40.6	40.6	2.17	2.4	2.4	44.6
	2030	2.4	1.06	1.25	40.6	39.3	2.05	2.3	2.3	40.6
	2040	2.4	1.03	1.18	40.6	38.1	1.93	2.2	2.18	40.6
	2050	2.4	1.01	1.11	40.6	36.9	1.81	2.05	2.05	40.6
Variable O&M $2022 / MWhth	2020	3.9	3.9	1.0	3.3	2.3	1.2	1.3	1.3	3.3
	2030	3.9	3.9	1.0	3.4	2.3	1.1	1.2	1.2	3.4
	2040	3.8	3.8	1.0	3.4	2.3	1.1	1.2	1.7	3.4
	2050	3.8	3.8	1.0	3.4	2.3	1.1	1.2	2.2	3.4
Efficiency %	2020	383%	295%	98%	82%	86%	87%	87%	101%	116%
	2030	395%	305%	98%	82%	86%	87%	87%	103%	116%
	2040	403%	315%	98%	82%	86%	87%	87%	103%	116%
	2050	407%	320%	98%	82%	86%	87%	87%	103%	116%
Capacity MW		3	3	1,5	20	20	20	20	20	20

"The industry sectors are expected to be a key element in the economic growth of Indonesia, and energy demand is therefor expected to increase significantly in both short and long term, whereby decarbonization efforts are important to meet the declared target of reaching net zero emission by 2060."

2.2 Levelized Cost of Heat Analysis

To compare the costs of different heating technologies, the Levelized Cost of Heat (LCOH) is applied as it provides a comprehensive measure of the total cost of a technology over its lifetime. It represents the average cost per unit of heat supplied. The LCOH calculation incorporates both financial and technical data for each technology, including assumptions about operational parameters, cost of capital, and fuel prices. The key components for the LCOH calculation are:

Capital Costs (CAPEX):

- Initial Investment: This includes the cost of purchasing and installing the heating technology, such as equipment, infrastructure, and any necessary modifications to existing systems.
- Financing Costs: Costs related to obtaining capital, including interest and loan repayments, which are influenced by the cost of capital (Weighted Average Cost of Capital, WACC).

Operating and Maintenance Costs (OPEX):

- Fixed O&M: Expressed as a total annual cost, which is independent from the number of operational hours. Covers ongoing expenses for operating the technology, including labor, administration, and regular maintenance.
- Variable O&M: Expressed as a cost per unit of generated heat. Covers costs for periodic repairs, upgrades, and replacements required to ensure the technology remains functional over its lifetime, which depend on the operational hours. This also includes auxiliary materials such as water, lubricants or fuel additives.

Fuel Costs:

- Fuel Price: The cost of the fuel used to generate heat, which can vary based on market conditions, type of fuel, and regional pricing.
- Fuel Consumption: The amount of fuel needed to produce a unit of heat, influencing the overall cost based on fuel efficiency.

Operational Hours:

- The number of hours the technology operates each year, which impacts the total amount of heat produced and the distribution of capital and operating costs.

Lifetime:

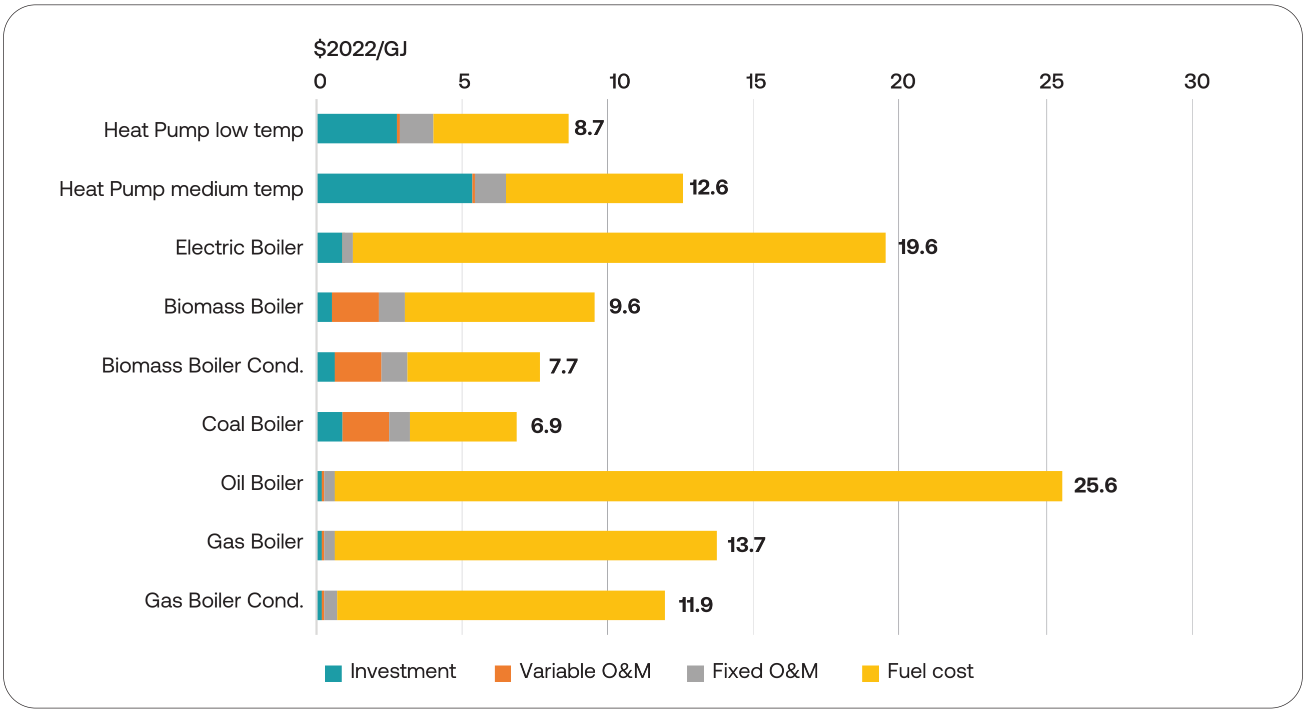
- The total number of years the technology is expected to operate effectively, influencing the amortization of capital costs over time. Can be defined as the maximum technical lifetime, or an economic lifetime typically based on the depreciation period of the investment

The following additional assumptions applied for this LCOH analysis:

- CAPEX and OPEX: Based on the data provided in Table 19.
- Technical Lifetime: 20 years.
- Cost of Capital (WACC): 10% per year.
- Operational Hours: 7,000 hours per year (across all the technologies/equipment analyzed).
- Fuel prices: Based on the average market price majority industrial consumers pay as of September 2024, listed in Table 20 and described in the subsequent section.

The central estimates of LCOH values for the current cost levels can be seen in **Figure 26.**

Figure 24: Levelized cost of heat comparison between technology options for current cost levels.



Coal boilers present the lowest LCOH at $6.9/GJ, mainly due to the low cost of coal. Gas boilers, priced at $13.7/GJ, with fuel costs being the main driver. Oil boilers are the most expensive at $25.6/GJ, where fuel costs dominate, making them less attractive.

Low temperature heat pumps are observed to offer a competitive cost of heat at $8.7/GJ, primarily due to their high efficiency and moderate O&M costs. However, they come with a higher initial investment cost. It is important to note that low temperature heat pumps although bearing this high investment cost, already are as competitive as the coal boiler from an LCOH perspective. Medium temperature heat pumps cost slightly more but are still competitive with conventional gas boilers.

Electric boilers, on the other hand, are significantly more expensive at $19.6/GJ, largely driven by the high cost of electricity, which makes up a major portion of their operating expenses.

Biomass boilers, with a levelized cost of heat (LCOH) of $9.6/GJ, strike a balance between fuel and investment costs. It's important to note that the cost of biomass boilers can vary significantly depending on the type of biomass used, necessitating a sensitivity analysis.

Condensing boilers have significantly lower costs than conventional boilers, indicating that the additional investment costs are outweighed by the reduced fuel costs. However, there is high uncertainty on the investment costs and potential performance of condensing boilers, as they are not commonly used in Indonesia, according to stakeholders. The low LCOH value is depending on additional investment costs being of similar relative size as what is seen in Europe and explained by (Danish Energy Agency, 2024).

Towards 2050, LCOH of heat pumps are expected to decrease by 10-12%, reaching 7.8 $/GJ and 11.0 $/GJ for the low and medium temperature types, as a result of decreased costs and improved efficiency, which is not expected for the other technologies. This development puts heat pumps at lower costs than biomass and natural gas boilers in the long term, indicating the potential savings to be gained through electrification.

In this analysis, a subsidized electricity price is assumed, this affects the competitiveness of electric technologies, while the market price of natural gas influences the cost profile of gas boilers. This pricing context needs to be factored in when comparing these technologies.

2.3 Fuel Costs

The fuel price is a key input to the LCOH estimation and should be considered carefully depending on the objectives of the study. The fuel prices used in this analysis reflect the current level for industrial consumers in Indonesia which is not necessarily a reflection of the full socioeconomic cost of the fuel. Below is an overview of the fuel cost data that has been used in this analysis.

Table 19. Summary of fuel prices for heating technology options in the industry sector. Prices marked in *bold* are used for the central estimates of LCOH. Prices are based on Lower Heating Value of the fuel.

BIOMASS	Price [IDR2022/kg]	Energy content [kcal/kg]	Price [USD2022/GJ]
Wood Pellet	1,800	4,200	6.4
Palm Oil Shell	1,650	3,825	6.4
Wood Chip	**1,450**	**4,075**	**5.3**
Rice Husk	610	3,200	2.8
NATURAL GAS	**Price [USD2022/MMBtu]**	**Conversion [$MMBtu_{LHV}/MWh_{LHV}$]**	**Price [USD2022/GJ]**
CNG regulated price	6	3.41	5.7
CNG market price	**12**	**3.41**	**11.4**
LNG price	18	3.41	17.1
DIESEL	**Price [IDR2022/L]**	**Energy content [kWh/L]**	**Price [USD2022/GJ]**
Market Price	13,400	10.70	21.7
COAL	**Price [USD2022/ton]**	**Energy content [kcal/kg]**	**Price [USD2022/GJ]**
Reference	125	6,322	4.7
HBA I	90	5,300	4.1
HBA II	**55**	**4,100**	**3.2**
HBA III	35	3,400	2.5
ELECTRICITY	**Price [$IDR2022/kWh_{el}$]**	**Conversion [GJ/MWh]**	**Price [USD2022/GJ]**
PLN Tariff (subsidised)	**1,035**	**36**	**18.0**
PLN tariff (non-subsidised)	1,700	3.6	29.5

Coal

Coal prices vary based on market conditions and coal types are typically categorized based on calorific value as well as other properties such as moisture, ash and sulfur content. In Indonesia a wide range of coal types are available. The analysis uses the official prices published in the Harga Batubara Acuan (HBA) index, which is used to determine the benchmark price of coal based on quality and market conditions (MEMR, 2024*b*). The analysis use the prices as of September 2024, but the different indexes have been stable and the lower calorific value coals generally fluctuate less than higher calorific value coal types traded for export.

These different grades are used depending on the energy needs and cost considerations of the industrial sector, but in this context, it is assumed that the coal type of HBAII with calorific value of 4100 kcal/kg is the most frequently used.

Natural gas

Natural gas is generally transported and delivered as CNG (Compressed Natural Gas). or LNG (Liquefied Natural Gas). CNG is cheaper and is primarily transported via pipelines, making it more suitable for domestic and industrial use in areas where pipelines are available. LNG tends to be more expensive due to the additional costs associated with its liquefaction, transportation, and regasification processes, and international market prices for LNG tend to fluctuate to a higher extent.

Presidential Regulation No. 121 of 2020 amends the previous regulation on natural gas pricing in Indonesia that sets a cap of 6 USD/MMBtu for certain industries, including fertilizer, petrochemical, steel, ceramics, and others. However, it is a smaller share of industries that are actually eligible for the capped price.

Customers using CNG from the domestic grid pay a tariff set by PGN depending on the size of the connection and annual usage. The costs for most industries are close to 12 USD/MMBtu, which is considered the central estimate in this analysis.

LNG is an option for industries without access to the main gas grid, but costs are generally higher and difficult to assess due to market fluctuations. International market prices for LNG in Asia have been as low as 6 USD/MMBtu in September 2020 and high as 24 USD/MMBtu in August 2022 (based on monthly averages for import for Japan) (World Bank, 2024). For this analysis, a price estimate of 18 USD/MMBtu is used based on the average prices over 2022-2024 as well as accounting for costs for regasification.

Oil

Industrial Diesel Oil (IDO) is widely utilized across various industries due to its effective performance in heavy-duty engines and machinery. IDO is characterized as a low-sulfur diesel fuel, which promotes cleaner combustion. This makes it a preferred choice in sectors such as construction, agriculture, and manufacturing, where efficiency and reliability are important.

As of September 2024, the price of diesel fuel, including IDO, is around IDR 13,250 per liter, although there are fluctuations based on regional differences in supply and demand (Pertamina, 2024).

Biomass

Biomass prices in Indonesia vary significantly based on the type of biomass, location, and supply chain factors. Common sources include agricultural residues (e.g., rice husks, palm kernel shells) and wood waste. Wood pellets and palm kernel shells (PKS) are generally traded internationally for export, and market prices are available, whereas most other types are traded domestically on bilateral agreements. Transportation and seasonal availability heavily influence these costs, often making biomass less reliable compared to fossil fuels.

Recent trends show increased demand for biomass as industries seek renewable energy solutions, pushing prices upward. However, inconsistent supply chains remain a key challenge for stable pricing.

The assumed prices are based on expected current market prices from local suppliers obtained as part of energy audits and expert consultations. Wood chips are identified as the most common biomass type used for process heating in industry and therefore used as a central estimate, but a sensitivity analysis highlighting the impacts of different biomass prices is provided in a subsequent section.

Electricity

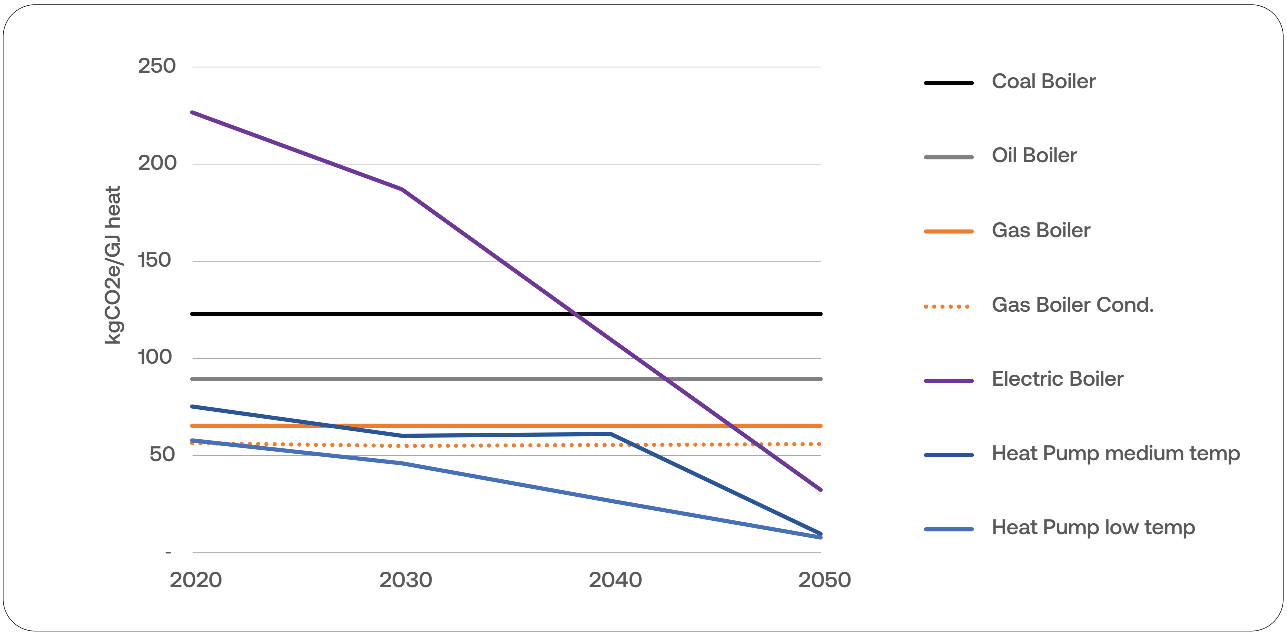
Most industry customers receive a subsidized tariff from PLN depending on the size of the grid connection. The tariff provided by PLN generally includes the regular usage fee but may also include additional charges, such as those incurred when electricity use exceeds 85% of the connected power or related to time of use. However, in this analysis, we use the standard PLN tariffs and do not include these extra charges or other adjustments. The unsubsidized electricity price is based on PLN's official rates for industrial customers as well as the full, unsubsidized tariff which is closer to the full cost of electricity generation (PLN, 2024):

- Subsidized electricity price of 1,035 IDR/kWh
- Unsubsidized price of 1,700 IDR/kWh

2.4 Process Heating: Emissions Data

Figure 27 shows the CO_2-eq. emissions per unit of heat produced, which are determined by the efficiency of the appliance and the type of fuel used.

Figure 25. Emissions from process heating technology options per unit of heat produced.



The analysis takes into account emission factors from both direct fuel combustion and indirect emissions from the electricity generation, including grid losses, for the heat pumps and electric boilers. Emission assumptions are aligned with the goal of achieving net-zero emissions by 2060, using the same assumptions of future development as in the transport chapter (ICCT, 2023).

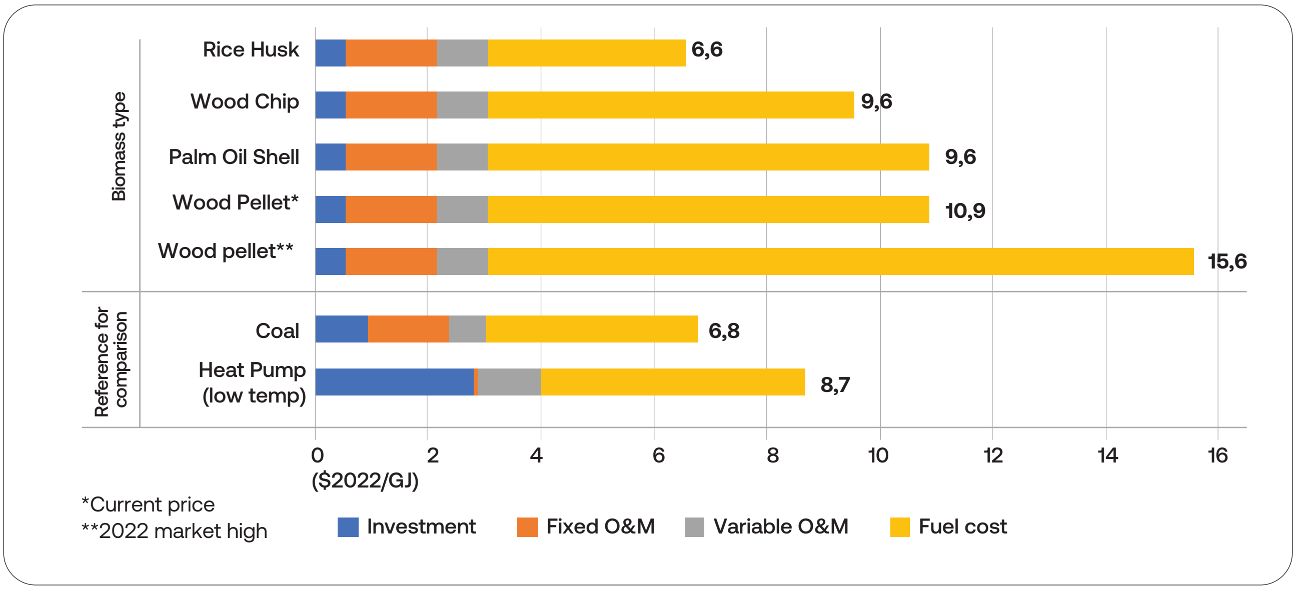
For conventional boilers, both efficiency and emissions remain relatively consistent due to the maturity of the technology and the standardized nature of the fuel sources. In contrast, emissions from electric heating technologies are expected to decline over time as the electricity grid becomes fully decarbonized by 2060. Heat pumps, owing to their higher efficiency, result in lower CO_2 emissions compared to electric boilers, which only themselves reach lower emissions than fossil fuels in the long term.

It should be noted that only emissions from the combustion of fossil fuels are included in the analysis; upstream emissions from extraction, treatment, methane leakage, etc., are not considered. Biomass is assumed to be emission-free, as accounted for in official statistics, and emissions from land use associated with biomass are not included.

2.5 Sensitivity Analysis: fuel costs

Fuel prices have a strong influence on the LCOH of various heating technologies. A sensitivity analysis on gas and biomass prices in heating appliances has been conducted as gas and biomass serve as significant energy sources for industrial heating, making it essential to understand how fluctuations in their prices impact the Levelized Cost of Heat.

Figure 26. Impact of biomass costs on LCOH with market prices



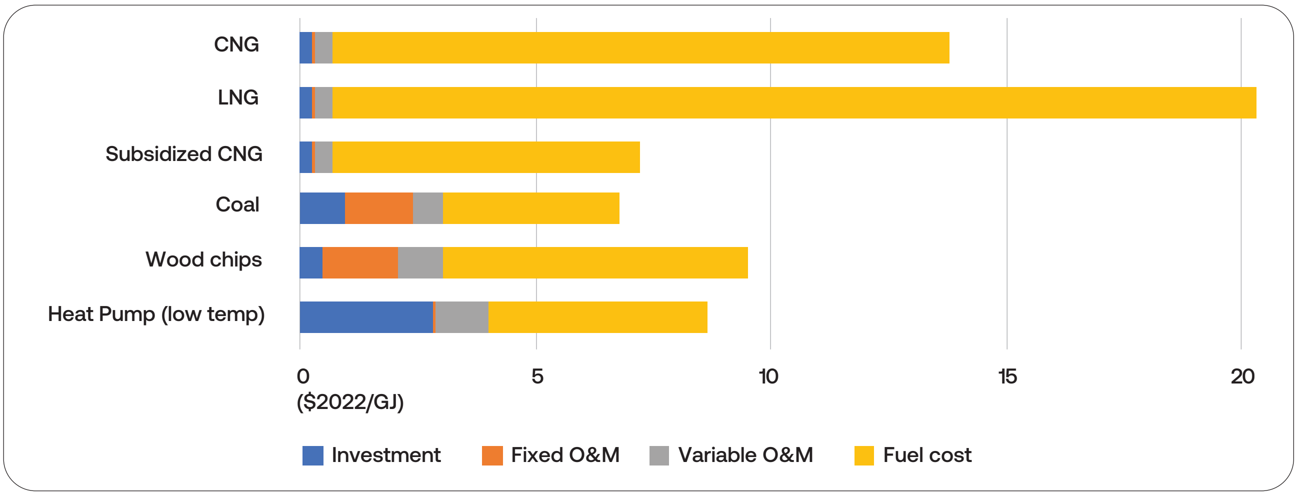
Fuel costs represent the largest component of the Levelized Cost of Heat (LCOH), making their evaluation crucial. Biomass prices can fluctuate significantly based on the type of biomass and market conditions, which in turn affects the LCOH. For instance, prices can range from approximately 600 Rp/kg for agricultural waste, such as rice husks, to around 2800 Rp/kg for wood pellets in the international market, particularly at the high levels observed at the end of 2022 for exports to South Korea and Japan.

While cheaper biomass options can make the LCOH competitive, their availability is often limited and typically requires local sourcing. Furthermore, it is anticipated that biomass prices will rise in the future due to increasing demand and constrained resource availability. Stricter sustainability requirements may also influence these costs.

Natural Gas price

Similarly, the LCOH for gas boilers can vary widely depending on the source of gas. Access to subsidized pipeline gas, priced at $6 per MMBtu, can reduce the LCOH to as low as $7 per GJ, making it competitive with coal. In contrast, using unsubsidized pipeline gas or liquefied natural gas (LNG) can lead to costs ranging from $14 to $20 per GJ, making it significantly more expensive than biomass or heat pumps. This shows that the pricing policy on natural gas can be an important driver or barrier for the deployment of lower emission heating technologies.

Figure 27. Impact of natural gas costs on LCOH.



2.6 Sensitivity Analyses

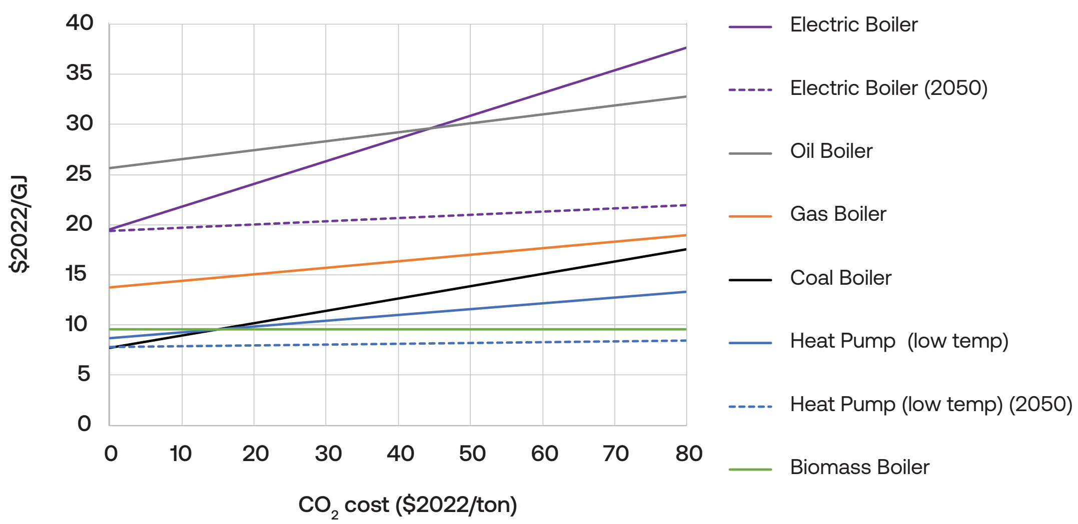
The potential cost of CO_2 emissions can significantly impact the Levelized Cost of Heat (LCOH) for different technologies as indicated in Figure 29. A CO_2 cost, which can reflect a potential future carbon tax or emissions trading scheme or as a proxy for other types of policies aimed at reducing emissions.

At CO_2 costs exceeding $15 per ton, condensing biomass boilers and heat pumps become competitive with coal boilers. As CO_2 costs increase, the competitive advantage of coal and gas boilers diminishes further. With electricity generation currently being based on high shares of fossil fuels, heat pumps and electric boilers are also impacted by CO2 costs, but low temperature heat pumps are still competitive with coal and gas due to their high efficiency. Electric boilers, however, see sharp increases in costs due to the high emissions factors.

Over time, as the emission intensity of electricity generation decreases, the effect of CO_2 costs on the LCOH of electric boilers and heat pumps will also decrease and become almost negligible in the long term. This also indicated Electric boilers become competitive against coal and gas boilers in the long term when the CO_2 cost exceeds $100 per ton.

Given the general assumptions on the LCOH calculations, the impact of potential CO_2 costs highlights the robustness of heat pumps and biomass boilers against coal and gas boilers, which shows the potential for decarbonization at effective cost levels.

Figure 28. Impact of CO_2 costs on LCOH.



2.7 Other Considerations and limitations of the analysis

The analysis of heating technologies involves several important considerations that extend beyond the straightforward calculation of the Levelized Cost of Heat (LCOH). While LCOH serves as a valuable metric for evaluating the economic viability of different heating options, it does not account for various factors that can significantly influence decision-making. These factors include sunk costs, system costs, and socio-economic costs associated with energy transitions. By examining these elements, a more comprehensive understanding of the economic implications of adopting new heating technologies can be achieved.

- **Sunk costs when replacing existing heating units**
  This analysis aims to determine the most effective technology when selecting between two new appliances, under the assumption that the existing one has reached the end of its economic lifetime. However, this scenario is not always reflective of real-world conditions. To facilitate the energy transition, it may be necessary to replace operational boilers that still possess remaining service life.

  For instance, consider the case of replacing a coal boiler that is halfway through its 20-year lifetime (after 10 years) with a new heat pump, which also has a 20-year expected lifespan. The annualized investment cost of the coal boiler is $1.0/GJ. Since the boiler is being retired early, $0.5/GJ of that investment cost should be added to the heat pump's investment for the first 10 years, or $0.25/GJ if the cost is distributed over the entire 20-year lifespan of the heat pump. This sunk cost increases the levelized cost of heat (LCOH) for the heat pump, resulting in a higher total cost per ton of CO_2 avoided.

  In summary, when replacing an existing coal boiler that still has remaining service life, it is essential to consider the early retirement of the boiler. The remaining value of the coal boiler's investment cost should be treated as a sunk cost and factored into the calculations for determining the additional cost per ton of CO2 avoided.

- **System costs**
  The LCOH analysis has some limitations. It primarily focuses on the costs of heat generation, neglecting infrastructure investments necessary to integrate new technologies into existing energy systems. For example, transitioning from fossil fuel-based heating to renewable solutions like heat pumps may require significant upgrades to the electrical grid, including transmission and distribution networks, to handle increased electricity demand. However, these grid upgrades are generally expected to be covered within the electricity price, though current tariffs, such as those from PLN, may not fully reflect these costs due to ongoing government compensation.

  The analysis also does not account for costs associated with grid connection upgrades at the industry level. If a business needs to increase its connection capacity due to installing heat pumps or electric boilers, this can lead to additional costs, depending on who bears the expense. These costs can vary by case, much like the way residential EV chargers may require upgrades to home electricity systems, as seen in other analyses.

  Moreover, the LCOH analysis does not consider the costs of balancing and storage solutions that might be necessary when relying on self-generated intermittent renewable energy sources like wind or solar. In such cases, additional investments in energy storage or backup generation may be required to ensure a stable heat supply. These costs can significantly affect the overall economic viability of heat pump systems but are not captured in the LCOH calculations, as it is assumed the electricity supply is available from the PLN grid when necessary.

  On the other hand, the analysis does not fully capture the systemic costs associated with gas infrastructure. If gas pipelines are not already in place, the fuel prices used in the analysis may not reflect the full costs of establishing the necessary infrastructure, such as pipelines or LNG receiving terminals (regasification units). These factors could influence the overall economic viability of both gas and renewable-based heating systems.

- **Socio-economic costs**
  Furthermore, the LCOH analysis typically excludes externalities such as environmental impacts and social costs associated with energy transitions. While LCOH is a useful metric for comparing direct economic costs, a more comprehensive evaluation should incorporate these broader considerations to provide a complete picture of the costs and benefits of different heating technologies.

  In summary, while the LCOH analysis is a valuable tool for assessing the cost-effectiveness of heating technologies, it has inherent limitations in its scope. A more holistic approach that includes system costs, infrastructure investments, and externalities is essential for a complete understanding of the economic implications of transitioning to new heating technologies.

2.8 Summary

Based on the short analysis of the different technology options in the previous sections, the following points can be summarized:

- **Industry sectors in Indonesia are responsible for a substantial share of energy demand and emissions**, with process heating accounting for the largest category of consumption. There is significant potential to reduce emissions and enhance energy efficiency using current technologies, particularly for low and medium-temperature heating.

- **Electrification emerges as a viable alternative to fossil fuels** in sectors such as food and beverage, textiles, chemicals, and other manufacturing industries like rubber and plastics.

- **Low-temperature heat pumps are already commercially available and competitive in terms of costs and emissions**, making them an important tool for increasing energy efficiency and lowering emissions.

- **However, the electrification of higher-temperature processes (above 90 °C for hot water and steam) currently involves higher costs** than most alternatives.

- **Despite this, positive developments are anticipated, positioning electrification as a key strategy for decarbonization** as electricity generation evolves toward net-zero emissions.

- **While heat pumps offer long-term cost savings, they necessitate larger upfront investments** compared to other heating technologies.

- **Biomass boilers present a low-cost option for achieving zero emissions**, yet there is considerable uncertainty surrounding fuel costs and availability.

- **It may be beneficial to prioritize biomass use for high-temperature processes** and specialized industries that require direct burning, rather than for low and medium-temperature demands that can be more easily electrified.

- **For continued use of biomass and natural gas, results indicate a significant potential in condensing version of boilers**, which are more efficient and have lower total levelized costs, hence it would be beneficial to increase awareness and availability of the technology more widely.

Residential Building Sector

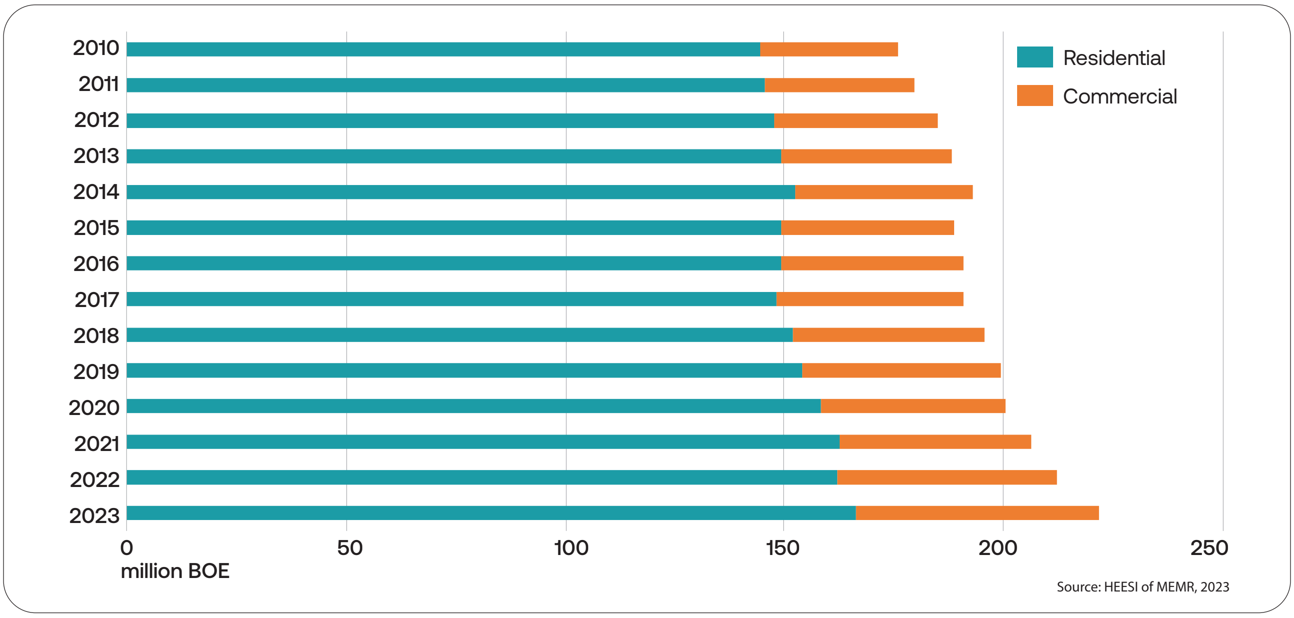
3. Residential Building Sector

This section aims to provide comprehensive information to help stakeholders policy makers understand and evaluate various technologies for energy efficiency, emissions reduction, and overall economic performance of various household appliances. Regulation and compliance information such as standards and certification data have been excluded as they are widely available in other domains including studies by CLASP. Thus the latter can be consulted for further information.

Buildings Energy Consumption and GHG Emissions

The building sector in Indonesia comprises residential and commercial sectors. In 2022, these two sectors contributed 18% to the total final energy consumption in Indonesia. This share could be higher if building premises in the industrial sector are included.

Figure 29. Indonesian Building energy consumption



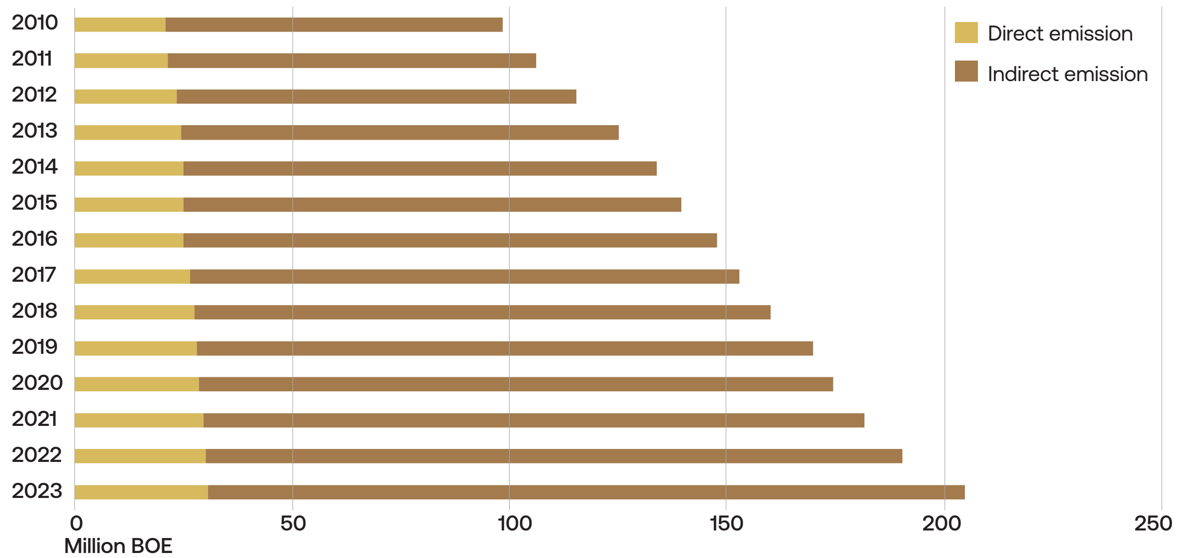
Electricity is the most dominant energy form used in the building sector. It accounted for 60% of total electricity consumption in 2022 (MEMR, 2023). Space cooling, lighting, cooking, water heating, appliances and equipment are the most energy consuming end use sectors. The use of electricity for cooking in Indonesian households is still quite small, less than 1% (BPS Statistic, 2023) compared to other more popular fuels like LPG, natural gas and kerosene. Electricity demand in Indonesia has grown at 5.8% per year between 2010 and 2023, which is much faster than other types of energy used in the building sector (MEMR, 2023).

In line with the increasing GDP per capita, IEA envisages that the residential energy demand in ASEAN countries including Indonesia will rise more than three times, up to 800 TWh in 2040. The shares of that residential energy demand by end use, from the highest are appliances 53%, cooling 25%, cooking 13%, water heating

6% and lighting 3%. Space cooling grows fastest, about three times by 2040 compared to the current demand. According to the MEMR and INDODEPP study in 2022, total building floor area is forecasted to grow to 4% initially then gradually decline to 2% by 2050. Therefore, the need for space air conditioning in the hot and humid climate like Indonesia will increase and push more energy demand for cooling.

Furthermore, buildings are responsible for a significant amount of greenhouse gas (GHG) emissions. GHG emissions from building activities in Indonesia grow at a rate of 5.6% per year or from 99 million tons in 2010 to 205 million tons of CO_2 eq. in 2023. The GHG emissions per unit energy consumed in the building sector increased from 0.56 tons of CO_2/BOE in 2010 to 0.92 tons of CO_2/BOE in 2023. Improving building energy efficiency will directly reduce the amount of energy needed, which can lower greenhouse gas emissions, especially if the energy comes from cleaner sources. Enhanced energy efficiency is a key strategy in reducing the environmental impact of buildings and mitigating climate change.

Figure 30. Building GHG emissions



Source: HEESI of MEMR, 2023

In the building sector, combining advanced building appliance technologies with Minimum Energy Performance Standard (MEPS) policy enables a comprehensive approach to achieving net-zero emissions. MEPS provides the tools to measure, verify, and optimize energy performance, ensuring that the adoption of energy-efficient appliances and systems delivers the expected benefits. By integrating these technologies and strategies, buildings can significantly reduce their energy consumption and carbon footprint, moving towards their net-zero emission targets effectively. The MEMR has published a regulation on MEPS for general appliances and equipment in 2021 (*Peraturan Menteri ESDM No. 14/2021 tentang Penerapan Standar Kinerja Energi Minimum Untuk Peralatan Pemanfaat Energi*) and its derivatives on specific appliances like, LEDs, electric fans, air conditioners, rice cookers, and refrigerators between 2021 and 2023. Manufacturers must ensure these products meet MEPS before they can be sold in the Indonesian market.

A number of building appliances and equipment with different level of technologies, energy efficiencies, cost, energy intensities and emission reduction potentials are presented in the following section of this chapter. The appliances represented in this analysis are those that constitute the highest share of energy consumption in residential households with a combined contribution of more than 90% share of electricity consumption from an estimated range of 42 electrical appliances in households according to the CLASP 2020 Indonesia Residential End Use Survey. Namely; rice cookers, refrigerators, televisions, air conditioners, cooking stoves, lights and water heaters. The aim of this chapter is to provide insight energy efficiency data for these identified appliances and the options within the energy service, cost data and compare the life cycle costs and GHG abatement cost in business as usual scenario compared to a NZE scenario where revision of MEPS is applied.

Cost and GHG Emission Assumptions.

A number of assumptions are made for the cost and GHG emission analyses. These apply to all appliances presented in this chapter for building sector. The general assumptions are the following:

- The typical appliance prices are taken from the Indonesian online markets, e.g. Tokopedia, Shopee, and others.
- The appliance operational data such as usage frequency, lifespan, energy consumption, and others refer to the 2019 CLASP survey results.
- Using Consumer Price Index (CPI) to get the real prices from the nominal prices of the appliances and electricity.
- The electricity price is projected to increase at a rate of 3.6% per year based on the historical data.
- According to Mark Ellis et. al. (2007), the real price of electric appliances has declined 15 - 40% from the base year for twenty years. Therefore, about 30% price reduction is assumed for the No MEPS scenario and 20% price reduction for the MEPS scenario are reasonable values for the future real price projection of the appliances in the building sector.
- Cost Recovery Factor method is applied for annualizing the price to get the capital cost using 10% discount rate and the different appliance lifespans.
- The grid GHG emission factor is taken from ICCT, 2023 study report. The report shows that the Indonesian GHG emission factor will decline from 0.773 in 2022 to 0.114 kg CO_2 eq/kWh in 2050.
- A Net Zero Emissions Scenario by 2060 in the energy sectors has been used in this analysis for illustration purposes. The actual outcome numbers from this analysis are therefore based on the underlying assumptions of this scenario.

3.1 Lighting

Technology and energy efficiency data

The building lighting system in Indonesia still relies on incandescent, CFL and LED lamps. Based on the 2019 CLASP survey on residential lighting, 57% of households already use LED. The rest still use CFL (41%) and incandescent (7%) lamps. It is expected that lamp technologies like incandescent and CFL could be phased out from the market in the near future. The same CLASP survey report also mentions that the average number of lighting operational hours are about 7.4 hours a day in one year.

The efficiency level of lamps is indicated by efficacy value. The efficacy value provides information about how many lumens of light are emitted per unit watt of electricity. LED lamps offer a long operational life and are highly energy efficient. The efficacy of new LEDs continues to rise, it would need to reach about 140 lm/W by 2030 to align with the Net Zero Scenario, which would be around 30% higher than the 2022 average. Indonesia has implemented MEPS policy on lighting, especially on LED (MEMR, 2021 and 2022). The MEPS value that has been set for the LED is no less than 80 lumen/watt. Table 2 shows a comparison of the energy efficiency of LED lamps when compared to CFL and incandescent lamps. LED lamps are 87 – 90% more efficient than incandescent lamps and 45 – 55% more economical than CFL lamps.

Table 20. Wattage comparison among LED, CFL and incandescent based on the same illumination

Illumination (lumen)	LED (watt)	Indandescent (watt)	CFL (watt)
450	4 – 5	40	9 – 13
1,100	9 – 13	75	18 – 25
2,600	25 – 28	150	30 – 55

Source: BPPT, 2012

In the future, it is expected that the operational cost of LEDs will drop significantly due to the latest technology trends in the lighting technology such as *internet of things, wireless lighting among others (Realty, 2023)*[24].

There are a few technologies that have potential to replace the LEDs in the future. One of those promising technologies is laser device (LD) lighting. Although this technology offers some very interesting advantages, it also has challenges. Laser lighting is currently in research and development stage and it is twice as efficient as LED. They are also more compact and require less material to manufacture.

Lighting cost and emission data

LED lamp prices have experienced a rapid decline in pricing globally. For about ten years, the LED lamp price in the US has dropped by 93%. Focusing on Europe, the price of directional LED lamps has dropped by 80-90% over the last five years (CLASP, 2016).

Information regarding the cost of different lighting technologies is very important for consumers when deciding which technologies to purchase for lighting of their homes. There are a number of parameters that have to be taken into account when comparing different technologies such as initial cost or capital cost, energy consumption, lifespan, the maintenance cost, and also the GHG emissions.

Table 21. Costs and GHG emissions of different lighting technologies

Type of Lamps	Approximated Luminous Flux (lumen)	Wattage (watt)	Lifespan (hours)	Typical Unit Price (IDR)	Capital Cost (IDR)
Incandescent	800	60	1,200	15,000	33,763
FL	800	14	8,000	35,000	14,231
CFL	800	14	9,000	35,000	12,863
LED	800	8	20,000	30,000	5,926

Type of Lamps	Annual Energy Consumption (kWh)	Energy Cost (Rp. 1,445/ kWh)[25] (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/ kWh)	Annual GHG Emission [26] (kg of CO2 eq.)
Incandescent	162.06	234,177	267,940	1,653	142.13
FL	37.81	54,641	68,872	1,822	33.16
CFL	37.81	54,641	67,504	1,785	33.16
LED	21.61	31,224	37,150	1,719	18.95

Type of Lamps	Annual Cost Savings [27c)] (IDR)	Annual GHG Emission Savings (kg of CO2 eq.)	GHG Abatement Cost (IDR/kg CO2 eq.)
Incandescent	-	-	-
FL	199,068	108.97	-1,516.98
CFL	200,436	108.97	-1,529.53
LED	230,790	123.18	-1,599.50

24 Available at: https://realty.economictimes.indiatimes.com
25 PLN electricity tariff
26 Java-Bali power grid's emission factor: 0.877 kg CO_2/kWh; Directorate General of Electricity – MEMR (2018)
27 Compared to incandescent lamps

Table 21 shows the annual cost and GHG emission comparison among different lamp technologies in the market for the same luminous flux. For the same lumen level and operational time, the LED can save 86% and CFL saves 77% of energy compared to the incandescent lamps. Because it is more efficient, the use of 8 watt LED lamps will provide energy savings of 140.45 kWh and total cost savings of IDR 230,790 compared to the incandescent lamps. In fact, the total cost per kWh of LED lamps are now the lowest compared to other types of lamps except incandescent lamps.

Lighting life cycle cost (LCC) and GHG abatement cost of MEPS

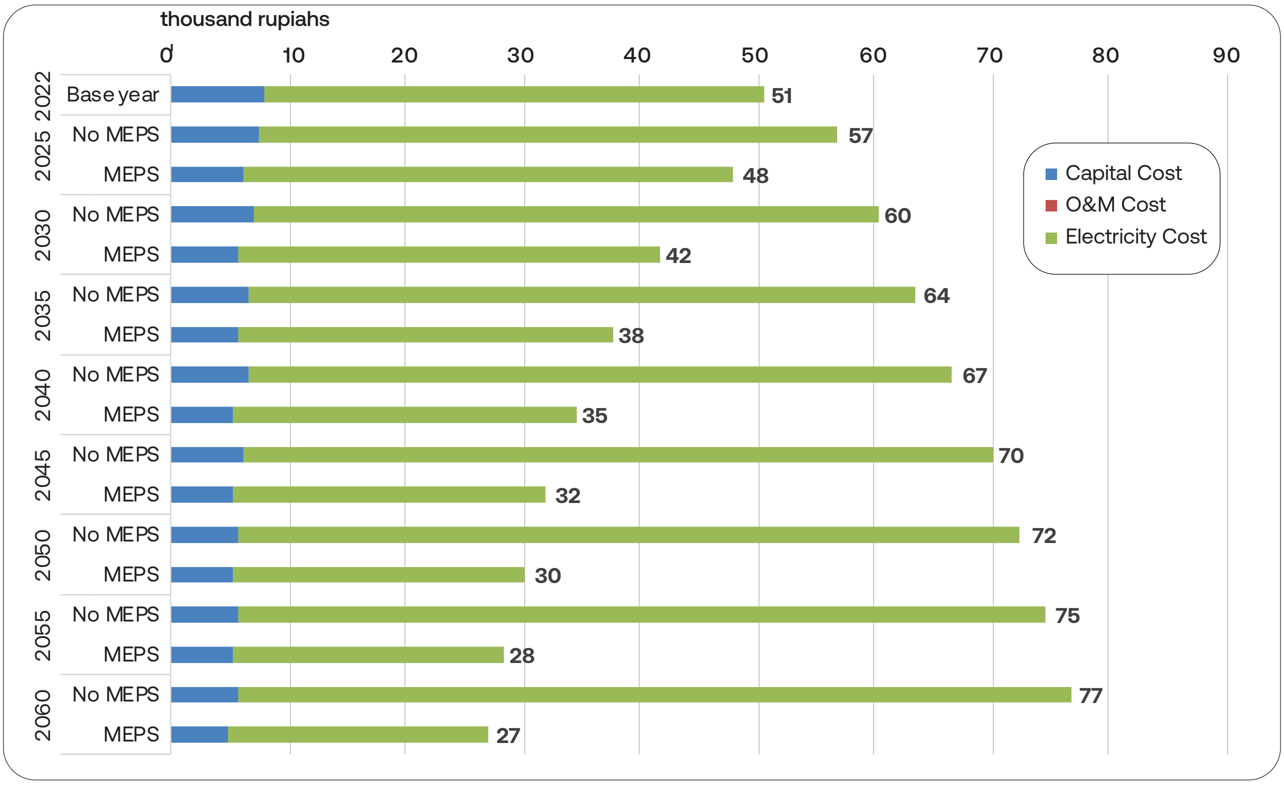
Life Cycle Cost (LCC) analysis of a Minimum Energy Performance Standard (MEPS) program implementation involves evaluating the total cost of adopting and maintaining energy-efficient measures and comparing it to the benefits gained. The goal is to determine the most cost-effective way to comply with MEPS while maximizing energy savings and overall value. Improving lighting energy efficiency through MEPS program can significantly reduce energy consumption, lower operating costs, and contribute to environmental sustainability and achieving Net Zero Emission targets.

Table 22. Assumed LED Lighting MEPS[28]

Year	2022 (base year)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS Efficacy (lm/watt)	80	94	118	142	165	189	213	236	260
Energy Efficiency Index	1	1.18	1.47	1.77	2.07	2.36	2.66	2.95	3.25
Maximum Energy Consumed	1	0.85	0.68	0.57	0.48	0.42	0.38	0.34	0.31

Assuming that the MEPS for lighting will be revised every 5 years, **Figure 31** shows the assumed minimum energy performance compared to the base year of 2022. It means that the maximum energy consumption in 2060 must be 31% of energy consumption in 2022 or it could be said that the minimum energy efficiency in 2060 must therefore be 225% more efficient than that in 2022.

Figure 31. Life cycle cost (LCC) of lighting by scenario (No MEPS vs. MEPS (real cost))



28 Based on Indonesia NZE targets by MEMR

According to a study published in ECEEE Summer Study proceedings, there are correlations among appliance prices, energy consumptions and MEPS implementations (Ellis et. al., 2007). The study underscores that the real household appliance prices and energy consumptions decline as a new MEPS is introduced to the market. As shown in **Figure 33,** the real total cost of lighting under MEPS will be 65% lower compared to the real total cost under No MEPS scenario in 2060 due to the significant energy savings of the efficient lightings although the capital cost of the MEPS revision is higher than the No MEPS scenario.

Figure 32. GHG savings and abatement cost of MEPS for lighting

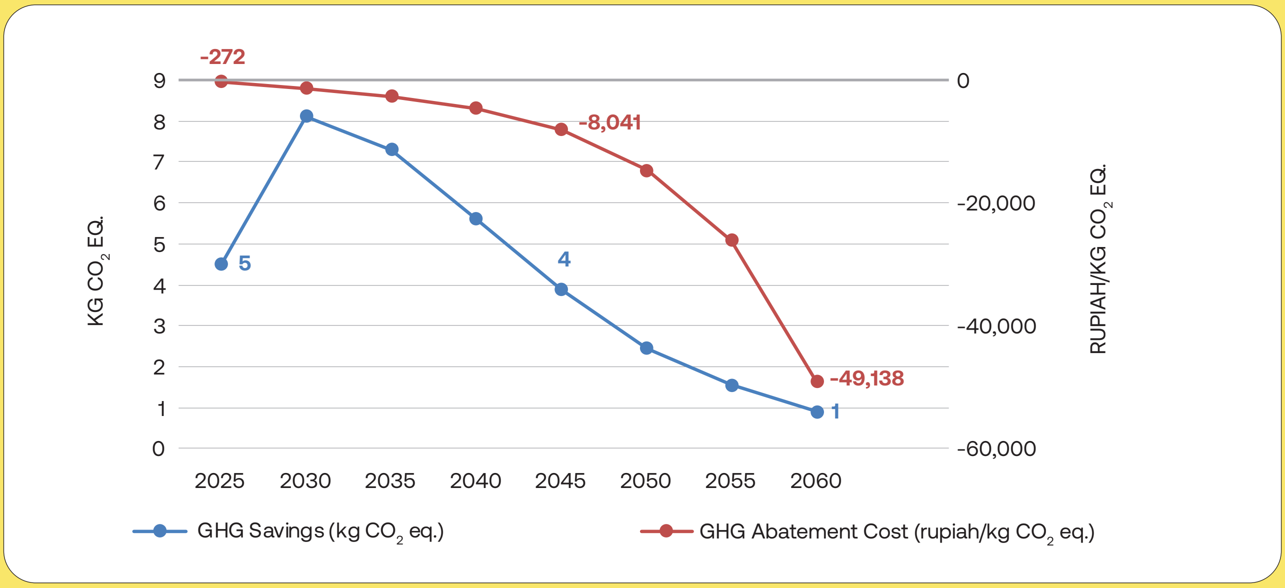


Figure 32 shows GHG Savings and Abatement Cost due to the implementation of MEPS on lightings. The GHG abatement cost is negative because the capital cost is low and the energy efficiency is high that results in large cost savings (see Figure 34). The GHG savings is still increasing until 2025 but it is then gradually decreasing due to the declining GHG emission factor.

According to a study published in ECEEE Summer Study proceedings, there are correlations among appliance prices, energy consumptions and MEPS implementations.

3.2 Air Conditioning

Air conditioning technology and energy efficiency data

In the National Energy General Plan (RUEN) the government has targeted a national energy efficiency of 17.4% in 2025 and 38.9% in 2050 compared to Business as Usual Scenario (MEMR, 2017). However, achieving the energy efficiency target is not easy. There are a number of challenges the government should face. One of them is the high level of consumer demand for air conditioning (AC). AC is the best appliance for space cooling in buildings, especially in a hot and humid climate like Indonesia.

The upfront and operational cost of AC appliances is still quite expensive for the most of Indonesian families. So, AC penetration in Indonesia is still low. According to the 2019 CLASP survey, only 5% of families have AC. The ownership of AC that is owned by a family in Indonesia is just 1.15 units. The yearly average usage of AC in Indonesia is about 7.2 hours per day. The Indonesian government has regulated the level of energy use in air conditioners by issuing MEPS regulations in 2021 where MEPS for air conditioners must have a minimum CSPF (Cooling Seasonal Performance Factor) value of 3.4.

The performance of an AC is largely determined by the AC electrical power required and its cooling capacity. AC performance levels are different based on the EER (Energy Efficiency Ratio) value which is put on the AC packaging or manual. The higher EER or CSPF values, the more energy efficient are the ACs

Air conditioner cost and emission data

Table 23 represent the cost and GHG emission data of various AC technologies. The technology descriptions of the ACs can be found in the aforementioned CLASP study. While the below table can be consulted for comparative purposes on costs and emission data.

Table 23. Costs and GHG emissions of different AC technologies

Type of AC	Power (PK)	Cooling Capacity (Btu/hr)	Lifespan (years)	Typical Unit Price (IDR)	Capital Cost (IDR)	O&M Cost [a] (IDR)
AC Standard	½	5000	10	2,500,000	406,863	250,000
AC Low Wattage	½	5000	10	3,000,000	488,236	300,000
AC Inverter	½	5000	12	3,500,000	513,672	350,000

Type of AC	Annual Energy Consumption [b] (kWh)	Energy Cost (Rp. 1,445/ kWh) (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/ kWh)	Annual GHG Emission [c] (kg of CO_2 eq.)
AC Standard	4,927.5	7,120,238	7,777,101	1,578	4,321.42
AC Low Wattage	4,003.6	5,785,202	6,573,438	1,642	3,511.16
AC Inverter	3,175.5	4,588,598	5,452,270	1,717	2,784.91

Type of AC	Annual Cost Savings [d] (IDR)	Annual GHG Emission Savings [d] (kg of CO2 eq.)	GHG Abatement Cost [d] (IDR/kg of CO_2 eq.)
AC Standard	-	-	-
AC Low Wattage	1,203,663	810.26	-983.39
AC Inverter	2,324,831	1,536.51	-1,248.26

Sources:
a) Assumed 10% of unit price
b) based on Manjula Siriwardhana, et. al., 2017 and https://www.berapawatt.com/jenis-jenis-ac-tips-memilih-yang-hemat-listrik
c) Java-Bali power grid's emission factor: 0.877 kg CO2/kWh; Directorate General of Electricity – MEMR (2018)
d) compared to AC Standard

Air conditioner life cycle cost (LCC) and GHG abatement cost of MEPS

Assuming that the MEPS for air conditioners will be revised every 5 years, **Table 24** shows the assumed minimum energy performance compared to the base year of 2022. According to this analysis, the maximum energy consumption in 2060 must be 41% of energy consumption in 2022, thereby the minimum energy efficiency in 2060 be 141% more efficient than that in 2022.

Table 24. Assumed inverter air conditioner MEPS

Year	2022 (baseyear)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS CSPF	3.73	4.15	4.84	5.53	6.23	6.92	7.61	8.31	9.00
Energy Efficiency Index	1	1.11	1.30	1.48	1.67	1.85	2.04	2.23	2.41
Maximum Energy Consumed	1	0.90	0.77	0.67	0.60	0.54	0.49	0.45	0.41

Note: Based on Indonesia NZE targets by MEMR

Figure 33. Life cycle cost (LCC) of an air conditioner by scenario (MEPS vs. MEPS (real cost))

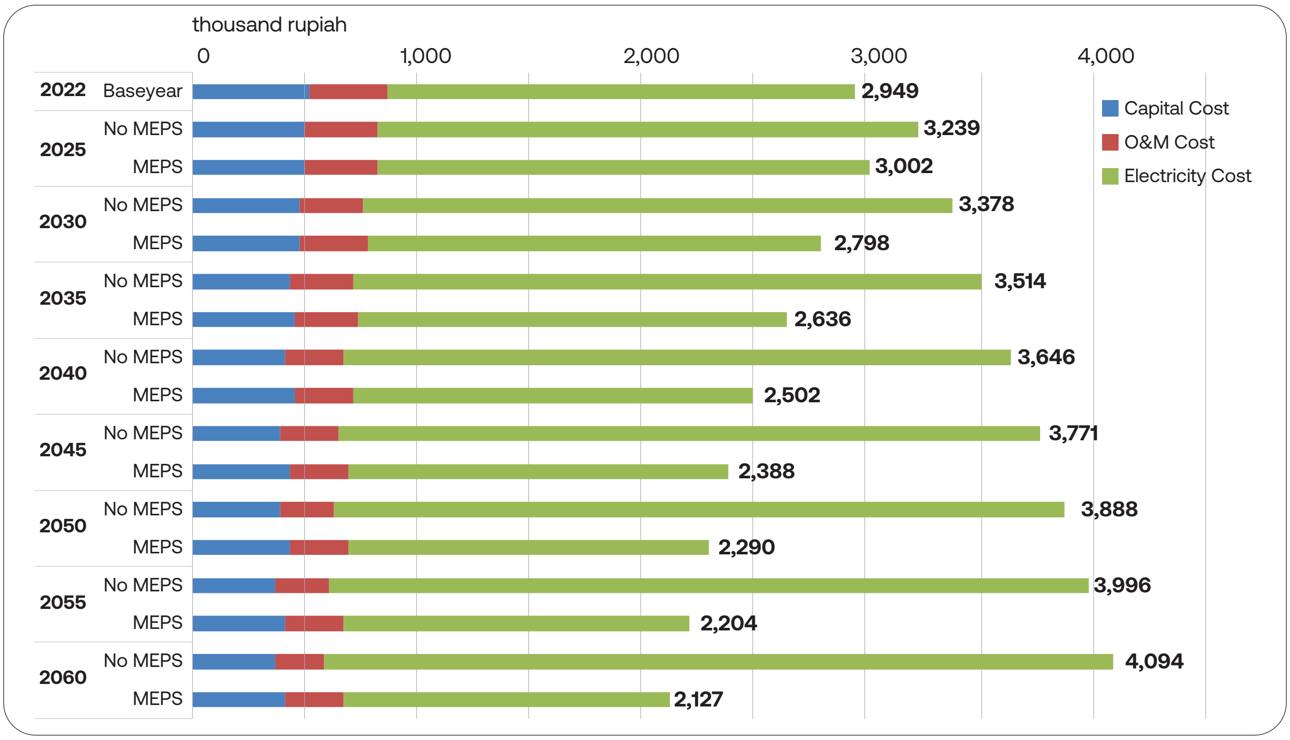
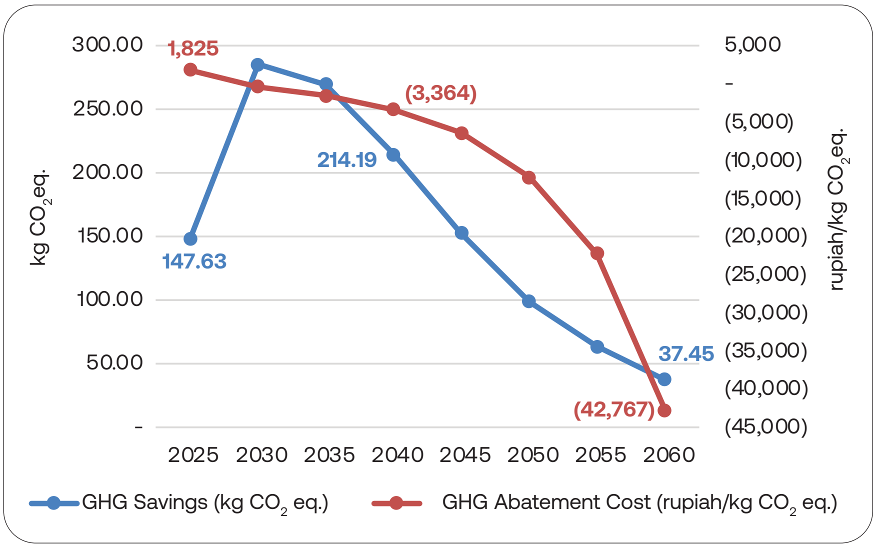


Figure 34. GHG savings and abatement cost of an air conditioner MEPS



The total cost of air conditioner in the MEPS scenario would be 48% less than in the no MEPS scenario in 2060. This also gives the negatives values of the GHG emission abatement cost for the energy efficient air conditioner adoptions (see **Figure 36**). Here we also observe a decline in the GHG due to the declining GHG emission factor.

3.3 Television

Television technology and energy efficiency data

The influence of television on Indonesian families seems to be strongly integrated into people's daily lives. CLASP survey data for 2019 shows that about 93% of households own televisions in Indonesia. Ownership per household is 1.07 units of TV. The yearly average usage is 6.5 hours per day. The habit of Indonesian people who like to watch TV and the still high use of CRT TV technology which is energy-intensive makes TV one of the household appliances that consumes quite a lot of energy. Most of the respondents (80%) use television with wattage between 30 and 100 W.

Television cost and emission data

Table 25 represent the cost and GHG emission data of various TV technologies. The technology descriptions of the TVs can be found in the aforementioned CLASP study. While the below table can be consulted for comparative purposes on costs and emission data.

Table 25. Costs and GHG emissions of different TV technologies

Type of TV	Lifespan(hours)	Typical Unit Price (IDR)	Capital Cost (IDR)
CRT TV 24 inch	30,000	1,350,000	192,757
LED TV 42 inch	60,000	2,500,000	274,659
Plasma TV 42 inch	50,000	8,000,000	923,969
QLED TV 42 inch	70,000	7,000,000	744,743
OLED TV 42 inch	60,000	13,000,000	1,428,229

Type of TV	Annual Energy Consumption (kWh)	Energy Cost (Rp. 1,445/kWh) (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/kWh)	Annual GHG Emission [29] (kg of CO2 eq.)
CRT TV 21 inch	240.90	348,101	540,858	2,245	211.27
LED TV 42 inch	135.23	195,411	470,070	3,476	118.60
Plasma TV 42 inch	481.80	696,201	1,620,170	3,363	422.54
QLED TV 42 inch	192.72	278,480	1,023,223	5,309	169.02
OLED TV 42 inch	168.63	243,670	1,671,899	9,915	147.89

Type of TV	Annual Cost Savings [30] rupiah)	Annual GHG Emission Savings b) (kg of CO2 eq.)	GHG Abatement Cost (IDR/kg CO2 eq.)
CRT TV 21 inch	-	-	-
LED TV 42 inch	70,788	92.67	1,316.16
Plasma TV 42 inch	-	-	-
QLED TV 42 inch	-	42.25	15,979.22
OLED TV 42 inch	-	63.38	20,886.68

29 Jawa-Bali power grid's emission factor: 0.877 kg CO_2/kWh; Directorate General of Electricity – MEMR (2018)
30 Compared to CRT TV

Television life cycle cost (LCC) and GHG abatement cost of MEPS

Table 26. Costs and GHG emissions of different TV technologies show the assumed minimum energy performance compared to the base year of 2022. Here the maximum energy consumption in 2060 must be 27% of energy consumption in 2022. To achieve this, the minimum energy efficiency in 2060 must be 266% more efficient than that in 2022.

Table 26. Assumed LED television MEPS

Year	2022 (baseyear)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS Power On (watt)	38.11	34.03	30.49	23.10	18.59	15.49	13.33	11.69	10.40
Energy Efficiency Index	1	1.12	1.25	1.65	2.05	2.46	2.86	3.26	3.66
Maximum Energy Consumed	1	0.89	0.80	0.61	0.49	0.41	0.35	0.31	0.27

Note: Based on Indonesia NZE targets by MEMR

Figure 35. Life cycle cost (LCC) of a television by scenarios of No MEPS and MEPS (real cost)

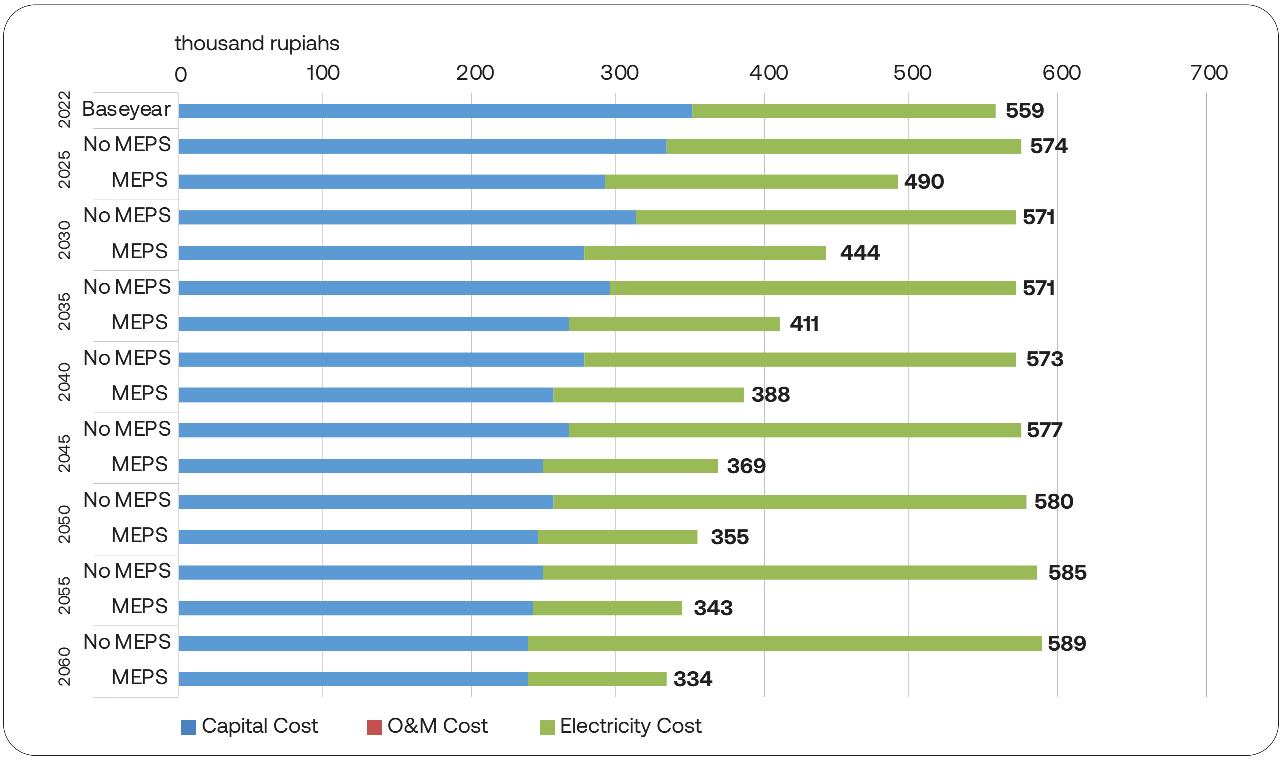
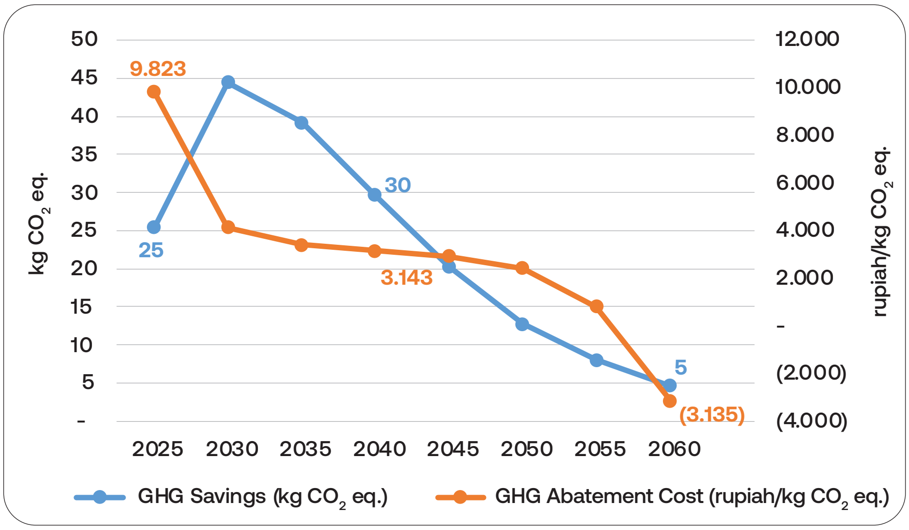


Figure 36. GHG savings and abatement cost of a television MEPS



The GHG emission abatement cost analysis for a television has different results compared to lightings or air conditioners. The capital cost of televisions is high but the electricity savings or cost savings are not big enough to compensate the capital cost. This gives the positive values of GHG abatement cost for televisions.

3.4 Refrigerator

Refrigerator technology and energy efficiency data

Refrigerators are household appliances that have become part of the lifestyle, especially in urban areas. Refrigerator electricity consumption in the household sector on average is in second place after ACs if the household has an AC unit. If there is no AC unit, the refrigerator is generally the most energy consuming appliance in households, reaching an electricity consumption of 6.4 – 29.61% of total household electricity needs.

Refrigerator cost and emission data

Table 27 represent the cost and GHG emission data of the main refrigerator technologies. The technology descriptions can be found in the aforementioned CLASP study. While the below table can be consulted for comparative purposes on costs and emission data.

Table 27. Cost and GHG emission data of the main refrigerator technologies

Type of Refrigerator	Volume (liters)	Lifespan (years)	Typical Unit Price (IDR)	Capital Cost (IDR)
Non Inverter	200	10	2,500,000	406,803
Inverter	200	14	3,500,000	475,112

Type of Refrigerator	Annual Energy Consumption [31] (kWh)	Energy Cost (Rp. 1,445/kWh) (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/kWh)	Annual GHG Emission [b)] (kg of CO_2 eq.)
Non Inverter	200.75	290,084	696,887	3,471	176.06
Inverter	146.00	210,970	686,082	4,699	128.04

Type of Refrigerator	Annual Cost Savings [c)] (IDR)	Annual GHG Emission Savings [c)] (kg of CO_2 eq.)	GHG Abatement Cost [32] (IDR/kg CO_2 eq.)
Non Inverter	-	-	-
Inverter	10,805	48.02	8,246.52

Refrigerator life cycle cost (LCC) and GHG abatement cost of MEPS

Table 28 shows the assumed minimum energy performance compared to the base year of 2022. The analysis shows that the maximum energy consumption in 2060 must be 49% of energy consumption in 2022 or we could say that the minimum energy efficiency in 2060 must be 103% more efficient than that of 2022.

Table 28. Assumed inverter refrigerator MEPS

Year	2022 (baseyear)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS Energy Consumption (kWh/year)	246	228	202	182	165	152	140	130	121
Energy Efficiency Index	1	1.08	1.22	1.35	1.49	1.62	1.76	1.89	2.03
Maximum Energy Consumed	1	0.92	0.82	0.74	0.67	0.62	0.57	0.53	0.49

Note: Based on Indonesia NZE targets by MEMR

31 Appliance 101 Available at: https://101appliance.com/inverter-vs-non-inverter-refrigerator-is-it-worth-it/
32 Compared to non-inverter refrigerator

Figure 37. Life cycle cost (LCC) of a refrigerator by scenarios of No MEPS and MEPS (real cost)

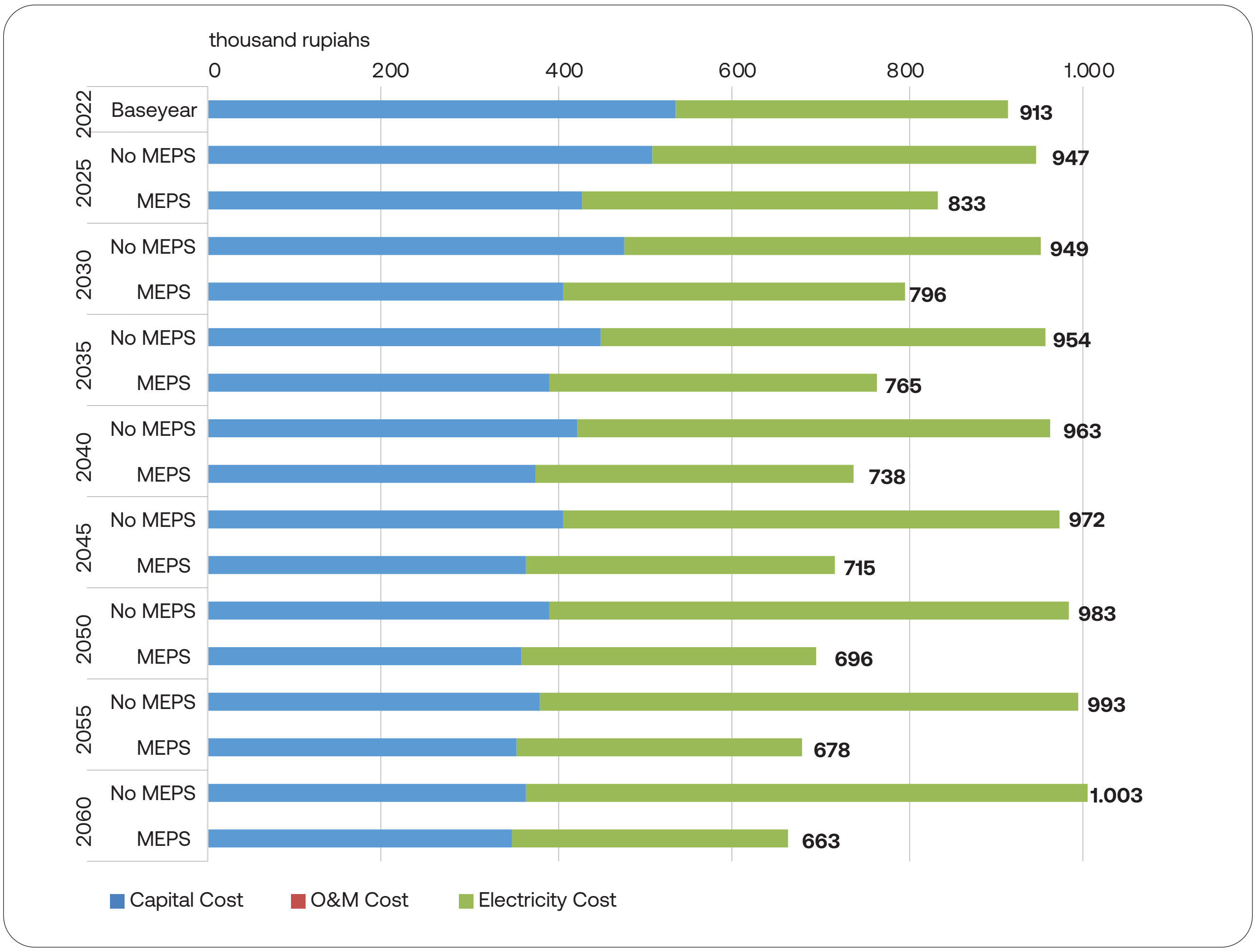
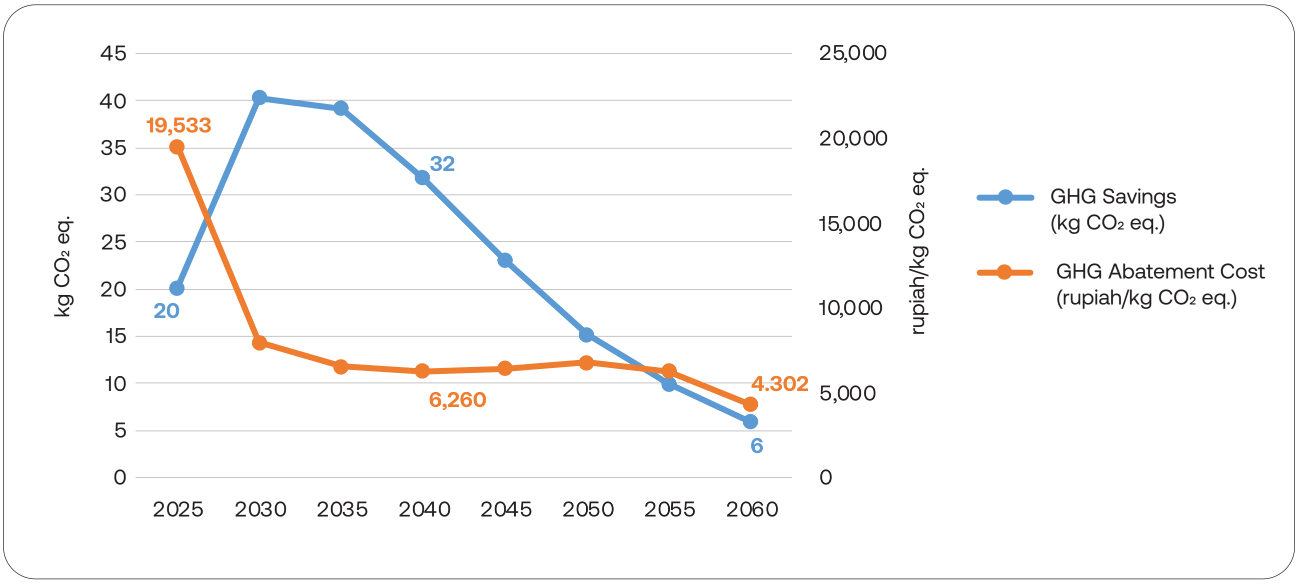


Figure 38. GHG savings and abatement cost of a refrigerator MEPS



Similar to the televisions, Figure 41 the GHG emission abatement cost of the refrigerators is positive until 2060. The operational cost savings are still less than the capital cost of the inverter refrigerators.

3.5 Rice Cooker

Rice cooker technology and energy efficiency data

Based on the CLASP study in 2019, the majority of respondents owned rice cookers with wattage between 300 and 350 W (55%). Most units had 1 to 2 L of dry rice capacity (88%). Most respondents used a 1:1 or 1:2 ratio of rice to water (69%). Some households are still using steamers to cook rice. According to this CLASP survey, the penetration of rice cookers is only 69% with the ownership per household being 1.01 units. The average daily usage hours is 6 (six) hours where about 4.5 hours are used for warming up the rice.

There are many types of electric rice cookers on the market, each with its own set of features. The heating element is the main component of the rice cooker that transforms electricity into heat that cooks the rice. Although there are various marketing words for the heating technology, all heating technology can be categorized as “Electric Resistance” type and “Induction” type.

Rice cooker cost and emission data

Table 29 represents the cost and GHG emission data of the main rice cooker technologies. The technology descriptions can be found in the aforementioned CLASP study. While the below table can be consulted for comparative purposes on costs and emission data. Induction type rice cookers emit higher GHG emissions, and are still more expensive. They do not give energy, cost or GHG savings yet compared to electric resistance type rice cookers. The advantages of induction rice cookers are just make the cooked rice more fluffy and therefore preferred by consumers.

Table 29. Costs and GHG emissions of different rice cooker technologies

Type of Rice Cooker	Capacity (liters)	Wattage of cooker/ warmer (watt)	Lifespan (years)	Typical Unit Price (IDR)	Capital Cost (IDR)
Electric Resistance	1.8	350/30	5	300,000	79,139
Induction	1.8	1000/30	5	1,000,000	263,797

Type of Rice Cooker	Annual Energy Consumption (kWh) [33]	Energy Cost (Rp. 1,445/kWh) (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/kWh)	Annual Total Emission [b)] (kg of CO_2 eq.)
Electric Resistance	240.90	348,101	427,240	1,665	211.27
Induction	323.02	466,771	730,568	2,261	283.29

Rice cooker life cycle cost (LCC) and GHG abatement cost of MEPS

In the case of rice cookers, the maximum energy consumption in 2060 is expected to be 58% of energy consumption in 2022, thus to achieve this, the minimum energy efficiency in 2060 is expected to be 72% more efficient than that in 2022.

Table 30. Assumed electric resistance rice cooker MEPS

Year	2022 (baseyear)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS Energy Consumption (kWh/year)	147	139	128	118	110	102	96	90	85
Energy Efficiency Index	1	1.06	1.15	1.25	1.34	1.44	1.53	1.62	1.72
Maximum Energy Consumed	1	0.95	0.87	0.80	0.75	0.70	0.65	0.62	0.58

Note: Based on Indonesia NZE targets by MEMR

33 Cooking time of the induction is 50% less than the electric resistance

Figure 39. Life cycle cost (LCC) of a rice cooker by scenarios of No MEPS and MEPS (real cost)

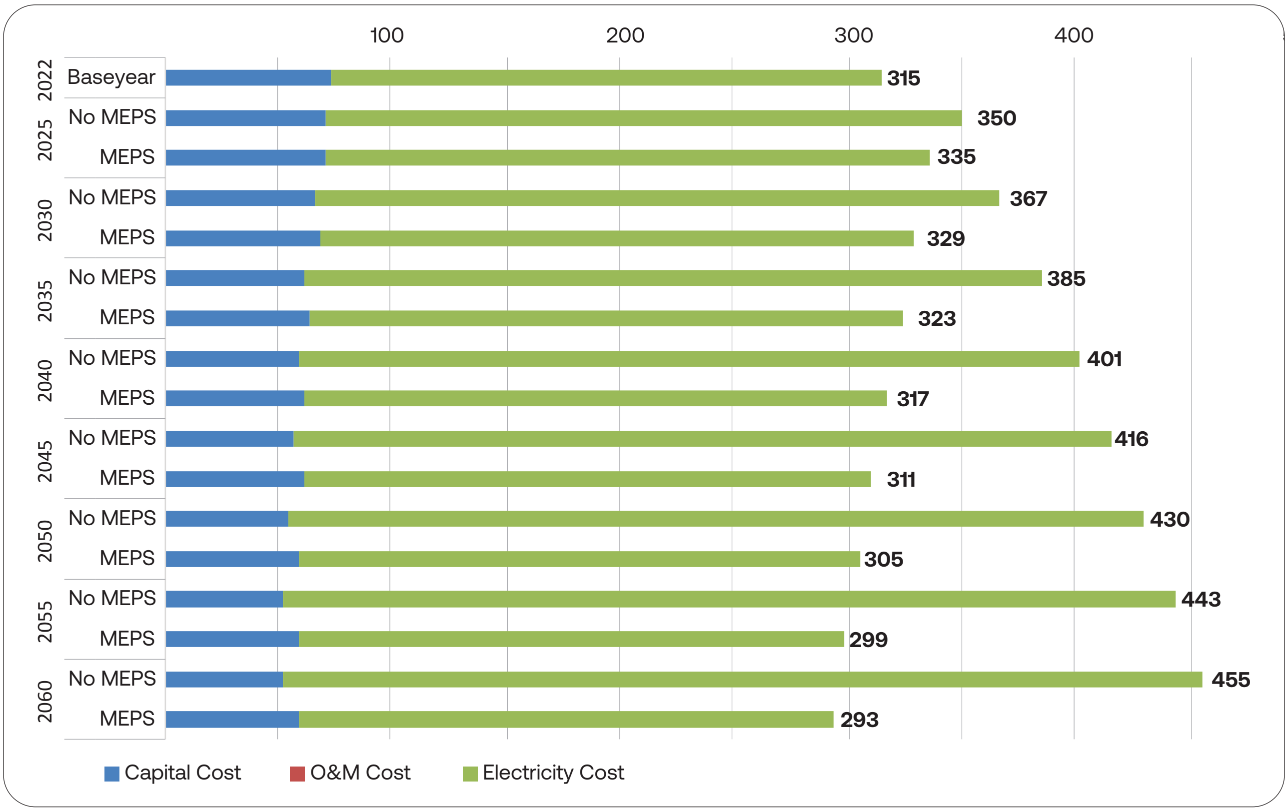
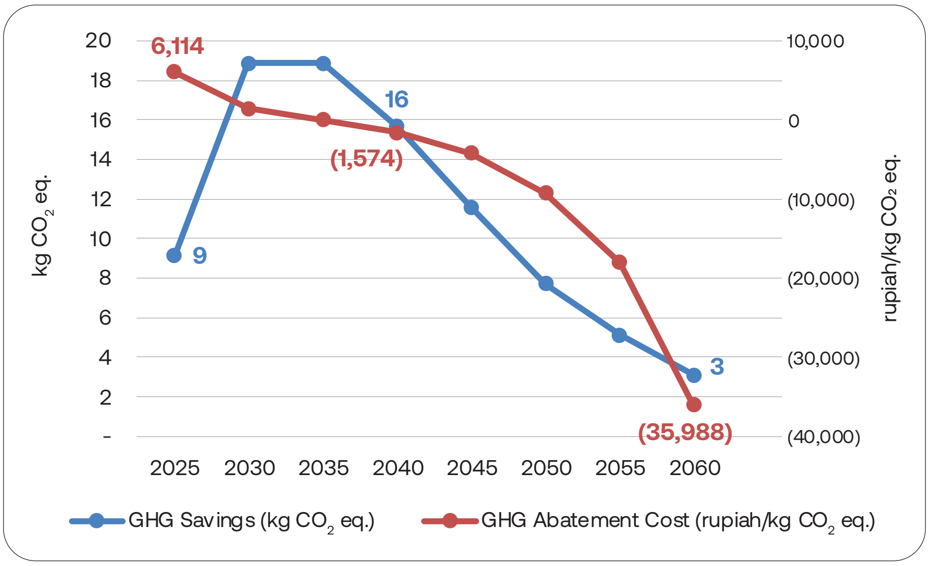


Figure 40. GHG savings and abatement cost of a rice cooker MEPS



When the energy efficiency of the electricity resistance rice cooker is improved, the electricity savings of the rice cooker will get higher compared to the No MEPS scenario. Due to this, GHG abatement cost of the rice cooker, which is initially positive, will gradually turn into negative until 2060.

3.6 Cooking Stove

Cooking stove technology and energy efficiency data

Indonesia's cooking technologies reflect a blend of traditional and modern practices, utilizing various energy sources. Kerosene, city gas, LPG, biomass and charcoal remain prevalent, while electric and inductive cooking methods are becoming more common, especially in urban settings. The adoption of renewable energy solutions is still growing, showcasing a potential shift toward more sustainable cooking practices.

LPG (liquefied petroleum gas) is a major energy source for cooking in Indonesia, particularly for household and commercial uses in urban areas. LPG and city gas are crucial components of Indonesia's cooking energy landscape, supported by government policies and increasing demand in both households and businesses. Its cleaner-burning properties make it an important alternative to traditional cooking fuels, contributing to improved health and environmental outcomes.

Cooking stove cost and emission data

Table 31 represents the cost and GHG emission data of the main stoves technologies. The technology descriptions can be found in the aforementioned study. While the below table can be consulted for comparative purposes on costs and emission data.

Table 31. Costs and GHG emissions of different cooking stove technologies

Type of Stoves	Capacity	Efficiency	Lifespan (years)	Typical Unit Price (IDR)	Capital Cost (IDR)
LPG Stove	0.18 kg/hr	55%	15	350,000	46,016
Electric Stove	1500 watts	75%	15	900,000	118,326
Induction Stove	1500 watts	90%	15	1,500,000	197,211

Type of Stoves	Annual Energy Consumption (kWh)	Energy Cost (Rp. 1,445/kWh and 18,833/kg for LPG [34]) (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/kWh or rupiah/kg)	Annual Total Emission [35] (kg of CO2 eq.)
LPG Stove	131.40 kg	2,474,700	2,520,716	19,184	420.55
Electric Stove	803.00 kWh	1,160,335	1,278,661	1,592	704.23
Induction Stove	669.17 kWh	966,951	1,164,162	1,740	586.86

Type of Stoves	Annual Cost Savings [36] (IDR)
LPG Stove	-
Electric Stove	1,242,055
Induction Stove	1,356,554

Table 31. Costs and GHG emissions of different cooking stove technologies shows interesting results on the cost and GHG emissions of the different cooking stove technologies. Regarding the cost, the electric and induction stoves will give smaller annual total cost due to the higher energy efficiency which results in lower energy consumption even though higher upfront cost. Regardless of efficiency considerations, consumer choices are also influenced by preferences, as gas is often seen as better suited for traditional cooking needs. Consequently, fuel stacking is commonly observed, where households utilize multiple energy technologies depending on their specific requirements or desired outcomes. But, regarding the GHG emissions, the LPG stoves are cleaner because the current grid emission factors are still high, around 0.88 kg CO_2 eq/kWh. The coal fired power plants still dominate the power plant mix in Indonesia.

34 Pertamina LPG price and PLN wattage and electricity tariff category
35 Jawa-Bali power grid's emission factor: 0.877 kg CO_2/kWh; Directorate General of Electricity – MEMR (2018) and LPG emission factor of 3,2 kg CO2/kg
36 Compared to the electric LPG stove

Cooking stove life cycle cost (LCC) and GHG abatement cost of MEPS

In the case of stoves, the maximum energy consumption in 2060 is expected to reach be 91% of energy consumption in 2022. Translating to a 10% more efficiency needing to be reached by 2060.

Table 32. Assumed induction stove MEPS

Year	2022 (baseyear)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS Efficiency (%)	87	88	89	90	91	92	93	94	96
Energy Efficiency Index	1	1.01	1.02	1.03	1.05	1.06	1.07	1.08	1.10
Maximum Energy Consumed	1	0.99	0.98	0.97	0.96	0.95	0.93	0.92	0.91

Note: Based on Indonesia NZE targets by MEMR

Figure 43. Life cycle cost (LCC) of an induction stove by scenarios of No MEPS and MEPS (real cost)

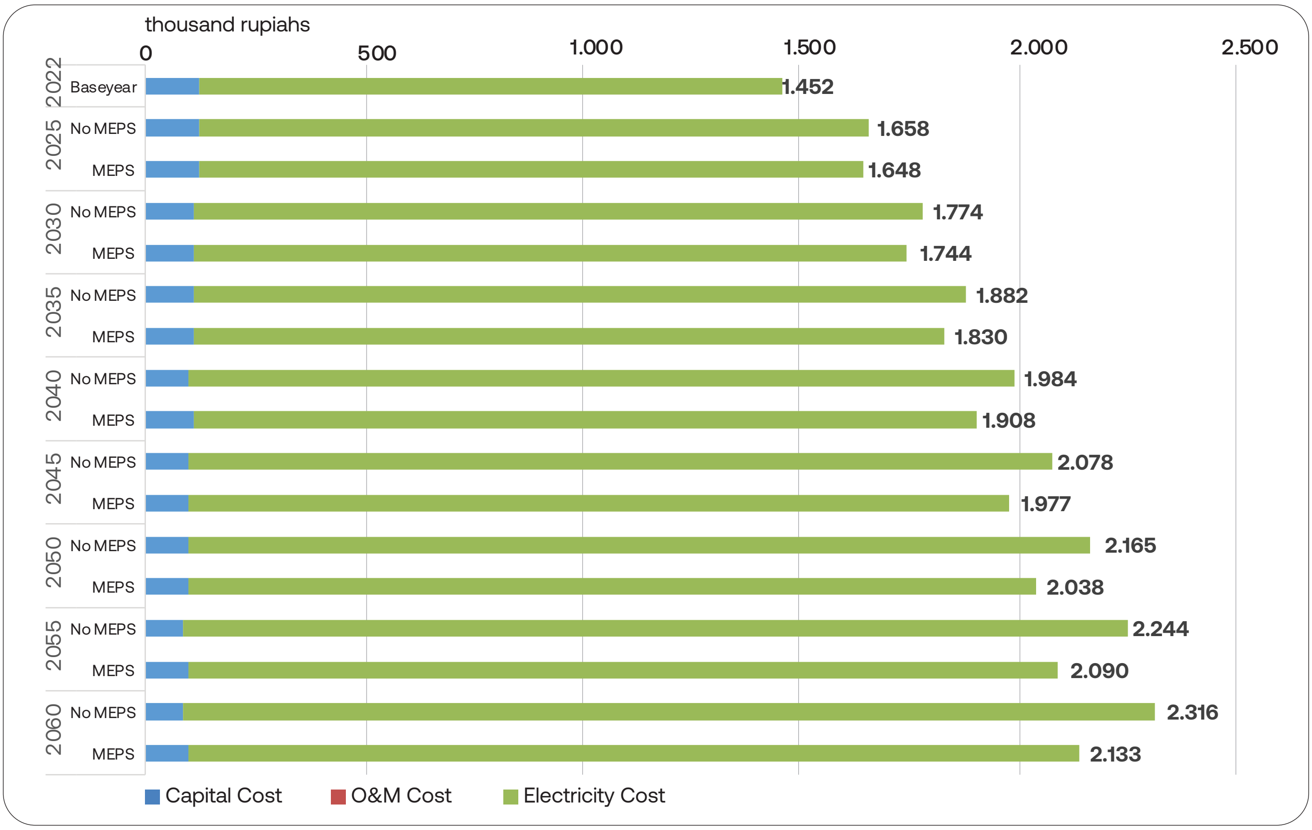
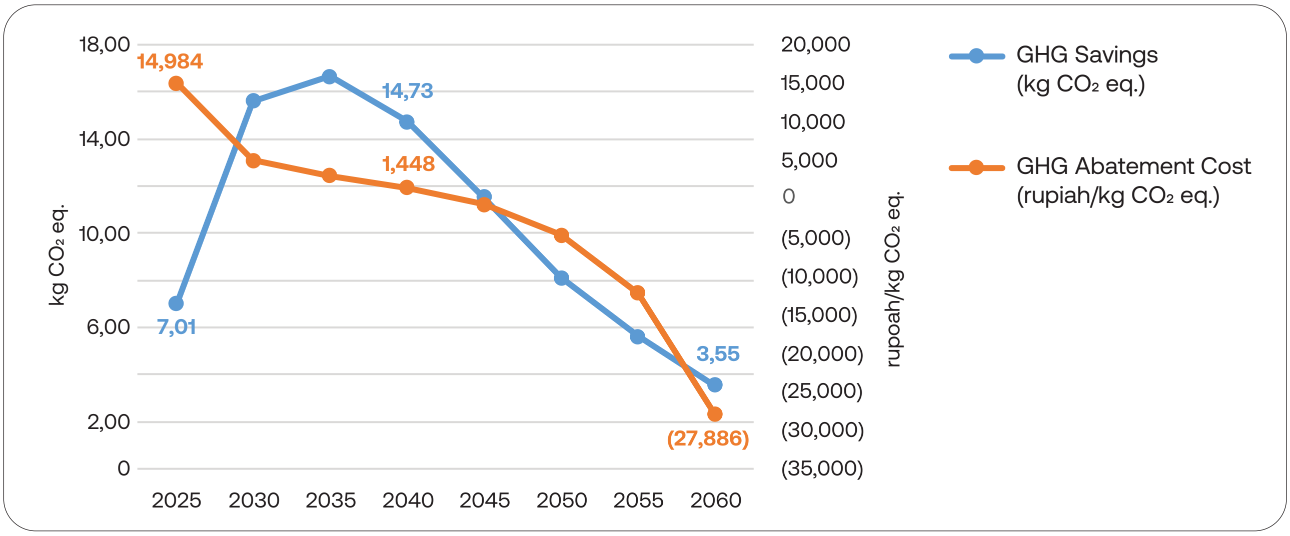


Figure 44. GHG savings and abatement cost of an induction stove MEPS



3.7 Water Heaters

Water heater technology and energy efficiency data

In Indonesia, various water heating technologies are used, reflecting the country's diverse energy resources and needs. Here are some common methods:

- Solar Water Heaters: These systems utilize solar panels to harness energy from the sun, making them popular in many regions, especially in rural areas. They are cost-effective in the long term and reduce reliance on fossil fuels.
- Electric Water Heaters: Common in urban areas, electric water heaters are convenient and easy to install. However, they can be expensive to operate due to electricity costs.
- Gas Water Heaters: These are widely used in households and commercial establishments. They can run on LPG (liquefied petroleum gas) and are valued for their efficiency and quick heating capabilities.

Water heater cost and emission data

Table 33. Costs and GHG emissions of different water heater technologies

Type of Water Heater	Capacity	Efficiency	Lifespan (years)	Typical Unit Price (IDR)	Capital Cost (IDR)	O&M Cost (IDR)
Electric (with tank)	1500 watt/ 80 L	70%	12	4,000,000	587,053	300,000
Solar	80 L	50%	20	14,000,000	1,644,435	1,050,000
Heat Pump	500 watt/ 80 L	300%	15	15,500,000	2,037,844	1,162,500

Type of Water Heaters	Annual Energy Consumption (kWh)	Energy Cost (Rp. 1,445/kWh) (IDR)	Annual Total Cost (IDR)	Annual Total Cost (IDR/kWh)	Annual Total Emission (kg of CO_2 eq.)
Electric	78.21	113,013	1,000,066	12,787	68.59
Solar	-	-	2,694,435	-	-
Heat Pump	6.08	8,786	3,209,130	527,817	5.33

Type of Water Heaters	Annual GHG Emission Savings [37] (kg of CO_2 eq.)	GHG Abatement Cost (IDR/kg CO_2 eq.)
Electric	-	-
Solar	68.59	32,971
Heat Pump	63.26	43,910

Since the upfront cost of the solar and heat pump water heaters are still expensive, there are no annual cost savings for these two technologies compared to the conventional electric water heaters. In terms of GHG emissions, the solar and heat pump water heaters do give savings because of their high energy efficiency. The solar water heaters do not consume electricity from the grid thus no GHG emissions during use phase.

Water heater life cycle cost and GHG abatement cost of MEPS

The maximum energy consumption in 2060 is expected to be 20% of energy consumption in 2022, alternatively, the minimum energy efficiency in 2060 must be 400% more efficient than that in 2022.

37 Compared to the electric water heater

Table 34. Assumed electric water heater MEPS

Year	2022 (baseyear)	2025	2030	2035	2040	2045	2050	2055	2060
MEPS UEF(%)	40	45	53	61	68	76	84	92	100
Energy Efficiency Index	1	1.12	1.32	1.51	1.71	1.91	2.11	2.30	2.50
Maximum Energy Consumed	1	0.89	0.76	0.66	0.58	0.52	0.48	0.43	0.40

Note: Based on Singapore MEPS on Water Heater (https://www.mse.gov.sg/cos2024). UEF is Uniform Energy Factor

Figure 45. Life cycle cost (LCC) of a water heater by scenarios of No MEPS and MEPS (real cost)

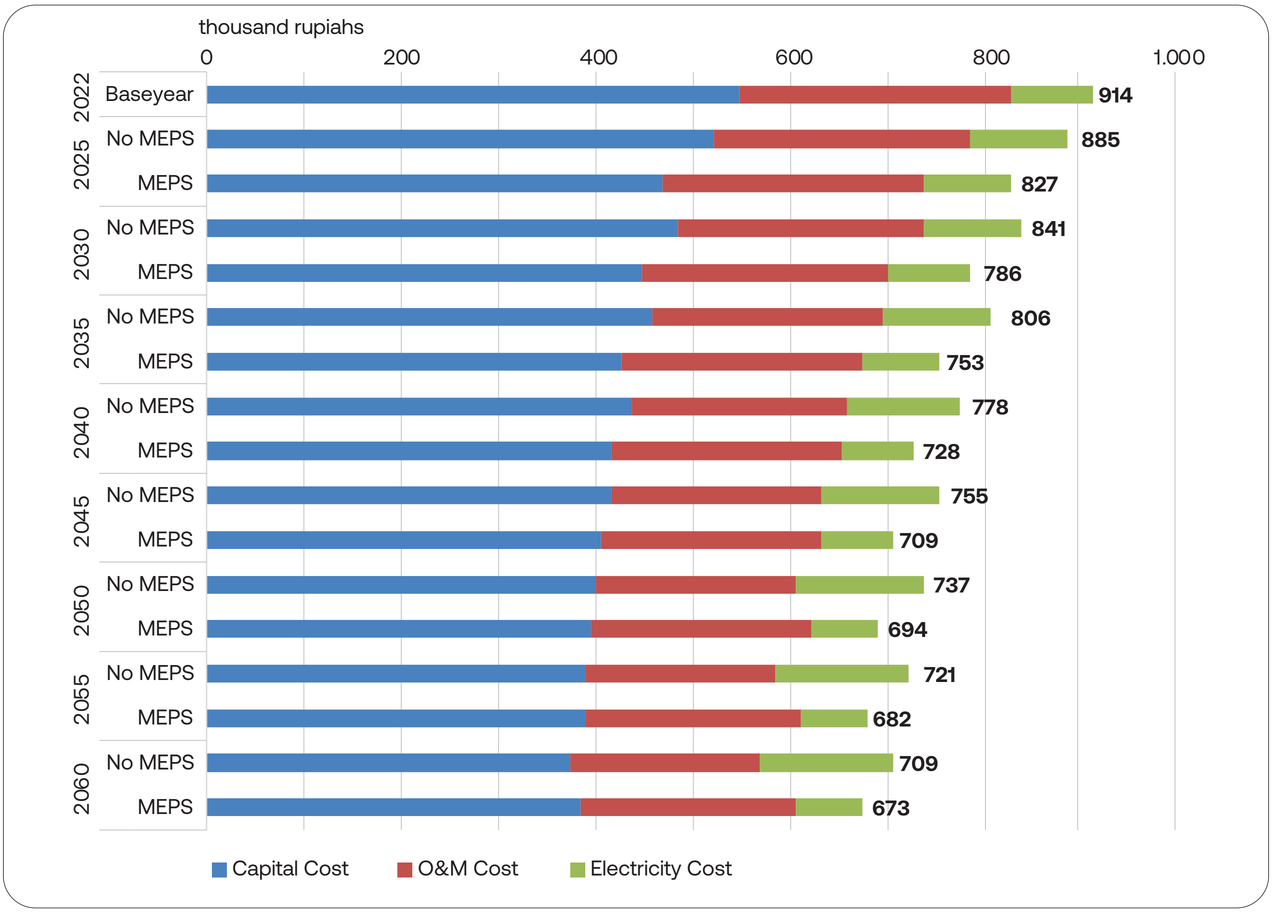
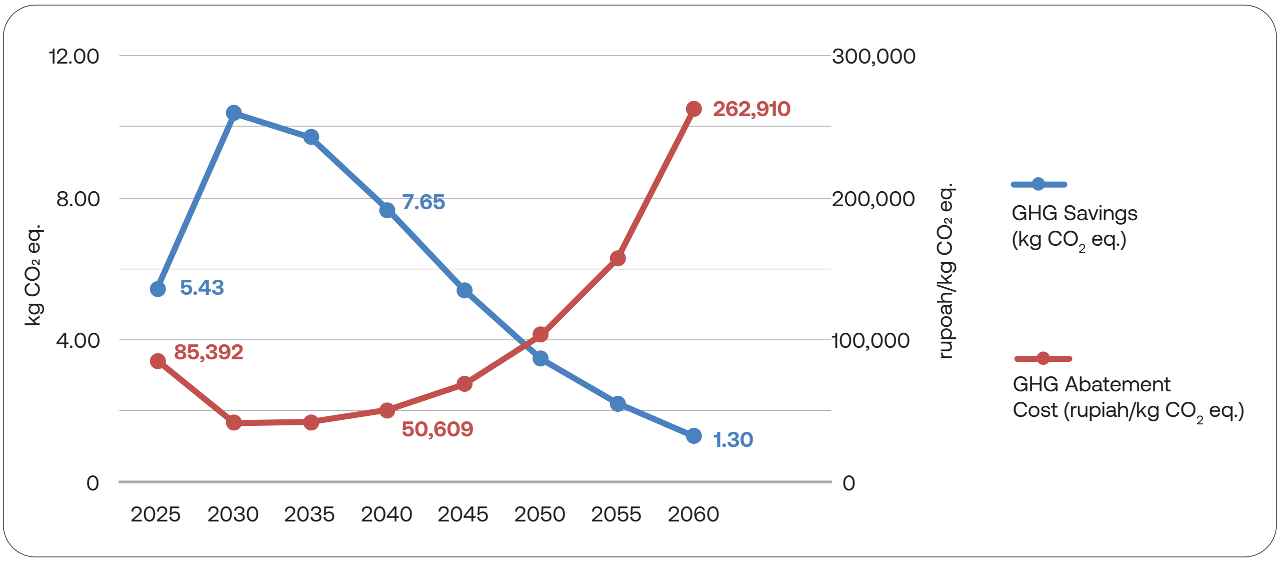


Figure 46. GHG savings and abatement cost of a heater water MEPS



3.8 Summary

Based on the analysis of the key appliances that account for the largest share of energy consumption in residential buildings, the following insights were derived:

- **Residential buildings represent more than 75% of the energy consumption in buildings,** thus, ensuring improved efficiency of electrical appliances and cooking is important, with Minimum Energy Performance Standards (MEPS) being an important tool.

- **Electricity is already a dominant source of energy**, thus most emissions are upstream in the electricity generation mix, therefore greening of the electricity mix remains a key priority.

- **MEPS are key tools to drive the penetration of more efficient appliances in the market** but their implementation should be carefully considered to ensure domestic manufacturers ability to comply and minimise potential negative impacts on local supply chains. Partnering with manufacturers to promote the production and availability of high-efficiency appliances in the domestic market has derived benefits.

- **Incentives for energy-efficient appliances in the form of subsidies and rebates could provide financial incentive for consumers** to purchase energy-efficient appliances and thereby reducing upfront costs.

- **Public awareness campaigns to educate consumers about the benefits of energy-efficient appliances**, focusing on cost savings and environmental impact are paramount for informed consumer decision making.

- **Electrification still has a role to play within cooking**, as LPG remains the primary source of energy yet electrified cooking is more efficient, ranging from 75-90% depending on technology whilst LPG stoves have 55% efficiency. The total annual costs are also significantly lower for electric stoves.

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