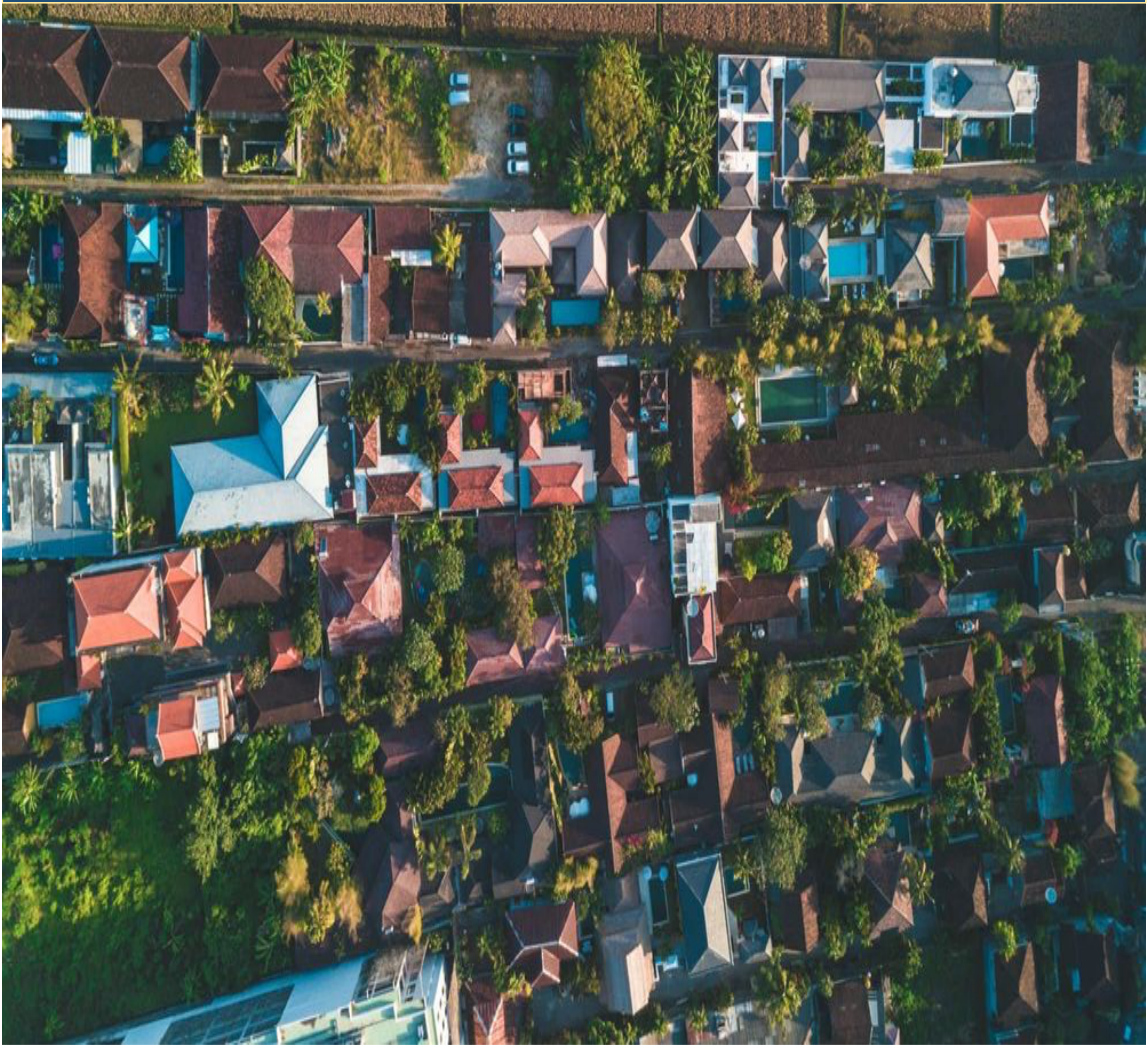
Decarbonising residential sector of Indonesia by strengthening energy efficiency and rooftop PV policies



TU Delft

Decarbonising residential sector of Indonesia by strengthening energy efficiency and rooftop PV policies

by

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in partial fulfilment of the requirements for the degree of Master of Science in Sustainable Energy Technology
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I never imagined leaving India three years ago to pursue a master's degree at TU Delft. Through this thesis, I have understood many aspects of buildings, learned from experts, understood the idea behind research and evolved as a student. This thesis has even inspired me to think of ways to make my parents' house in India less energy intensive and more sustainable. I am thankful for choosing this topic. Without the support of some people, this thesis will not be possible. First of all, I am indebted to Jannis Langer for providing me with prompt feedback, politely reiterating the comments and being patient with me. He gave constant support and helped me to prioritize. I am grateful to Kornelis Blok for simplifying some complex concepts and providing me way forward whenever I was stuck. I am also thankful to Queena Qian for her input on the building side and for helping me connect my thesis's outcomes with Indonesia's NDC commitment. I am grateful to the Indonesian thesis circle group, where I learned different perspectives of energy transition from fellow students and obtained excellent feedback on my topic. Finally, my sincere thanks to Linda Kamp for checking up on me daily to enquire about by mental being and helping me on this journey. She was always there to provide mental support, without which I couldn't have reached this place. My heartfelt thanks to her. I am also thankful to all experts that I interviewed during this nine month journey.

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Abstract

Indonesia has ambitious targets to reduce its greenhouse gas emissions by 29 to 41% by 2030 and to achieve net-zero emissions by 2060. The residential sector in Indonesia consumes close to fifty percent of the country's overall electricity demand. In the last decade, the residential demand for power has doubled, indicating a substantial rise. As a country with more than 17,000 islands, it is crucial to tackle the global warming implications including rising sea levels, significant drought risk, and rainfall fluctuations due to increased emissions arising from the surging energy consumption of Indonesia. Renewable energy installations, especially solar rooftop, and energy efficiency initiatives are some effective strategies to reduce Indonesia's household emissions. Therefore, the purpose of this thesis is to study the decarbonisation potential of the residential sector's supply and demand sides through energy-efficient appliances, efficient building envelope design, and rooftop PV deployment. This report majorly addresses the research gap in evaluating the impact of continuous revision to appliance performance standards and the impact of current efficiency standards fixed by the government. To answer the research problem, three scenarios from 2023 to 2030 are designed; business as usual, government policy, and ambitious. Using the bottom-up stock model method, the projected electricity consumption of four appliances (air conditioner, refrigerator, rice cooker, and LED lamps) was determined. For rooftop PV, the electricity production was forecasted using the PVwatts software, and scenarios were created based on government targets, and considering the high rooftop PV growth in Vietnam. Finally, the policy recommendations were proposed after analysing the electricity saved, mitigated emissions, and generating costs saved in these scenarios from the residential sector.

The analysis of Indonesia's residential demand sector revealed that efficient building envelope and appliance alone can cut the residential sector's electricity use by 18% by 2030. In addition, it was observed that the energy consumption of appliances could stabilise by 2030 as a consequence of aggressive energy efficiency policy measures. Among the four appliances analysed, air conditioners provide the largest energy savings (about 60 percent) due to their higher energy use and greater household penetration in coming years as a result of urbanisation and higher living standards. Existing mandated efficiency standards for refrigerators are well below the average efficiency in the market, preventing energy savings and market transformation towards efficient appliances. Significant financial savings owing to the elimination of fossil-fueled power generation due to demand-side interventions amount to two billion US dollars. While analysing the supply side of Indonesia's residential sector, it was observed that in ambitious scenario for rooftop PV may reach 79 GW by 2030 which would lead to decarbonisation of the supply side of residential side by 50%. In the optimistic scenario, the rooftop PV penetration in households could reach 64% by 2030, considering 1 kWp per house and the total rooftop area required for rooftop PV could be around 250 million square metres. The savings on the supply side resulting from the elimination of fossil fuel generation are close to 6 billion dollars. Considering the demand and supply interventions, the net demand for energy from the grid in the residential sector of Indonesia could be 165 TWh, 130 TWh, and 57 TWh under the three different decarbonisation scenarios. These measures can cut the net electricity consumption

from grid in the residential sector by 65%. These demand and supply solutions would enable Indonesia to achieve at least 20 percent of its NDC target by 2030, which is crucial given that the current emission contribution of residential buildings in Indonesia is close to 16%. The results clearly demonstrate the enormous potential for decarbonising the residential sector in Indonesia, both on the supply and demand sides.

This analysis resulted in some policy recommendations, one of which is that Indonesia could revise energy performance thresholds for appliances every two years as energy savings could double as compared to a scenario following the current revision cycle. The current efficiency standard for refrigerator is non impactful and may be ratcheted up soon. Like in the case of Vietnam, the Feed-in Tariff (FiT) could potentially increase the deployment of rooftop PV, so it is suggested to implement FiT for rooftop PV in Indonesia. For further research, it is suggested that financial constraints and economic impact of energy efficiency solutions from consumers' perspective could be explored, energy savings from other widely used appliances like fans, CFL lamps could be investigated and the impact of setting minimum energy performance standards (MEPS) for rooftop PV in Indonesia could be further analysed.

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Nomenclature

Abbreviations

Abbreviation	Definition
GHG	Green House Gas
TPES	Total Primary Energy Supply
PV	Photo Voltaic
BAU	Business As Usual
NDC	Nationally Determined Contributions
IEA	International Energy Agency
MEPS	Minimum Energy Performance Standards
LED	Light Emitting Diode
TV	Television
AC	Air conditioner
CFL	Compact Fluorescent Lamps
GDP	Gross Domestic Product
FiT	Feed in Tariff
BPS	Best Practice Scenario
CIS	Continuous Improvement Scenario
LEAP	Low Emissions Analysis Platform
LCC	Life Cycle Costing
RETScreen	Renewable-energy and Energy-efficiency Technology Screening software
ABM	Agent Based Modelling
USA	United States of America
OTTV	Overall Thermal Transfer Value
ASEAN	Association of Southeast Asian Nations
CSPF	Cooling Seasonal Performance Factor
AEC	Annual Energy Consumption (kWh/year)
HE	Heating Energy (Wh/litre)
OTTV	Overall Thermal Transfer Value (W/m^2)
SNI	Indonesian National Standard)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ISO	International Organization for Standardization
DC	Direct Current
GWP	Global Warming Potential
SHGC	Solar Heat Gain Coefficient
MEMR	Ministry of Energy and Mineral Resources

Abbreviation	Definition
U4E	United for Efficiency
MPWH	Ministry of Public Works and Housing
ES	energy Saved
EM	Emission Mitigated
E	Energy
IPCC	Intergovernmental Panel on Climate Change
PwC	PricewaterhouseCoopers
CLASP	Collaborative Labeling and Appliance Standards Program
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
GEF	Global Environment Facility
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
MEPSy	CLASP database for projecting appliance energy usage
CAGR	Compounded Annual Growth Rate
BPP	Cost of Power generation
IPP	Independent Power Producer
ESCO	Energy Service Companies
GIZ	German Agency for International Cooperation
GGI	Green Growth Initiative

Symbol

Symbol	Meaning
v	Version
U	Heat transfer coefficient (W/m^2/K^{-1})
K	Kelvin
m	Metre
W/w	Watt
k	Kilo
m	Mass
M	Mega
G	Giga
h/H/hr	Hour
T	Terra
Btu	British Thermal Unit
Tr	Ton of refrigeration
V	Volt
%	Percentage
J	Joule
kg	Kilogram
C	Celsius
l	Litre
g	growth rate

Index

Index	Meaning
adj	Adjusted
i	Year
°	Degree
$	US Dollar

Chapter 1

Introduction

1.1 Indonesia's energy supply and demand

Indonesia is one of the fastest growing economies of the world and is the largest economy in Southeast Asia [27]. The total primary energy supply has more than doubled in last thirty years [28]. This substantial growth to some extent is transpiring at the expense of environment. According to IEA, close to 80% of the total primary energy supply of Indonesia is still dependent on fossil fuels [28]. As per the Government Regulation No. 79 of 2014 on National Energy Policy, at least 23% by 2025 and 31% by 2050 of Indonesia's energy portfolio should be from renewable energy [29]. On the global forum, Indonesian government has set a Nationally Determined Contribution (NDC) objective of lowering its GHG (Green House Gas) emissions by 29 percent (unconditionally) to 41 percent (conditionally) by 2030 as compared to Business-as-Usual scenario [30]. The distinction between conditional and unconditional targets is that conditional targets will be met only if other developed countries provide finance for clean energy projects in Indonesia, but unconditional targets will be met regardless. Deploying renewable energy sources and taking energy efficiency measures are some successful strategies for achieving these clean energy targets. In the demand sector, the energy use is dominated by industry (36%), transport (34%) and residential (20%). Despite the fact that the residential energy share is modest, household electricity demand is the largest and has doubled in the last decade as shown in Figure 1.1 [31]. The objective of this thesis is to investigate the decarbonisation potential in the residential sector through energy efficiency and rooftop photovoltaic policies. This thesis is crucial as it is one of the few cases in which a balanced approach is chosen between supply side and demand side of the energy system. The outcome of this thesis would be valuable for Indonesian policymakers in understanding the underlying potential of energy efficiency and effectively utilizing it to accelerate Indonesia towards its clean energy ambitions.

1.2 Problem statement

As shown in Figure 1.2 , the residential sector electricity demand of Indonesia is highest amongst all sectors (45%) [31]. It is estimated that electricity demand from houses in 2030 could increase by 1.5 times to 165 TWh in 2030 from 117 TWh in 2021 [32]. With increased urbanization (2.2% annual growth rate), annual Gross Domestic Product (GDP) growth (3.7% in 2021) and income growth per capita (3.8% in 2019), the buying capacity of households will increase and the energy use is expected to surge [33]. Although Indonesian government has an ambitious target of becoming net zero by 2060 [34] and has set a target of reducing 1% annual reduction in energy intensity till 2025 [35], it is not on track to accomplish this goal. The gap between ambition and on-the-ground implementation is a consistent challenge in Indonesia's policy framework. The energy efficiency regulations are relaxed, monitoring and compliance of these standards are limited. The lack of customer awareness regarding energy efficiency is an additional obstacle. Currently, only 6.5 percent of Indonesians are aware of the energy efficiency standards for appliances despite being in place for more than six years. Indonesia reiterated the need for energy security during the recently concluded G20 summit [36]. Evaluating the potential of energy efficiency policies and bolstering them in terms of design, execution, and compliance could aid Indonesian policymakers in achieving energy security and other clean energy objectives.

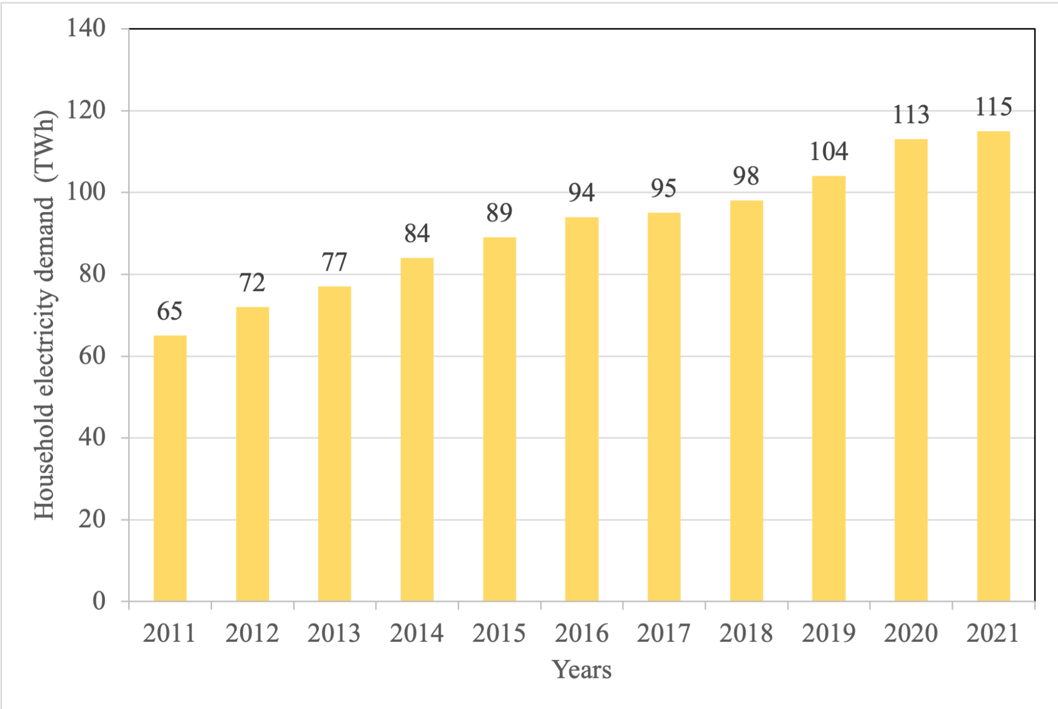

Figure 1.1: Electricity demand growth in Indonesian residential sector [31]

In case of electricity supply side of Indonesia, the growth of renewable energy especially solar energy is weak. With only 0.15 GW of installed solar capacity in 2020, solar contributes to less than 0.05 percent of Indonesia's power generation in 2020 [37]. On-site renewable energy generation is a promising strategy for decarbonising households. As a result of on-site renewable energy production, consumers become prosumers (someone who consumes and generates energy). This has the dual benefit of reducing energy grid dependence and lowering electricity costs, as well as reducing carbon emissions. Currently, the total rooftop PV installation is only 34 MW, with only 8.3 MW deployed on residential rooftops [16]. In stark contrast, Vietnam, another ASEAN nation, has cumulatively installed more than 9 GW of rooftop PV [38] with an astounding growth rate of 2,435% last year (Indonesia's growth rate last year was 8.3%). This transformation can be attributed to Vietnam's successful implementation of Feed in Tariff policies [39]. One of the factors hindering the growth of solar energy in Indonesia is the fossil fuel industry's strong lobbying efforts; as a result, the implementation of some regulations is delayed or watered down [32], [40]. By projecting rooftop PV growth in multiple scenarios of moderate and strong public policy framework, Indonesia could learn and consequently incorporate some lessons learned from Vietnam's growth model.

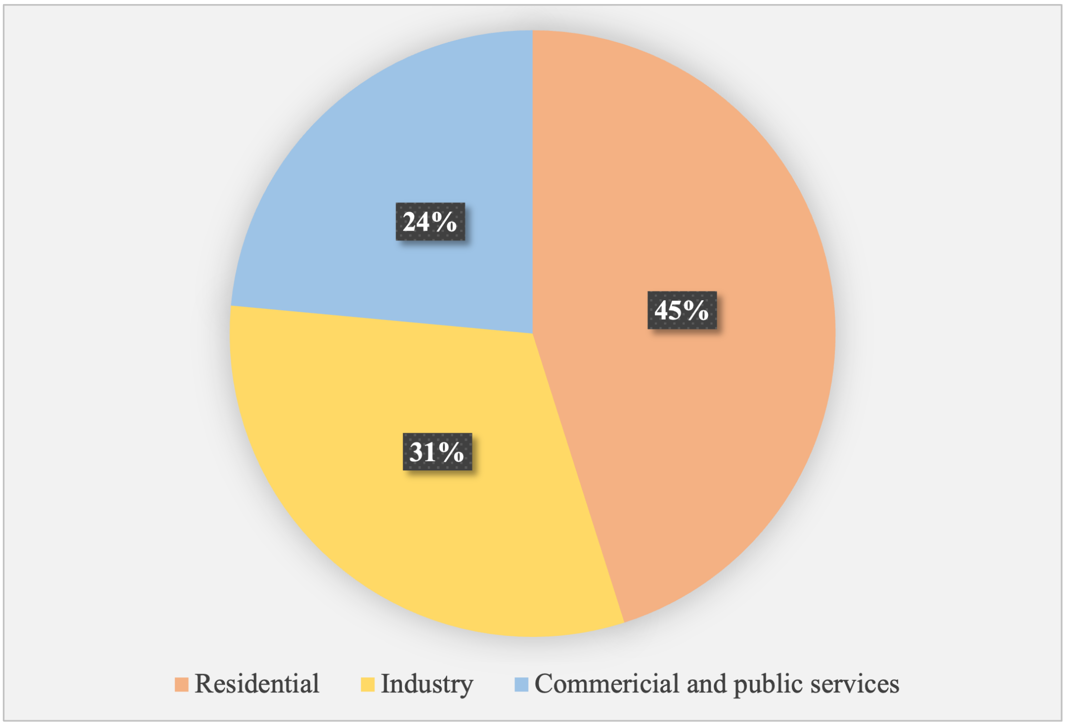

Figure 1.2: Share of electricity sales in various sectors
[31]

1.3 Research objective

The primary goal of this research is to examine the energy saving and energy generation potential of energy efficiency and rooftop PV strategies respectively, in abating the surge of residential sector's energy demand in 2030. Three objectives are used to attain the main research goal. The first objective of this study is to construct energy usage scenarios for household appliances under modest and rigorous energy efficiency regulations. The second objective is to forecast the rise of rooftop PV in various contexts. The final objective of this research is to propose policy recommendations to the Indonesian government to strengthen these policies from design, implementation, and compliance standpoint.

1.4 Research questions and approach

The main research question is

"What is the impact of energy efficiency and rooftop PV policies on Indonesia's residential sector and what policy interventions can be recommended to further increase its impact in 2030?"

The main research questions will be discussed by answering the following sub questions.

1. What is the status of existing research and current regulations of Indonesia's energy efficiency and rooftop solar PV policies in residential sector?

2. What is the impact of the current appliance standards, stringent appliance standards and efficient building envelope design on energy use of household sector in 2030?

3. What is the projected rooftop PV electricity generation in 2030 under various scenarios?

4. What are the policy constraints of current regulations, and what policy interventions can be recommended to enhance the impact of these policies?

The first question is answered by performing a literature study to comprehend the current state of research and then examining Indonesia's existing energy efficiency and rooftop PV policies. To anticipate the impact of these policies under mild and rigorous conditions, different scenarios are developed for the second question. The third question requires forecasting the growth of rooftop PV in different contexts. Finally, the policy constraints of the existing policies are discussed, and policy proposals derived from the above analysis are presented.

1.5 Outline of thesis

This section provides a concise summary of the thesis outline. The Chapter 2 is a literature assessment of energy efficiency and rooftop PV policy publications. Indonesian household sector's current energy efficiency and rooftop PV regulations are also examined in chapter 2. Chapter 3 outlines the research methodology. The outcomes arising from this study method are discussed in Chapter 4. Consequently, chapters 5, 6, and 7 comprise of discussion, conclusion, and further research recommendations respectively.

Chapter 2

Literature and policy review

This section reviews existing literature and policies to better understand the research gap in Indonesia's energy efficiency policy. Recently, Indonesia is getting a lot of traction with respect to research in clean energy primarily because it is the largest consumer and producer of energy in Southeast Asia [27].

2.1 Review of existing literature

In this section, a literature review is conducted to analyze the current status of research on Indonesian energy efficiency, rooftop PV policies for the residential sector, and to learn about the methodology employed in similar studies conducted in other nations. A summary of the literature review can be found in Table 2.1. The literature review to explore energy efficiency in other sectors of Indonesia (industry, transport) is performed in Appendix A.1.

2.1.1 Appliance energy performance standards

In this section, research methods used to analyze the impact of energy efficiency legislation are reviewed, followed by current research in Indonesia. Augustus and Martino [41] evaluate the impact of Minimum Energy Performance Standards (MEPS) of refrigerators in Brazil. Augustus and Martino [41] uses a bottom up approach along with econometric parameterisation to estimate the impact of MEPS, GDP, appliance price, GDP/capita are used to model first the appliance ownership rate. Then the sales are modelled in such a way that it depends on economic growth and increase of households with first appliance purchase. Afterwards, the retirement rate is identified by using probability distribution function of appliance lifetime. By combining all these functions, a stock forecast model is prepared. Two scenarios are taken by Augustus and Martino [41] in this research paper. Base scenario simulates the continuation of current performance standards and ambitious scenario evaluates the impact of stringent appliance performance standards. Finally, the energy savings is calculated by taking the difference of energy use of the stock under these two scenarios. Zhou et al. [42] assesses the impact of MEPS for 37 products in China. Zhou et al. [42] uses two types of bottom up end use model approaches for different categories of products. The Low Emission Analysis Platform (LEAP) model is used for 11 products and is based on demographic, macroeconomic data and the ownership rate of appliances. The other bottom up approach which is based on forecasting of appliance stock is performed utilizing the diffusion, shipment, retirement, and replacement rates. The appliance's diffusion rate is determined by a regression model that takes household income into account. Stock growth saturation is compared with developed nations like the USA and Japan to avoid overestimating sales growth. Three scenarios were developed; a frozen scenario (MEPS level frozen), a scenario of Continued Improvement Scenario (CIS, one level

Table 2.1: Summary of literature review

Reference	**Method**	**Location**	**Sector**		
			Building envelope	**Appliance**	**Rooftop PV**
Augustus and Martino, 2010 [41]	Stock model using Bottom up approach	Brazil		X	
Zhou et al., 2011 [42]	LEAP model	China		X	
Salleh et al., 2018 [43]	Sales model	Malaysia		X	
Hariadi et al., 2016 [44]	Survey	Indonesia		X	
Kusumdevi et al., 2015 [45],	LEAP model	Indonesia		X	
Goudarzi and Mostafaeipour, 2017 [46]	Empirical study and Life cycle costing	Iran	X		
Elnabawi, 2021 [47]	Designbuilder software	Gulf nations	X		
Koirala et al., 2021 [48]	Dynamic panel data	USA	X		
Al-Tamimi and Fadzil, 2012 [49]	Ecotectv5.6 software	Malaysia	X		
Vidinopoulos et al., 2020 [50]	Relation between rooftop area & population density	ASEAN			X
Hamunagan and Hariyanto, 2020 [51]	Bass Diffusion model	Indonesia			X
Silalahi et al., 2021 [52]	Using PV watts/person	Indonesia			X
Tarigan, 2020 [53]	Solargis and RETscreen software	Indonesia			X
Haryadi et. Al, 2016 [44]	ABM	Indonesia			X
Hidayatano et al., 2020 [54]	System dynamic approach	Indonesia			X

revision every four to five years), and Best Practice Scenario (BPS, stringent MEPS to achieve the best technology in the market). By comparing the CIS and BPS scenarios to the frozen scenario, the energy savings are finally computed. It is found that maximum energy saving was accrued from air conditioner MEPS. Salleh et al. [43] demonstrated the energy savings entailed by implementation of MEPS for five appliances in Malaysia. Salleh et al. [43] compares the energy consumption of sold appliances of higher efficiency products (3, 4 and 5 star rated product) to a situation where all sales are of the 2 star rated product (MEPS) using sales data from manufacturers and importers. This model ignores stock growth, retirement and replacement rate of appliances. This method is similar to what policymakers in India and Indonesia use to assess the total energy saved because of the enacted MEPS regulations. [55], [56].

Hariadi et al. [44] analyses the energy efficiency action plan for households of Indonesia. It compares Net Present Value (NPV), energy savings, financial and policy barriers between a high and low energy efficient product like TV, AC, and refrigerator. On similar lines, Kusumdevi et al. [45], focuses on examining Indonesia's energy demand using Low Emission Analysis Platform (LEAP) model for 2050, Business As Usual (BAU) and with energy efficiency scenario in four sectors of household; cooking, lighting, cooling and entertainment system. This research paper highlights that significant energy savings and carbon dioxide mitigation is accrued through energy efficiency measures. Apart from research papers, the policy impact and market assessment on India's and Indonesia's appliances by CLASP, LBNL, PwC was reviewed [24–26, 55, 57–59]. The report by IEA exploring the trends of space cooling in Southeast Asia, energy transition in buildings of Southeast Asia was also reviewed to understand the current regulations of energy efficiency across Association of Southeast Asian Nations (ASEAN) countries [2, 60, 61].

Research gap

According to the CLASP policy database, 47 nations have enacted more than 400 MEPS regulations globally till date, demonstrating the significance and prevalence of MEPS regulation [1]. However, in the Scopus search only one article was found when Minimum Energy Performance Standard and Indonesia was searched. Rahman et al. [62] compare MEPS regulation in Malaysia to other MEPS programs in Indonesia, Singapore, China, and South Korea. Based on comparisons and evaluations of other countries' experiences, final recommendations are provided by Rahman et al. [62] for Malaysia. A knowledge gap is noted in evaluating the effectiveness of current MEPS regulations launched by Ministry of Energy and Mineral Resources (MEMR) for appliances of Indonesia. Although two research papers [45], [44] highlight the scenarios of deployment of efficient appliances but it do not take into account the impact of current MEPS and the impact of continual revision of MEPS on energy use of appliances. This report attempts to fill this knowledge gap.

2.1.2 Efficient building envelope design

In this section, the existing research articles discussing the impact of energy efficient building design is discussed. According to Goudarzi and Mostafaeipour [46], there are different passive cooling techniques (green roof, roof pond, underground buildings and wind catcher) that could be applicable to reduce the cooling load of houses in a city of Iran. All these four methods were implemented on a residential building to verify the actual energy savings and wind catcher was found to be the best in reducing the overall energy demand. One important characteristic of building that determines how its envelope will behave in terms of energy is thermal transmittance, often known as U-value ($W/m^2/K^{-1}$). The amount of heat that passes through a specific element per unit area per time is known as the U-value [63]. Elnabawi [47] evaluates the effects of various building codes for energy efficiency in four Gulf region nations. The prescribed U-value of various country codes are applied on a base residential building model. Following that, the Designbuilder software replicates the energy building performances of the base model under various building codes. The software's data is then used to analyze the peak cooling load reduction, life cycle costing, and simple payback period [47]. Koirala et al. [48] assesses the effectiveness of energy efficiency laws in 48 states of USA during the period of 1990 to 2017. They use a dynamic panel data model and a two-step generalized method to calculate the residential energy consumption per person. The study also highlights an interesting finding, namely that theoretical energy savings from energy efficiency codes are inflated by about 32%. Liu et al. [64] emphasize the impacts of energy-efficient building rules in China in terms of energy, environmental, and economic factors. For China's urban and rural areas, this study proposes two scenarios with varying degrees of building energy efficiency code enforcement. The residential energy is then modelled as a function of floor space and determines how much energy is saved in the two scenarios once energy-efficient building rules are put in place. This research suggests that energy-efficient building not only has a direct impact on energy savings, but also contributes to economic growth and pollution reduction. Al-Tamimi and Fadzil [65] explores how four passive envelope designs, which are outlined in Malaysia's green building regulations, can enable high rise residential structures to reduce their annual and peak cooling loads. The dimensions of an actual residential twin tower in Malaysia serve as the basis for the Ecotectv5.6 software's simulation of the cooling energy reduction. The basic cooling load is determined by the software using information such as the room's dimensions, air infiltration, Coefficient of Performance (COP) of the cooling system, temperature conditions, and other data factors. Next, the model simulates the reduction in cooling load for each passive design strategy, such as window to floor ratio, thermal insulation, glazing, and external shading. The article underlines that the best method to minimize the cooling demand and peak cooling load is thermal insulation [65].

Presently, government buildings of Indonesia have 46% less efficiency than commercial buildings because of lack of proper examination of environmental impact assessment [66]. Sahid et al. [66] proposes certain green procurement principles which could enhance energy savings in buildings. According to Puspitasari et al. [67], Indonesia has made four laws for green buildings. Puspitasari et al. [67] analyses these green policies related to buildings and found that although these laws are prevalent but still these green building laws need to be implemented in regional levels by mayors. And without mandating the implementation of these laws in cities, stakeholders will be cautious in investing green buildings [67]. In the end,Puspitasari et al. [67] proposes some qualitative recommendations to address this issue. Further, green buildings need to be profitable for the investors to be interested, a study analyses the life cycle cost assessment of a green building in Indonesia [68].

Research gap

Eight research papers were discovered after searching Scopus for keywords; energy efficient building and Indonesia. These papers mainly discuss the impact of Overall Thermal Transfer Value (OTTV) on the cooling energy use [69], the effect of efficient building envelope in achieving net zero energy homes [70], and how building envelope design in Indonesian office buildings can reduce cooling energy use by up to 43% [71]. However, the impact of new residential building with efficient envelope design in reducing cooling energy of the overall residential sector of Indonesia has not been evaluated and this knowledge gap is being addressed in this report.

2.1.3 Rooftop PV

This section discusses the literature that has already been published on a variety of topics related to rooftop photovoltaic, including technical potential, projected growth, and economic evaluation. Vidinopoulos et al. identify and evaluate the technical potential of various renewable energy sources in ASEAN nations. In order to project the development of rooftop PV, a relationship between rooftop area and population density is used. Vidinopoulos et al. [50] also takes into account annual efficiency improvement of 0.5 percent newly installed panels. The technical potential of urban rooftop solar energy is calculated to be 1042 TWh in Indonesia [50]. Hamonagan and Hariyanto [51] make projections on Indonesian residential rooftop PV growth from 2020 to 2030 in relation to declining PV prices. Using the prior sales data, a Bass Diffusion model is used to forecast long-term diffusion of rooftop PV in the market. Frank Bass designed the Bass Diffusion model, which depicts the penetration of new products in the market as a relationship between existing consumers and prospective consumers [72]. This approach classifies rooftop PV adopters into initiator and imitator categories. The PV adoption rate is modelled as a function of historical sales, price, number of first buyers, coefficient of initiators and imitators. It only takes into account Jawa Bali residential houses that does not receive any subsidies. The final results demonstrate that faster rooftop PV growth saturation is attained when solar PV price drop increases [51]. Silalahi et al. [52] make predictions on how several solar technologies, including ground-mounted, agrivoltaics, floating solar PV, and urban rooftop PV, will contribute to meeting Indonesia's electricity demand in 2050. In 2050, Silalahi et al. projects that Indonesia's total annual electricity consumption would be 9000 TWh. The rooftop PV growth rates in Australia, Singapore, and Indonesia are first compared and then, Singapore's rooftop PV watts per person is computed and those findings are extrapolated for Indonesia. By using this technique, the estimated 2050 electricity output from rooftop solar in Indonesian cities ranges from 50 to 1700 TWh [52]. Tarigan [53] evaluates the net metering policy of MEMR, launched for homeowners with rooftop PV systems of Indonesia. The approach used by Tarigan involves selecting a house in Surabaya. Solargis software is then used to simulate the solar output potential from a 3 kW_p. Renewable-energy and Energy-efficiency Technology Screening (RETscreen) simulation is used to measure the economic and environmental benefits. Tarigan highlights that even with the conservative net metering regulation, the payback period is still in the range of 9 to 10 years in Indonesia.

Another relevant study by Hariadi et. al [44] uses agent-based modelling (ABM) to examine the rooftop PV adoption rate among Indonesian residential end customers. The ABM is used to simulate the impact of PV price reductions, subsidies, and electricity sales by rooftop PV owners to PLN on the adoption rate among Indonesian residential users. According to Hariadi et al. [44], subsidies have a less significant effect on adoption rates than price reductions. Haryadi et al. [44] makes the interesting discovery that neighbours installing PV and a community's acceptance of the new technology have an impact on Indonesian residential rooftop PV adoption. Hidayatano et al. [54] employs a system dynamic approach along with policy analysis framework to assess the effectiveness of net metering and net billing policies on the adoption rate of rooftop PV in Indonesia. Outhred and Retnanestri [73]compare the rapid expansion of rooftop PV in Australia to that in Indonesia and offers policy recommendations to enhance rooftop PV implementation in Indonesia. Do et al. [39] examines Vietnam's key drivers for solar and wind growth in order to offer recommendations to other ASEAN nations. Do et al. [39] uses an approach that involved reviewing relevant literature and conducting structured interviews with stakeholders. Strong social and political support, public awareness about air pollution, gracious FiTs (Feed in Tariffs), and the lack of local component requirements are determined to be the main drivers for the tremendous growth of solar PV in Vietnam. Do et al. [39] highlights that the Vietnam model suffered from certain flaws like; short deadline for

FiT, uncertainty of regulations, and a weak electrical transmission system.

Research gap

Two research publications have addressed how the price of PV and subsidies affect rooftop PV growth in Indonesia. But no study explored the electricity generation potential in Indonesia if rooftop PV was developed at a faster pace, e.g. as seen in Vietnam. This report addresses this knowledge gap by replicating the rooftop PV growth of Vietnam in Indonesia to understand lessons learned from Vietnam model.

2.2 Review of current Indonesian policies

Indonesia's present energy efficiency and rooftop PV legislation are evaluated in this section. This part is essential for comprehending the policy framework, its scope, and limitations in order to assess its effect on the energy structure. Ministry of Energy and Mineral Resources (MEMR) is the supreme body responsible for drafting energy-related regulations, Ministry of Public Works and Housing is responsible for drawing up green building regulations, and Ministry of finance is responsible for allocating incentives, rebates, and tax exemptions resulting from energy efficiency regulations. Under MEMR, seven General Directorate with diverse functions and responsibilities are in place. In this research, only three General Directorates are relevant:-

- General Directorate of New and Renewable Energy (NRE)- responsible for formulating energy laws related to renewable energy supply.
- General Directorate of Electricity - responsible for formulating energy laws related to electricity.
- National Energy Council (DEN) - tasked with setting long term energy plan for the nation by designing energy outlook.

The residential energy efficiency laws, such as those governing rooftop solar policy, efficient building envelopes, and appliances, will be the main emphasis of this study.

2.2.1 Appliance energy performance standards

In this section, the energy efficiency regulations pertaining to appliances in Indonesia are first examined and then compared with other countries. Nearly all households have appliances which consumes energy. In a business as usual case, the energy efficiency of appliances in the market grow at a small rate which leads to appliance stock consuming higher energy over time. To tackle this energy rise, the policymakers implement minimum energy performance standards (MEPS) to transform the market towards efficient appliances and consequently reduce energy rise. This works by banning the sale of products below a threshold efficiency. With continuous upgrading of these thresholds the energy savings are increased as the efficient appliances become embedded into stock and reduce the overall operation energy use. Same logic is applicable to comparative labelling. Comparative labelling which is followed by Indonesia provides thresholds for different efficiency classes of appliances. In Europe the comparative energy labeling exists from (A-G), in Indonesia it exists from (1 to 5 star) with A and 5 star being the most energy efficient. So far Indonesian government has enacted MEPS regulations for four appliance namely; air conditioner, refrigerator, rice cooker and fans. In the following section, each of these regulations is discussed in detail.

Table 2.2: Existing energy performance standard for Indonesian appliances [11–14]

Appliances	**Performance metric**	**Performance thresholds**				
		1 star	**2 star**	**3 star**	**4 star**	**5 star**
Air conditioner	CSPF	3.1	3.4	3.8	4.2	5
Refrigerator	AEC (kWh/year)	0.85*Vadj+270	0.75*1 star	0.75*2star	0.75*3star	0.75*4star
Rice cooker	HE (Wh/litre)	250	230		190	170
Fans (blade size less than 12 inches)	SV (m^3/min)	0.6	0.72	0.84	0.96	1.08
Fans (blade size greater than 12 inches)	SV (m^3/min)	1	1.2	1.4	1.6	1.8

- Air conditioner (AC)- First appliance to have mandatory energy performance thresholds in Indonesia was air conditioner. This was introduced in 2015, and the standard was updated in 2021 [16]. All split air conditioner models, both inverter and non-inverter, up to a cooling capacity of 27000 Btu/hr (2.25 Ton of refrigeration or 7.9 kW) are covered by the regulation. The energy performance parameter is Cooling Seasonal Performance Factor (CSPF). The CSPF is the ratio of cooling energy supplied by air conditioner in whole year to the electrical energy consumed by it during the standard testing conditions of SNI ISO 5151:2015. The energy performance table (star rating table) for air conditioner is given in Table 2.2 and this scheme is valid for next four years [11].

- Refrigerator- Last year in 2021, the performance standards for 3 new equipment were launched and refrigerator was one of them. Unlike air conditioners, refrigerators have a higher penetration rate in the households. This standard covers all types of refrigerators till a capacity of 300 litre, with rated voltage not exceeding 250 V [13]. The energy performance parameter is annual energy consumption of the refrigerator in standard operating test conditions as mentioned in the standard SNI 8557-3:2018. The energy performance thresholds are given in the Table 2.2.

- Rice cooker- Rice cooker performance standard was launched last year in 2021. This regulation is applicable to all rice cookers with rated voltage not more than 250 V and upto a capacity of 3 litres. Electrical rice cooker with a function of warming and cooking is most popular in Indonesia. The electrical energy consumption for rice cooker is calculated as per SNI IEC 60335-1 standard [14] and the energy performance index is Heating Energy (HE) in Wh/l, which is electricity consumption for cooking per litre. The start rating table for rice cooker is provided in Table 2.2.

- Fans- In a tropical nation like Indonesia, homeowners rely primarily on fans to achieve thermal comfort. The regulation launched in 2021 together with rice cooker and refrigerator, it covers all types of fans with blade diameter from 6 inches to 24 inches. The energy performance indicator in case for fans is service value. Service Value (SV) is calculated by taking ratio of airflow capacity (m^3/min) to power input to the fan (watt) at the specified voltage and frequency as per SNI IEC 60879:2013 standard. As the size of blade increases the energy performance increases, so there are two energy ratings as shwon in Table 2.2 one for blade diameter less than 12 inches (less stringent) and other for blade diameter greater than 12 inches more stringent) [12].

In the years ahead, MEMR intends to roll out performance criteria for the following appliances: blender, water pump, washing machine, iron, induction cooktop, and electric motor [74].

2.2.2 Comparing performance standards with other countries

Energy saving by improving energy efficiency of the appliances is not a new phenomena and many countries in the past have used this policy instrument. The first energy efficiency standard for appliance was launched in California in 1970s which lead to reduction of energy use of refrigerators by 75%. Developing economies are usually lagging in developing the appliance standards [1]. As per European Commission [75], by 2030 energy savings from energy labels of 10 product groups will be more than 230 million tonne of oil equivalent. As more and more appliances are brought under the gambit of appliance performance standards the energy savings increases significantly. Starting in 2009, India launched 11 mandatory appliance performance standards and it saved 56 Billion units in 2019 [59]. The Table 2.3 compares Indonesia's current adoption status of appliance performance standards with other countries. As visible from the table, China and the EU implemented MEPS far earlier, therefore they have higher number of appliances covered by MEPS and as a result saved more energy over time. If an appliance standard is adopted early on, the penetration of efficient appliances in stock increases over time, and energy savings are significantly higher than with a country that implements MEPS later on. Figure 2.1 shows that Vietnam is the front runner in ASEAN region for MEPS, with a total of 18 MEPS regulations implemented since 2005. A list of all MEPS regulations in the ASEAN countries is provided in the Appendix A.4.

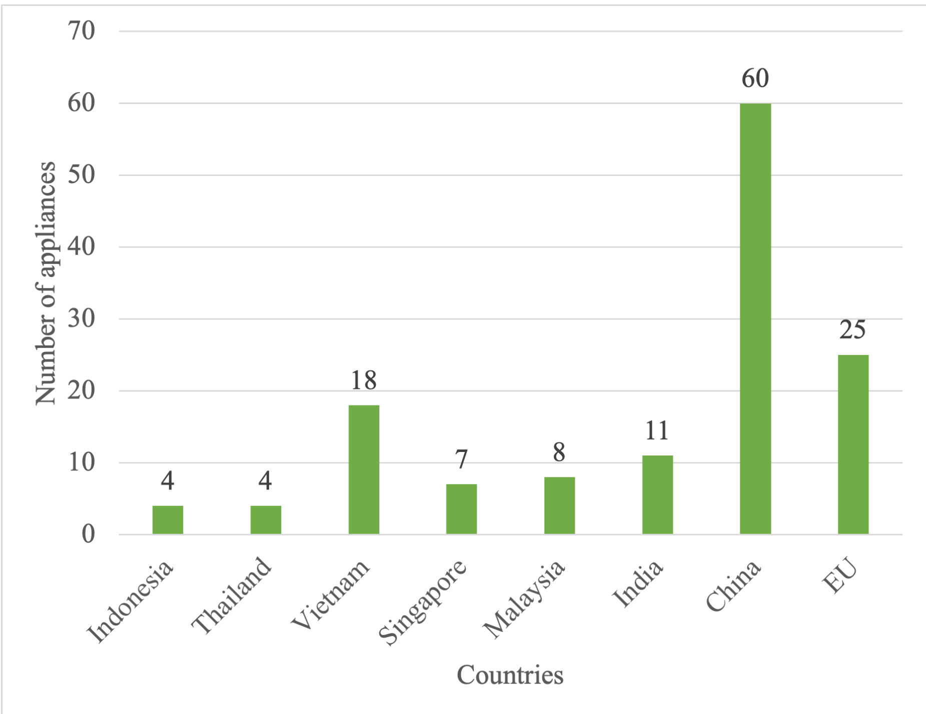

Figure 2.1: MEPS regulations in different countries as of 2022 [1]

Table 2.3: Comparing countries based on MEPS adoption (2022) [1]

Countries	**Appliances with mandatory MEPS**	**Year first MEPS launched**	**Major appliances**
Indonesia	4	2015	AC, fans, rice cooker and refrigerator
Thailand	4	1993	AC, refrigerator, lights, Washing machine
Vietnam	18	2005	AC, fans, refrigerator, water heater, washing machine, lights, TV, rice cooker, computers and others
Singapore	7	2012	TV, lights, cloth dryer, AC, refrigerator and others
Malaysia	8	2013	Washing machines, air conditioners, fans, microwave oven, refrigerator, rice cooker, TV, lights
India	11	2009	AC, refrigerator, fans, lights, water heater, TV and others
China	60	1989	Fans, TV, microwave, refrigerator, water heater, air conditioner, rice cooker,cooktop, washing machine and others
EU	25	1979	Dish washer,washing machine, cloth dryer, TV, refrigerators, lights, AC, ovens, space heaters, water heaters and others

To establish ambitious policy objectives, it is vital to compare Indonesia's energy efficient standards and technology to those of other nations. This section compares Indonesia's MEPS (minimum energy performance standards) and BAT (best available technology) with those of other countries. While analyzing these standards, it should be kept in mind that each country has its own methods for determining energy performance standards, such as varied ambient conditions, distinctive hours of operation etc.

As seen in Figure 2.2, Figure 2.3 and Figure 2.4 Indonesia is still capable of achieving higher efficiencies, as the best performing appliance presently in the market for each appliance category is vastly superior to corresponding Indonesia's current MEPS. For example, the energy efficiency of the most advanced air conditioning equipment is nearly double that of Indonesian air conditioners. Despite the availability of efficient appliances, a relaxed MEPS promotes inefficient products in the market, therefore undermining the clean energy objectives. As shown in Figure 2.3, the Indonesian refrigerator MEPS, in particular is much lenient as compared to other appliance. For instance, a MEPS refrigerator in the European Union consumes less than half energy as compared with a MEPS refrigerator in Indonesia. However, it should be noted that the data points presented in Figure 2.3 are based on the performance of a refrigerator with storage capacity of 165 litres. These results cannot be directly compared because the method of measurement, the testing standard, and the ambient temperature vary between countries. Apart from this, the individual volume of freezer compartment, wine compartment, fresh food compartment could also influence the energy consumption the refrigerator.

In the case of air conditioners, as shown in the Figure 2.2, Indonesia's MEPS remains slightly lower than that of the best-performing ASEAN country (Thailand), as well as that of India. The energy performance of various countries in the Figure 2.2 is of 2.6 kW cooling capacity air conditioner. However, it should be emphasized that outdoor conditions used by each country is different, thus the comparison is not as straightforward in the case of air conditioning. A study by Nihar et al. examine the different temperature profiles used by different nations and attempts to develop a harmonized standards for comparing the performance of air conditioners from several nations on a single platform. According to this method, the best available technology of air conditioner has a COP of 11.80, which is close to the best value shown in the Figure 2.2. The disparity in appliance access between the various locations is another intriguing aspect. In the case of an air conditioner, this phenomenon is common. Compared to high income, urban groups, air conditioning penetration rates in rural areas and low income groups will be significantly lower [76].

The performance standards of lights is usually set in technologically agnostic manner meaning irrespective of any technology used the MEPS will be same for all type of lights. For example EU has set a uniform MEPS for lights as 90 lumen/watt (barring incandescent lights). In India, however, there are different performance standards for CFL (65 lumen/watt) and LED lamps (90 lumen/watt) [6]. In this study, only the energy performance of LED lamps is considered. The energy performance by Indonesian LED lamps is comparatively better than rest of appliances, as the energy performance of its best LED lamp is close to the best in the world (20% difference). LED lamp performance is measured in terms of luminous efficacy (lumen/watt). As illustrated in the Figure 2.4 , the best LED lamp in Indonesia is comparable to the best LED lamp in India and ASEAN countries. There is presently no MEPS for LED lamps in Indonesia which has led to the market dominated by less efficient LED lamps of 65 lumen/watt despite the availability of LED lamps with 134 lumen/watt [24].

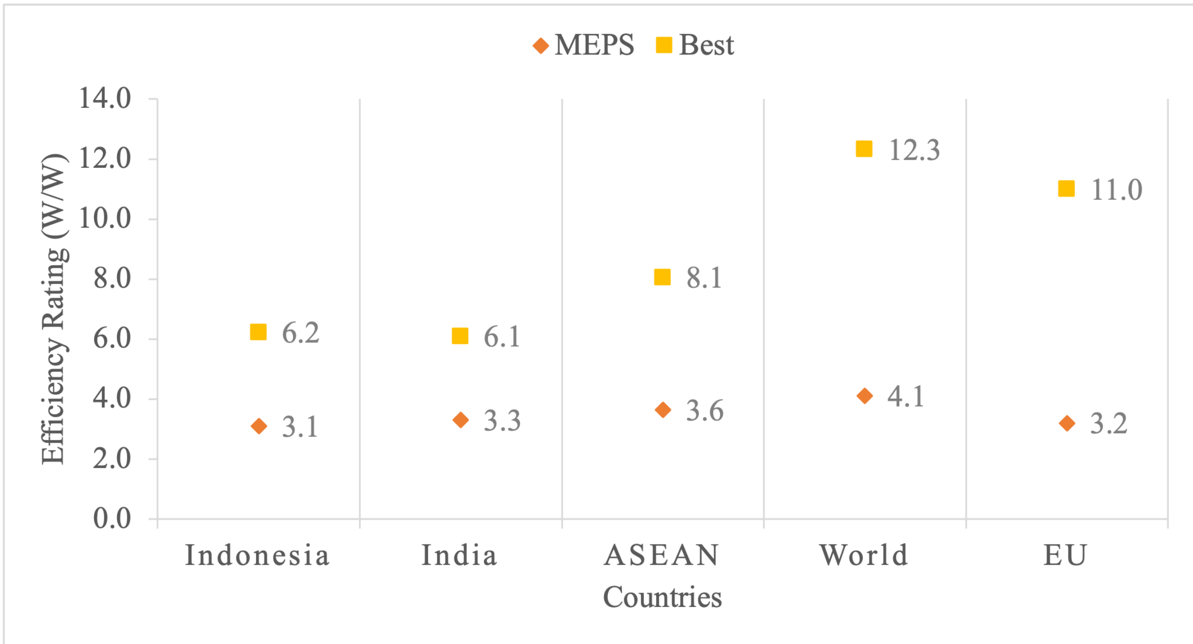

Figure 2.2: Efficiency of AC in different countries. [2].

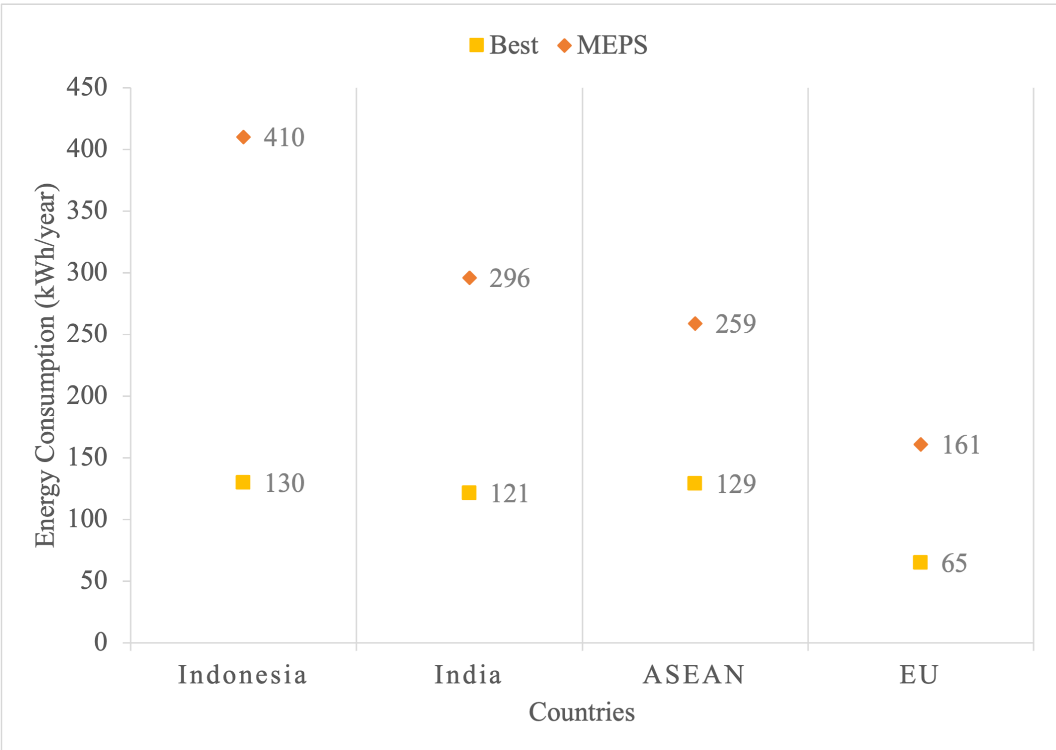

Figure 2.3: Efficiency of refrigerators in different countries [3–5].

2.2.3 Transforming towards efficient appliances

After comparing the efficiencies of appliance across various countries, in this section the various technologies available in these appliances are explored. The majority of air conditioners in the current Indonesian market is fixed speed AC model. Depending on the room's specified temperature, the fixed speed compressor operates either in the on or off mode. Since these compressors only have two states of operation for any cooling load, they are inefficient and

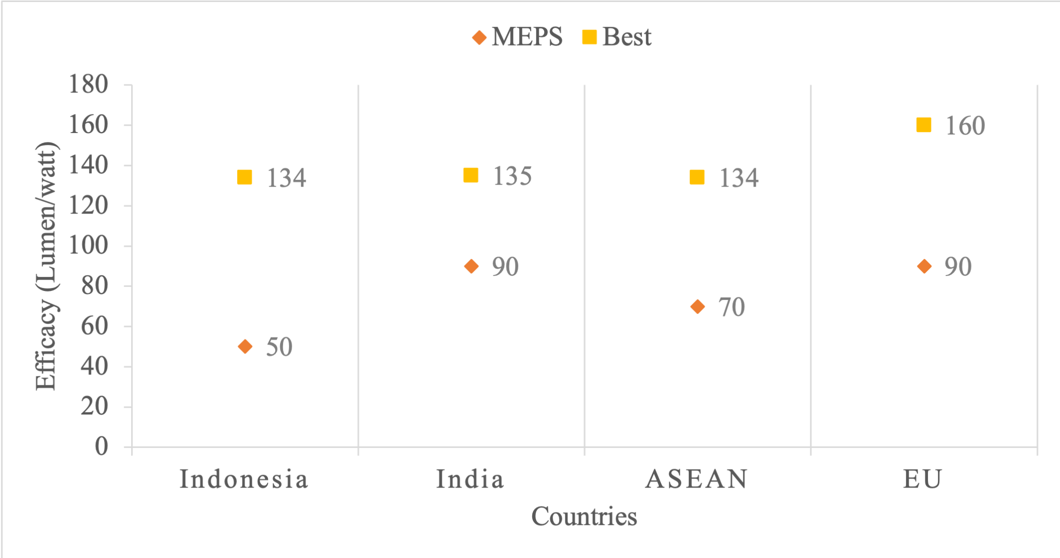

Figure 2.4: Efficacy of LED lamps in different countries. [4], [6].

typically use more energy while in use. As an alternative, inverter air conditioners or variable speed air conditioners have multiple steps in their operation and have the ability to alter the speed of the compressor in response to a changing cooling demand, so they can effectively deliver the necessary cooling [55]. Shah et al [77] emphasise that advancements in air conditioners involves use of advanced compressor technologies that are calibrated for low frequency operation, large heat exchangers coupled with thermodynamically effective materials, efficient DC fan motors, sophisticated metering devices, and smart sensors for temperature and humidity control. Refrigerants with a low global warming potential (GWP) are utilized in the most modern, most energy-efficient room AC models, which minimizes the direct carbon emissions from air conditioners [77].

The majority of refrigerators sold in Indonesia are direct-cool models with no forced cooling (comprising 60 percent of the market).The natural cooled refrigerators has more chances of frost being accumulation due to uneven cooling. Although frost free refrigerators provides better cooling and eliminates frost development, it has higher energy use due to heating coils to remove frost accumulation. Improved design, brush-less DC motors, and inverter compressors are a few examples of innovative, efficient technologies in refrigerators [78].

The majority of rice cookers in the Indonesian market use electrical resistance, with an efficiency range of 72% to 86%. Induction heating and induction pressure are more efficient technologies with efficiency in the range of 83% to 89% and 85% to 92%. The capacity of the rice cooker, the heating element, the number of functions it can perform, and the insulation all affect how much energy it uses. It is possible that the most appropriate insulation for the consumers' health might not be the most efficient insulation for reducing energy costs . Digital timers may shorten the standby or warming duration, which could be advantageous [26]. It can be observed from MEPS Table 2.2 of rice cooker that as volume increases the MEPS become more stringent. This is to account for the fact that as rice cooker's volume increases, its efficiency also increases.

Inefficient incandescent and compact fluorescent bulbs could be replaced by energy efficient LED lighting. CFLs also produce mercury waste, and the Minamata treaty of the United Nations calls for the eradication of mercury in all appliances [79]. Therefore, from an energy-savings and mercury-reduction standpoint, it would be advantageous to shift the lighting industry to more efficient LED bulbs with longer lifespans.

2.2.4 Efficient building envelope design

The principal thermal barrier between the interior and exterior of a building is formed by the building envelope. It determines the level of comfort, natural lighting and ventilation, as well as the amount of energy necessary to heat and cool a building. Building energy consumption in ASEAN is predicted to rise by 60 percent by 2030 and 120 percent by 2040 as compared with year 2020, with energy efficiency measures potentially reducing this trend by at least 20% [15]. As per an IEA report [61], the operation energy usage of building can be reduced by 40% alone via efficient building envelope. The efficient building envelope technologies can include exterior shading and architectural feature, low-SHGC (Solar Heat Gain Coefficient) windows, reflective roofs and wall coatings, optimised natural/mechanical ventilation [80].

Ministry of Public Works and Housing (MPWH), Indonesia recently revised and launched the green building regulation in 2021 [81]. The regulation MPWH 21/21 covers both residential and commercial buildings. The development of green buildings is fairly limited in Indonesia because these standards are not mandatory. The first green building regulations implemented at the municipal level focused on Java, starting in Jakarta in 2012, followed by Bandung in 2016 and Semarang in 2019 [82]. In Indonesia, more than 100 buildings have achieved voluntary green building certifications, and more than 3,000 buildings have met statutory green building requirements, totaling more than 20 million square meters [83].The green building regulation considers the whole life cycle of building from design stage to demolition and provides points to each energy saving/green measure implemented. Higher the points, higher the energy savings. Energy efficiency has a weightage close to 27% in the overall performance rating [81]. In this thesis the energy efficient building envelope design component of the green building regulation is focused upon, which are:-

- Reduced Window to wall ratio
- Overall Thermal Transfer Value (OTTV) less than 35 W/m^2. OTTV (W/m^2) measures the amount of heat transfer from the envelope of the building into the building as per ASHRAE 90A-1980
- Proper ventilation and shading

Apart from technical details, this regulation also offers financial incentives to the end user like reduced permit and service fees, reduced land and building taxes, technical support and advice from green building experts, reward in form of certificate, placard, for increasing the uptake of efficient buildings in Indonesia.

2.2.5 Comparing building envelope regulations with other countries

In developed economies like EU, building energy performing standards are present [84]. Similarly, in India, energy conservation building codes and energy rating regulation has been enacted for buildings [59]. In 2020, 23 percent of the total energy consumed in ASEAN region was from the buildings and according to ASEAN 6th energy outlook, 20% of energy growth in 2040 can be mitigated through energy efficiency [85]. ASEAN countries have launched building energy codes, labelling program and incentives for promoting efficient buildings. The Table 2.4 gives a summary of building energy efficiency policies in the major countries of ASEAN.

Table 2.4: Building energy efficiency regulation in ASEAN countries as of 2022 [15]

Countries	**Building energy codes**	**Labelling/ Certification**	**Incentives**
Indonesia	X	X	X
Malaysia	X	X	
Singapore	X	X	X
Thailand	X	X	X
Vietnam	X	X	X

2.2.6 Rooftop PV

This section examines the existing regulations enacted by government for rooftop PV. In 2013, the rooftop PV regulation was first introduced. This regulation has been revised numerous times, and the final regulation (MEMR regulation 26/2021) was released in 2021 [86]. Recent regulation introduces the notion of net-metering for families with rooftop PV and boosts the export/import limit to 100 percent. Previously, this was set at 65 percent, which meant that if a homeowner draws 100 units from the grid, only 65 percent of the 100 units generated from rooftop PV could be transmitted back to the grid. The additional electricity units supplied to the grid by a homeowner are used as credit for a period of six months. This provides an incentive for customers to install more residential rooftop PV to lower their energy consumption from the grid, hence reducing their energy cost and payback period for rooftop PV.. This bill will expedite the completion of projects by reducing the licensing requirements for rooftop PV systems. For residential families, the capacity and emergency fees will be waived. The reporting and monitoring procedures have been made completely electronic, minimizing bureaucracy [86]. However, this new regulation has been put on hold citing financial losses to PLN. In addition to the aforementioned rule, the Indonesian Ministry of Energy and Mineral Resources (MEMR) and the United Nations Development Programme (UNDP) Indonesia have created a solar rooftop incentive scheme. This incentive is intended to encourage the installation of rooftop solar systems, especially among PLN users from families, businesses, and small and medium-sized industries. Based on expert interview, it was found that residential rooftop PV owners are not allowed to install rooftop PV system with capacity exceeding 1.15 times the connected power capacity of the user.

In 2017, the One Million Rooftop Solar Initiative, or Gerakan Nasional Sejuta Surya Atap (GNSSA), was launched with the goal of boosting solar energy production and use in Indonesia, particularly rooftop solar photovoltaic applications. The Initiative aims to reach one million homes/buildings with a minimum rooftop solar installed capacity of 1 kWp or a total installed capacity of 1 GWp. [87]. Since 5 years of this initiative, it failed to reach even 4% of its target. The rooftop PV rules and guidelines of Indonesia have not been much successful in increase the uptake of rooftop PV. Residential owners are hesitant to buy rooftop PV owing to high upfront cost and pay back period of 9-10 years [53].

2.2.7 Comparing rooftop PV installation with other countries

Figure 2.5 illustrates the share of renewable electricity in total electricity among key Asian nations, as well as the fraction of solar energy in installed renewable electricity capacity. Vietnam, Thailand and Malaysia are doing better as compared with respect to Indonesia in terms of solar energy deployment. With only 0.15 GW of installed solar PV capacity, Indonesia lags far behind other nations in rooftop PV. The Table 2.5 compares solar and rooftop PV installation in Indonesia and other nations. China has the largest installed capacity for solar PV (307 GW) and rooftop PV (27.30 GW). In the ASEAN region, Vietnam has the most rooftop PV installations (9.5 GW), followed by Thailand (0.6 GW). The high growth in Vietnam can be attributed to gracious FiTs [39].

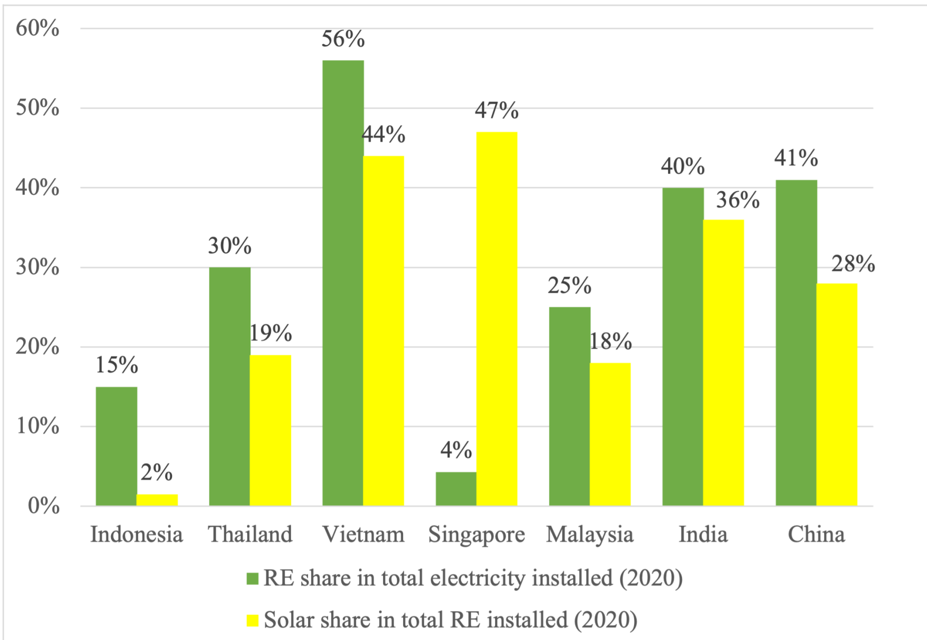

Figure 2.5: Share of renewable and solar PV installed power capacity by 2020 [7], [8]

Table 2.5: Total solar PV and Rooftop PV installation in various countries by 2021 [16–23]

Countries	**Solar PV installed (MW)**	**Rooftop PV installed (MW)**
Indonesia	155	34
Thailand	2,900	599
Vietnam	16,500	9,500
Singapore	632	60
India	40,000	7,000
China	306,000	27,300

2.2.8 Policy constraints

After review of the Indonesian efficiency and rooftop PV rules, this section examines the major limitations of these regulations. Indonesia has only four MEPS regulations, which is significantly less than other ASEAN nations such as Vietnam and Malaysia, who have released twice as many regulations for appliances [1]. The limited adoption of MEPS is a significant impediment, given that energy efficiency is a low-hanging fruit. By expanding the adoption of MEPS, energy savings across sectors could be enhanced. A robust network of laboratories capable of conducting both research and development (R&D) and compliance testing is crucial for advancing the development of energy-efficient home appliances. According to CLASP's market research studies [24–26], there are just a handful of testing labs for fans (5), freezers (12), rice cookers (12), and lights (5). Even among the existing testing labs, some are not accredited with the required testing standard; for instance, only two of the twelve labs that test refrigerators are accredited. Accreditation of testing tabs is crucial for preserving the reliability, accuracy and repeatability of test results. As a consequence, the annual testing capacity of Indonesia is quite low, which further contributes to weak monitoring. For example, consider the annual sales of refrigerators in 2020 which were 2.73 million, and highest annual testing capacity of Indonesian laboratories is just 4,800, which implies Indonesia can test less than 0.2% of all refrigerators sold on the market. For more details on the testing capacity of other appliances refer Appendix A.2. In India, a system of compliance checks is in place to continuously monitor the efficiency of appliances. If a manufacturer fails to comply with the MEPS in India, the manufacturer could be banned and the appliance model would be advertised in the news media as shown in Figure 2.6 [88]. However, no evidence of a robust compliance regulation was discovered for Indonesia.

Based on expert interview, it was found that there are no financial incentive in place to promote efficient buildings. This is primarily due to poor cooperation between governmental agencies. The lack of horizontal coordination between the ministries and vertical coordination between the central government and provincial government results in lax implementation of regulation and, as a consequence results in even lenient monitoring and compliance.

Despite the fact that the new legislation regarding net metering in the rooftop PV sector could increase rooftop PV penetration, it has been placed on hold due to financial losses to PLN [40]. According to the new business electricity plan of PLN (RUPTL), the obstacles to rooftop PV deployment are: oversupply of electricity; increased cost of generation for keeping the generators in buffer; investment cost to upgrade technologies for precise forecast of energy supply and demand; and grid strengthening may incur additional operational expenses [32]. The high up-front cost of efficient equipment and rooftop PV is also a barrier, as end users prefer cheap energy regardless of its source [89]. The mandatory local content regulation for photovoltaic is an additional barrier to PV's adoption as domestic producers cannot compete with cheap imported PV [40].

Despite the fact, that Indonesia has established some significant laws for appliances, rooftop PV, and buildings, it is still plagued by inadequate implementation, execution, and compliance. Understanding these limitations is crucial for overcoming these shortcomings.

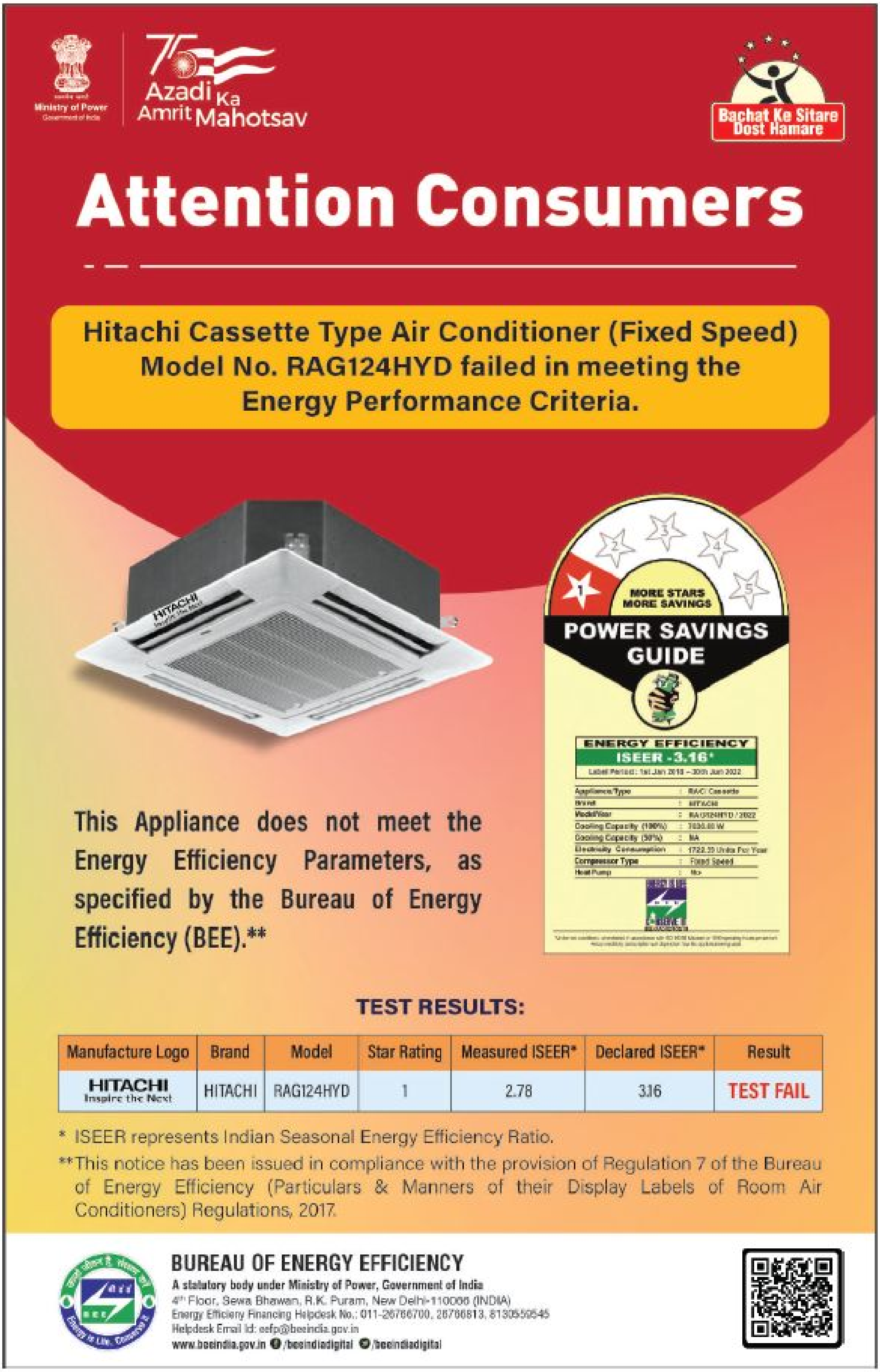

Figure 2.6: Public notice by the Indian government about an appliance which failed to meet its prescribed MEPS during compliance testing [9].

Chapter 3

Methodology

This section discusses the research method employed for this study. The aim of this report is to evaluate the emission mitigation potential of Indonesia in 2030 from three specific strategies; efficient appliances (rice cooker, refrigerator, lights, air conditioner), efficient building envelope to reduce cooling energy demand and rooftop PV deployment in the residential sector of Indonesia in 2030. First, the overall research method is reviewed in 3.1, then in section 3.2 the method to forecast the energy use of appliance stock in residential buildings is discussed and finally in section 3.3 the research method to forecast rooftop PV electricity generation in 2030 is examined. An overview of the entire research framework used for the projection is shown in Figure 3.2.

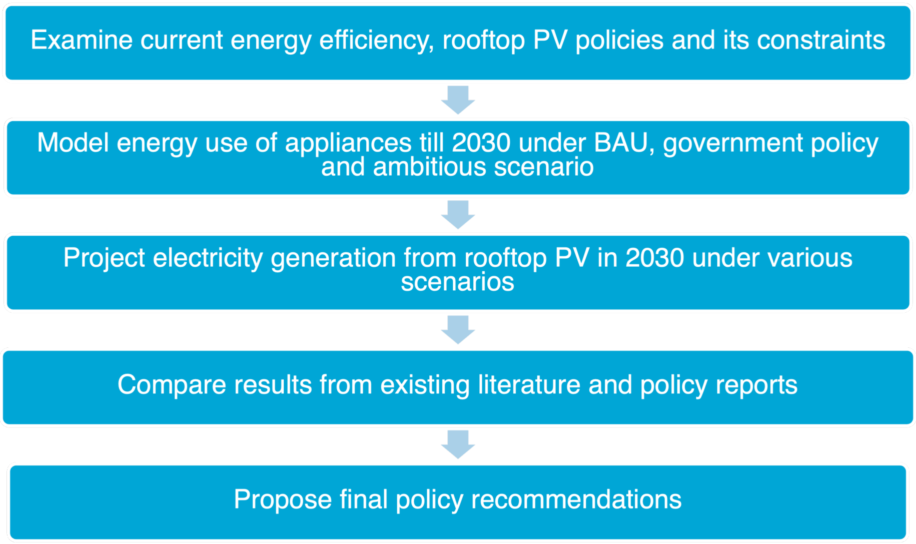

Figure 3.1: Research Methodology

3.1 Research method

As shown in Figure 3.1, the research methodology consists of examining the coverage, constraints of present energy efficiency and rooftop PV policies pertaining to the residential sector of Indonesia, then using the stock model bottom-up approach to forecast the energy use of households appliances till 2030 under various scenarios. Thereafter using PVWatts software and the growth rate of PV in different contexts, projection of rooftop PV electricity till 2030 is performed. The results obtained are compared with existing literature or other policy reports. Finally, the Indonesian government is presented with policy recommendations based on the

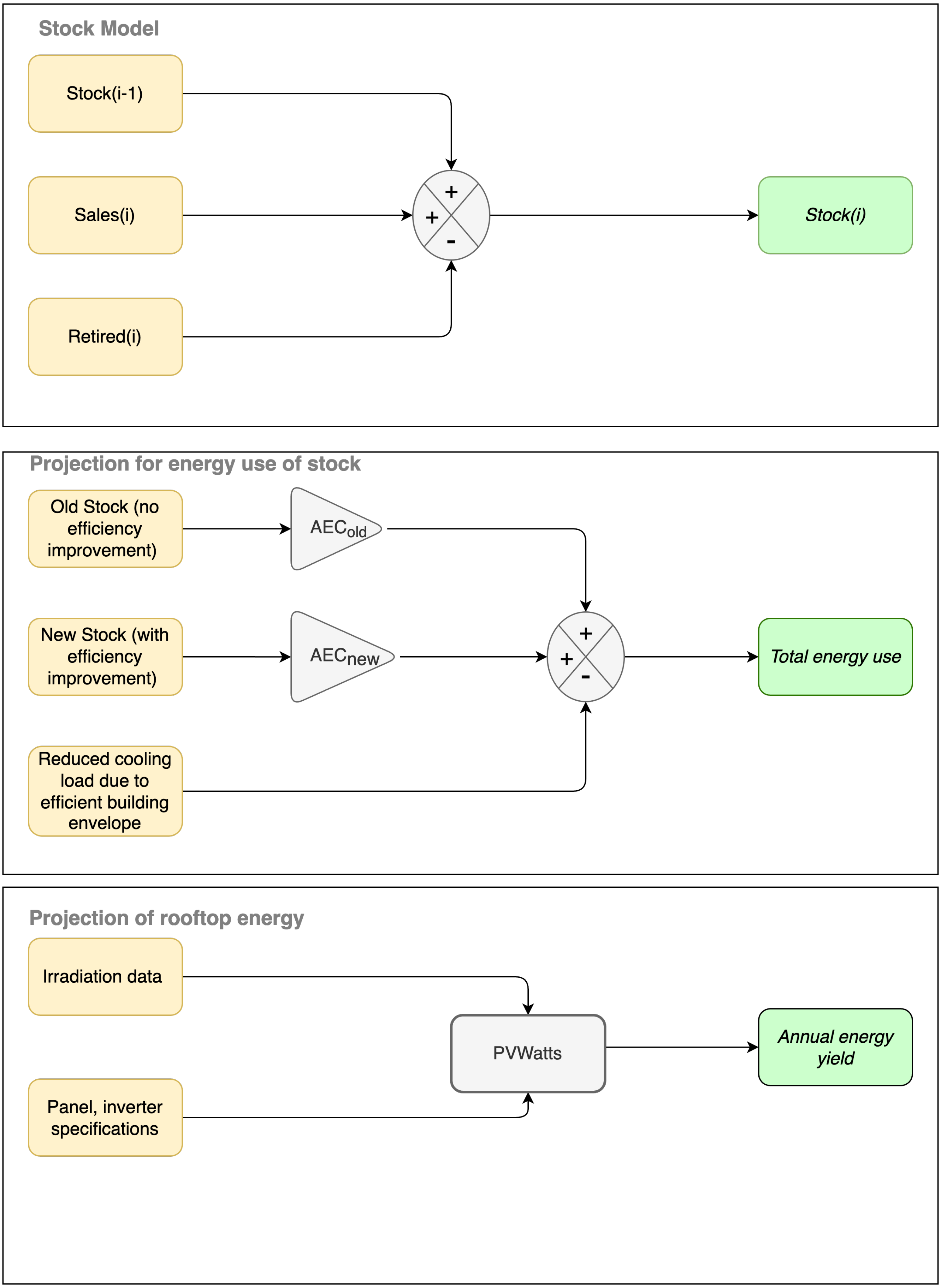

Figure 3.2: Overview of the research framework. *i is corresponding year. AEC is annual energy consumption of corresponding appliance.*

above analysis. The policy review of energy efficiency and rooftop PV regulations is already done in Section 2.2. During the course of this research, eight interviews were conducted with six unique Indonesian stakeholders, including residential end users, NGOs, financial institution, and government. During the discussion with two non-governmental organizations and one financial institution, sector-related statistics, policy reports, market survey reports, and policy compliance regulations were discussed. Two household end-users were interviewed to confirm the accuracy of secondary data collected and to assess the general understanding of energy efficiency in Indonesia. A government stakeholder provided information about the government's organizational structure, government publications, the implementation status of policies, and policy limitations. An overview of all interviews conducted is provided in the Table 3.1.

Table 3.1: List of interviews conducted with various Indonesian stakeholders

Date	**Actor Type**	**Topic discussed**			
		Appliances	**Rooftop PV**	**Buildings**	**Other**
13/10/2021	Residential end user	X			X
11/01/22 & 28/07/22	NGO	X			X
28/01/2022	Financial Institution		X		X
17/02/22 & 08/03/22	NGO	X	X	X	
08/03/2022	Residential end user	X			X
23/05/2022	Government		X		X

3.2 Energy usage projection for household appliances

The research method employs bottom-up approach to develop stock model for appliances in order to project their energy use till 2030. In this section, the steps involved in the modelling projected energy use of appliances till 2030 is discussed. Although an average Indonesian household uses more than 10 appliances, this report only considers air conditioners, refrigerators, refrigerators, and LED lamps because they account for 73% of household electricity use of an average Indonesian household, according to the CLASP residential survey report published in 2020 [57]. The growth of air conditioners is particularly interesting because of the high growth potential in the future and the massive energy savings that it can provide. In the subsequent sections, the stock model to project the stock growth is discussed in section 3.2.1, method to forecast energy usage of projected stock is examined in section 3.2.2, various scenarios of stock growth is reviewed in section 3.2.3, and lastly the model inputs data assumptions are mentioned in section 3.2.4.

3.2.1 Stock model

Before projecting the energy use of stock, it is crucial to develop a stock model using bottom up approach to evaluate the growth of stock from 2023 to 2030. The projection of appliance stock is dynamic and is influenced by factors such as population growth, rising appliance ownership rates, urbanization, and electrification rates [90]. The existing stock, stock growth, sales growth for each of the four appliance is primarily taken from different market survey reports done for Indonesia from 2019 to 2020. The stock model is described in the equation (3.1). All the four appliances have their own stock growth, sales growth which is influenced by the retirement of appliances and the sales of the new appliances.

$$\text{Stock}(i) = \text{Stock}(i-1) + \text{Sales}(i) - \text{Retired}(i) \tag{3.1}$$

The growth of the stock and sales is verified in relation to the increase of households. Penetration rate of an appliance is the share of households possessing that appliance. Penetration rate cannot exceed 100%. Based on the available reports, the annual retirement rate as a percentage of total stock for refrigerator, air conditioner, rice cooker and LED lamps was found to be in the range of 3%, 4-6%,7.5 -9%,11-13% respectively [2, 24–26, 58, 91, 92]. Amongst the households which own the particular appliance, ownership rate gives the average number of appliances in these households. The stock, penetration rate and ownership rate is related to each other as per equation 3.2. For example, the penetration rate of air conditioner is projected to be 34% a in 2030, then it means that 34% of the households have atleast one air conditioner in their house Amongst these houses, the ownership rate of AC is estimated to be 1.3 in 2030.

$$Stock = Households * Penetration(\%) * Ownership(number) \tag{3.2}$$

3.2.2 Method to forecast energy usage of appliances

After estimating the stock growth, the energy use of household appliances in Indonesia is forecasted by selecting a model as a representative of the entire particular appliance stock. To analyse the energy use of entire stock of the respective four appliances, a representative model which is the most popular model in the households is chosen and its annual energy consumption (AEC) per year is calculated in kWh/year. It is assumed that all the future sales and existing stock of appliances is comprised of the same representative model. The efficiency improvements are applied on the sales of the new appliances from 2023 till 2030. Over the years, the new efficient appliances get embedded into the stock and the total energy use of the appliances will grow at a smaller rate. It is assumed that all MEPS revision will take effect at the beginning of the year and all sales of efficient appliances and appliance retirements will take place at same time. The energy use calculated for each appliance, depicts the operational annual energy use of respective appliance stock at the end of each year. Additionally, it is presumed that stock does not change over the course of the year. The energy use of appliance stock in each year is calculated by the equation (3.4). For more details on the calculation method referA.3.

$$E(i) = \sum_{2023}^{i} \text{Sales}(i) * AEC_{new}(i) + \left(\text{Stock}(i) - \sum_{2023}^{i} \text{Sales}(i)\right) * AEC_{2022} \tag{3.3}$$

where $E(i)$ is the energy use of the particular stock of appliances like air conditioner in i^{th} year, $Sales(i)$ is the annual sales of the particular appliance in i^{th} year, $AEC_{new}(i)$ is the annual energy consumption of the typical efficient appliance sold in i^{th} year, $Stock(i)$ is the total stock of appliances in i^{th} year, AEC_{2022} is the annual energy consumption of the typical model which represents the entire stock in year of 2022.

3.2.3 Scenario description for appliances

The objective of projecting various scenarios in 2030 is to evaluate the energy use of these household appliances in 2030 under business as usual , government policy and ambitious scenarios. These scenarios could help the policy makers understand the impact of stringent policy regulations on the final energy usage of Indonesia. The period of analysis is from 2023 to 2030.

1. *BAU scenario* – Annually, the specific energy consumption of all household appliances, with the exception of the rice cooker, will decrease by 1 percent. For rice cookers, 0.75 percent of annual autonomous improvement in specific energy consumption is accounted for.

2. *Government policy scenario* – The present validity of the energy performance rating table of appliances (launched in 2021) is 4 years, so it's assumed that government will upgrade one level every four years i.e. 2025, 2029. MEPS of LED (Light Emitting Diode) lamps is assumed to be launched in 2023 (based on expert consultation) , so revision in case of LED will be in 2027.

3. *Ambitious scenario*- In this scenario, MEPS of the appliances will be upgraded one level every two years in 2023, 2025, 2027, 2029 for reaching close to the BAT (Best Available Technology) for respective appliances in current Indonesian market.

4. *Ambitious plus efficient building envelope scenario* –This scenario is an extension of ambitious scenario and only exists in case of air conditioner because only the cooling energy reduction from efficient building envelope is considered in this thesis. This scenario takes into account energy savings from reduced cooling load due to efficient building envelope design for all new residential buildings commencing from 2025, as well as energy savings from the ambitious scenario described above. In this scenario, first the cooling energy demand of all the new homes is reduced by efficient building envelope and then rest cooling demand is met by best available cooling technology. The year 2025 was chosen instead of 2023 because building projects that already have permits could take until 2025 to finish.

Finally the energy savings in the government policy scenario and ambitious scenario, as shown in Equation (3.5) is calculated by subtracting the respective energy usage of the stock in these scenarios with the BAU scenario. Similarly, the emissions mitigated in each scenario (3.6) is calculated by multiplying the energy saved with the grid emission factor 0.826 ton CO2equivalent/kWh.

$$E(i) = \sum_{2023}^{i} \text{Sales}(i) * AEC_{new}(i) + \left(\text{Stock}(i) - \sum_{2023}^{i} \text{Sales}(i) \right) * AEC_{2022} \tag{3.4}$$

$$ES(i) = E(i)_{ambitious} - E(i)_{BAU} \tag{3.5}$$

$$EM(i) = ES(i) * 0.826 \tag{3.6}$$

where, E(i) is the energy use of the stock, ES(i) is the annual energy saved, EM(i) is the emission mitigated.

3.2.4 Data inputs and assumptions

After discussing the stock growth model and forecasting energy use of appliances, in this section the input parameters and data assumptions taken in the model are discussed. The Figure 3.3 shows the method to estimate the annual energy consumption of Indonesian air conditioner.

For calculating the annual energy consumption of the representative model of an typical air conditioner, Indonesian government developed a model for 2920 hrs of annual AC operation, but it was not available in public domain. Therefore, the methodology used by India (partly tropical nation) was used to project the annual energy consumption of a typical air conditioner model. India's AC energy usage model estimates the annual energy consumption of AC by considering the outdoor temperature ranging from 16 degree to 43 degree for different amount of hours (temperature bins) for a total of 1600 hrs [88]. ISO 16358 standard is the standard which explains the procedure to develop these temperature profiles depending on the type of weather of each country. The energy value obtained from this model was for 1600 hrs [88] (India's standard) which is then proportionally scaled to 2920 hrs (Indonesia's standard). To integrate the impact of efficient building envelope design in reducing the cooling load, IEA [61] reports that in tropical countries building envelope can reduce cooling demand energy usage from 10% to 40% . The IPCC sixth assessment report Working Group III [93] states that various building envelope technologies can save energy ranging from 0 to 65%. Considering these two values, the energy saving potential by reduction of cooling load was taken to be a conservative 30% value in new urban households and 10% in new rural households. It was assumed that new rural households will only have fans and new urban households will have air conditioners, so energy saving potential in urban households will be higher.

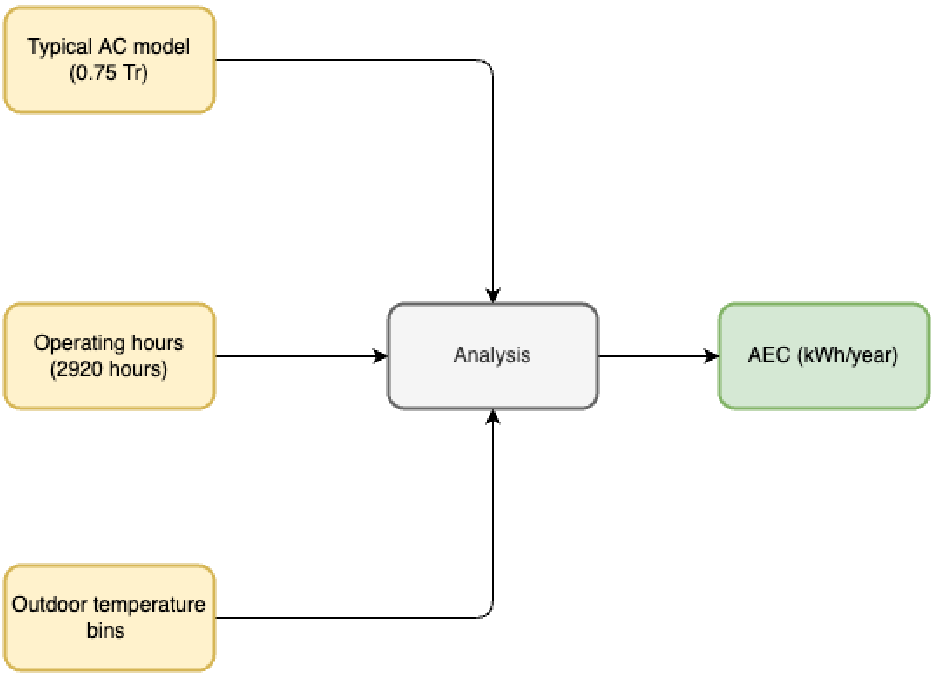

Figure 3.3: Calculation of Annual energy consumption for air conditioner in kWh/Year

The Figure 3.3 illustrates the approach to estimate the annual energy consumption of Indonesian air conditioner. For refrigerator, the annual energy consumption is a function of its storage volume, as depicted in the energy performance rating Table 2.2 of refrigerator. In case of refrigerator a typical model of 165 litre was taken as the representative model for Indonesian market and then the annual energy consumption (AEC) was calculated as shown in Figure 3.4.

The efficiency of electrical rice cookers in Indonesia ranges from low efficiency (electrical resistance) at 72% to high efficiency (induction heating) at 92% [26]. The total electricity usage of rice cooker is the sum of cooking energy, warming energy and standby energy as given in equation (3.10). The energy consumption of the rice cooker during cooking, warming and standby period is calculated by the equation (3.7), (3.8), (3.9) respectively [26]. Finally, all these energy are added and the whole sum is then multiplied with 365 to obtain the annual energy

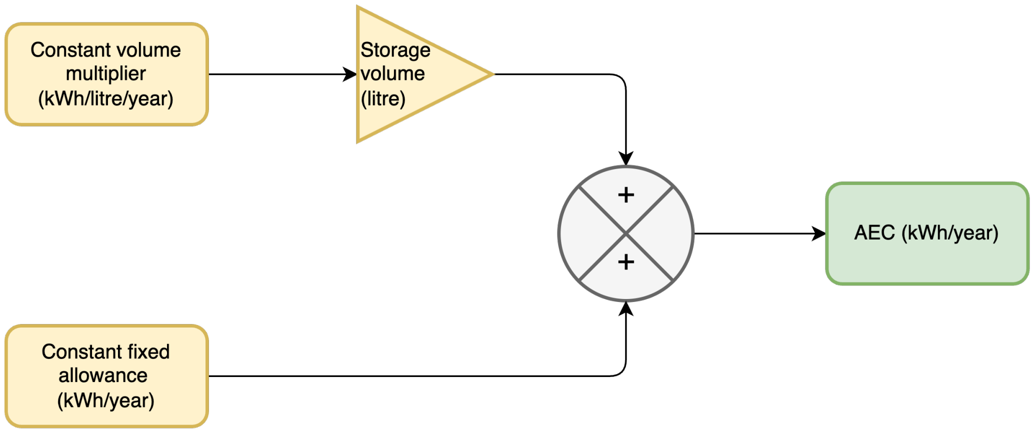

Figure 3.4: Calculation of Annual energy consumption for refrigerator in kWh/Year

consumption of rice cooker (3.10). The discussed method is explained graphically in Figure 3.6.

In case of LED lamps, the daily usage of lamps in Indonesian household is found to be 7.6 hrs. The annual energy consumption is calculated by multiplying the market average of LED lamp with the annual hours of operation as shown in the Figure 3.5

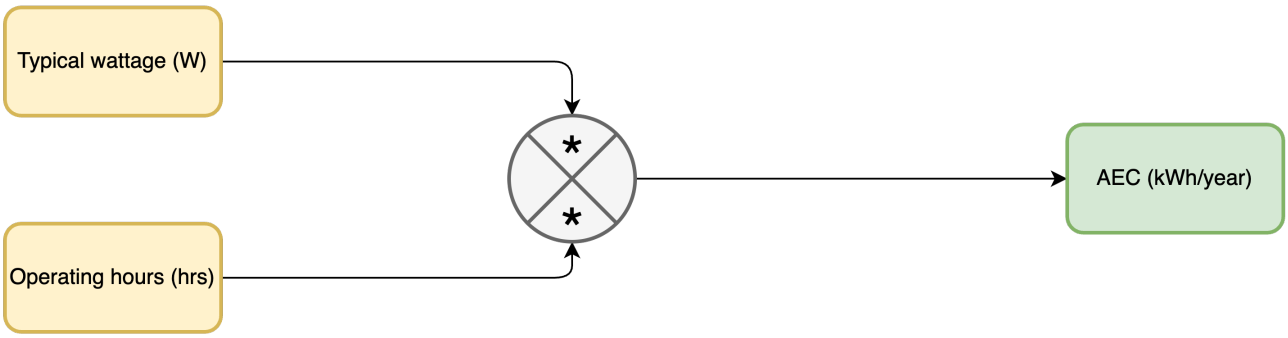

Figure 3.5: Calculation of Annual energy consumption for LED lamps in kWh/Year

$$E_{cooking} = (m * C_p * \Delta T)/\eta \quad (3.7)$$

$$E_{warming} = W_{warm} * t_{warmingperiod} \quad (3.8)$$

$$E_{standby} = W_{standby} * t_{standbyperiod} \quad (3.9)$$

$$E_{rice} = (E_{cooking} + E_{warming} + E_{standby}) * 365 \quad (3.10)$$

Where E_{rice} is the annual electricity used by rice cooker, $E_{cooking}$, $E_{warming}$, $E_{warming}$, $E_{standby}$, is the daily electricity consumption of a typical rice cooker during cooking, warming and standby mode. m is the mass of water, C_p is specific heat capacity of water, Δ T is the temperature difference. The temperature gradient represents the difference between water at room temperature (23 degree Celsius) and water that has been heated to 95 degrees Celsius [26].

An overview of all data inputs and assumptions taken for projecting energy use of the air conditioner, refrigerator, rice cooker and LED lamps is mentioned in Table 3.2, Table 3.3, Table 3.4 and Table 3.5 respectively.

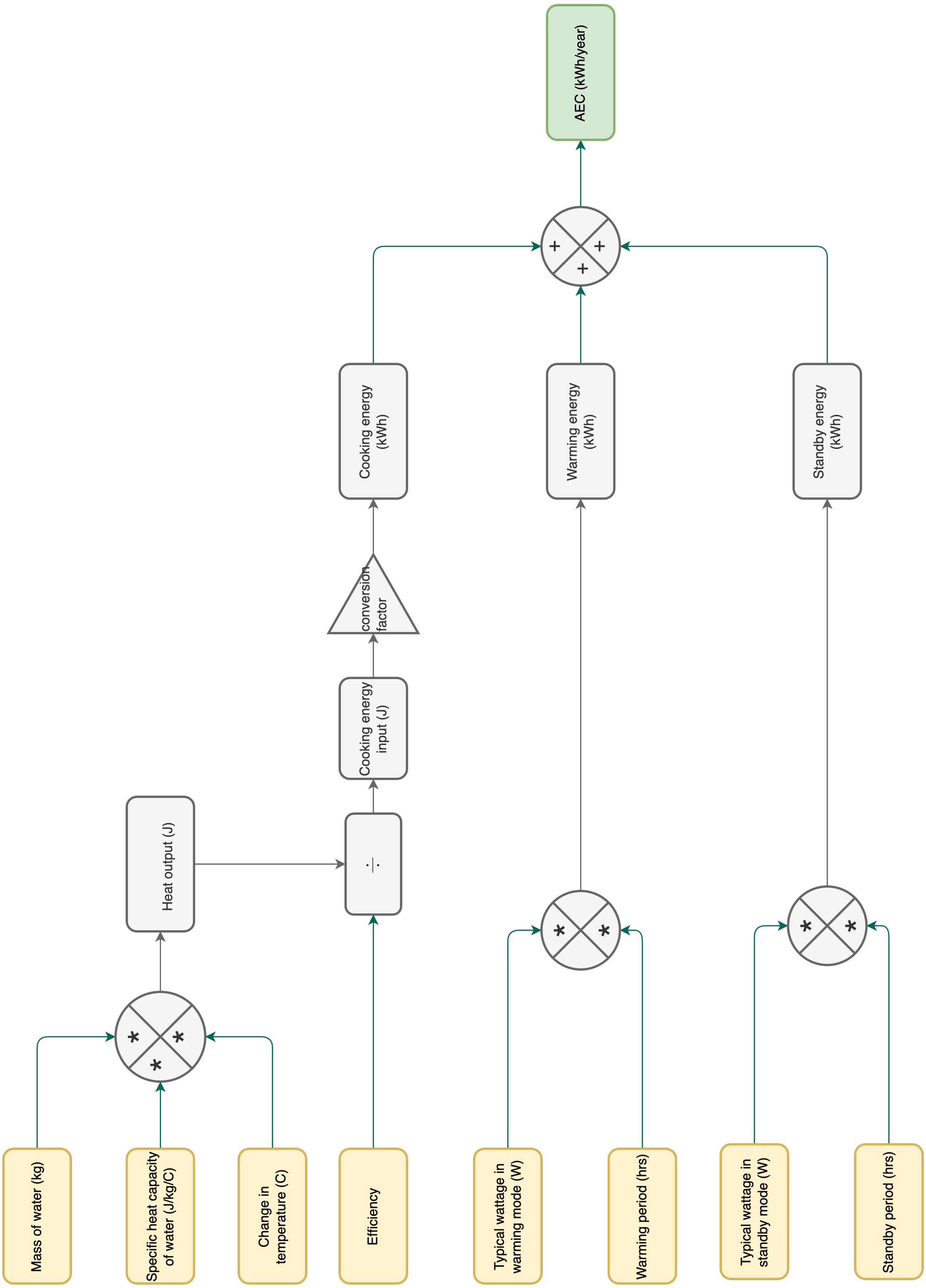

Figure 3.6: Calculation of Annual energy consumption for rice cooker in kWh/Year

Table 3.2: Air conditioner- Data inputs and assumptions taken

Item	**Value taken**	**Reasoning**	**Alternate values**
Representative model	0.75 Tr (tonnes of refrigeration) air conditioner	0.75 Tr (2.6 kW)is taken as 0.5 Tr was too small.	0.5 Tr model taken in clasp residential survey report of Indonesia [57]. 0.75 Tr is taken by LBNL's Indonesian AC report.In India, the market is dominated by 1.5 Tr AC [55].
Stock projection in 2030	35.8 million AC	The stock data as per MEPSy database [92] seems reasonable as other projections lead to higher penetration of AC. Also the MEPSy database revised in May 2022 seems more updated.	Stock data in 2030 as per UNESCAP report on Indonesia is 26.7 million [91], as per IEA it is 52 million [60] and as per MEPSY database stock is 35.8 million [92].
Annual hours of operation	2920 hrs	Based on expert consultation, it is confirmed that Indonesian government takes 2920 hrs for energy saving calculation.	2044 hrs as per LBNL's Indonesian AC market report [58]. 2628 hours as per Ipsos residential survey report [57]. 1600 hours is taken in India's energy saving methodology [59].
Presence of MEPS	Yes	The MEPS standard was launched in 2021 [11]	
Gap between consecutive performance level	10%		
Year of MEPS revision in "government policy scenario"	2025 and 2029	4 year revision cycle	
Year of MEPS revision in "ambitious scenario"	2023, 2025, 2027, 2029	2 year revision cycle	

Table 3.3: Refrigerator-Data inputs and assumptions

Item	**Value taken**	**Reasoning**	**Alternate values**
Representative model	165 Litre volume	Both 165 litre and 185 litre makes sense. In this report, 165 litre storage volume refrigerator considered.	185 litre taken in EDS survey of Indonesian refrigerator market [25]. 70% of the refrigerator market has volume less than 200 litre [25]. Report by U4E takes 165 litre as typical model for ASEAN region [5]. Refrigerators with 160-180 litre have the highest sales in India [94].
Stock projection in 2030	64.90 million	Stock data from MEPSy database and PwC report figures are close, so 64.90 million figure was taken.	Stock data in 2030 as per UNESCAP report of Indonesia is 91.2 million [91]. As per MEPSy database and PwC survey report of refrigerator market, the stock projection in 2030 is 64.9 million [92] and 70.7 million [25] respectively.
Annual hours of operation	8760 hrs	Refrigerator is usually operating throughout the year in households.	Both PwC report for Indonesia and India's energy saving calculation takes 8760 hrs of operation [59], [56]. Whereas in residential survey of Indonesian households done by CLASP, 8505 hrs was found [25].
Presence of MEPS	Yes	The MEPS standard was launched in 2021 [13].	
Gap between consecutive performance level	25%		
Year of MEPS revision in "Current MEPS scenario"	2025 and 2029	4 year revision cycle	
Year of MEPS revision in "BAT MEPS scenario"	2023, 2025, 2027, 2029	2 year revision cycle	

Table 3.4: Rice cooker- Data inputs and assumptions

Item	Value taken	Reasoning	References
Representative model	1.8 litre dry rice volume	Highest market share is 1.8 l.	AAs per rice cooker market survey of CLASP [26], 88 % of rice cooker are in the range of 1-2 Litre and the highest share is of 1.8 Litre. 70% of the people buy a rice cooker in range of 300-450 wattage [26]
Stock projection in 2030	85.40 million	The stock of 85.40 million [26] seems to be on a higher side , but no other data source for rice cooker was found.	The stock of 85.40 million [26] seems to be on a higher side , but no other data source for rice cooker was found.
Daily hours of operation	1.5 cooking event of 1hr, warming period of 6 hours, standby period of 16.5 hrs	As per CLASP report, an average household has 1.4 cooking events with 68% of the events in range of 30 min-1hr [26]. Warming period per household is 5.6 hrs [26]. Rest of hours were taken to be for standby mode.	
Presence of MEPS	Yes	The MEPS standard was launched in 2021 [14].	
Gap between consecutive performance level	8%		
Year of MEPS revision in "Current MEPS scenario"	2025 and 2029	4 year revision cycle	
Year of MEPS revision in "ambitious scenario"	2023, 2025 and 2027	2 year revision cycle. After three revision maximum efficiency (BAT) present in the market reached.	

Table 3.5: LED lamps- Data inputs and assumptions

Item	Value taken	Reasoning	Alternate values
Representative model	11 Watt LED model	11 Watt is higher than India's average wattage (9.65 W) and it seems reasonable.	Typical model was taken to be 11 W with 60 lumen/watt efficacy in PwC's lighting report of Indonesia [24]. 7 watt is taken in UNDP-GEF report of Indonesia [95]. The average wattage for LED in India is 9.65 Watt.
Stock projection in 2030	446 million	The stock of 446 million seems to be on a higher side.	As per PwC survey report of Lighting market of Indonesia, the 44% of market of Indonesia consists of LED lights, 42% of CFL lights and rest is from incandescent light in 2019 [24]. By 2030, the entire stock is projected to comprise only LED lights. The same data was used by UNDP report to prepare the road map for energy efficient lighting in Indonesia [95].
Annual hours of operation	2774 hrs	7.6 daily hrs seems reasonable.	PwC report [24] and UNDP-GEF report [95], both takes 7.6 hrs of daily operation of lights in residential homes. In India, however the operation of hours is 1200 hrs (3.3 hrs daily [59]).
Presence of MEPS	No	The MEPS standard is assumed to be launched in 2023 with MEPS being 60 lumens/watt.	
Expected gap between consecutive performance level	18%		
Year of MEPS revision in "Current MEPS scenario"	2023 and 2027	4 year revision cycle	
Year of MEPS revision in "BAT MEPS scenario"	2023, 2025, 2027, 2029	2 year revision cycle	

3.3 Method to project rooftop PV energy generation till 2030

The electricity generated from rooftop PV is calculated by using National Renewable Energy Laboratory's software named as PVWatts [96]. PVWatts estimates annual and monthly electricity production for a grid-connected rooftop or ground-mounted photovoltaic system based on design parameters and irradiation data input. The model uses the meteorological data of a location to determine the solar energy incident on the panel, the temperature model to simulate the effect of loss of efficiency due to temperature increase and finally the panel, inverter efficiency to arrive at the final annual energy yield in kWh/kWp rooftop PV [96].

An essential component of estimating rooftop PV energy output in Indonesia is determining the appropriate geographic location, as the average solar irradiance varies considerably across the country. The average daily solar irradiation of Indonesia is 4.625 kWh/m^2 according to Solargis report of Indonesia, 2017 [97] and it is 4.81 kWh/m^2 according to a MEMR rooftop PV document of 2020 [98]. As close to 60% of the population resides in Java [99] and the most populous city is the Jakarta [100], the location of Jakarta is taken for calculating the rooftop PV energy generated. Furthermore, the highest rooftop PV installation is in Jakarta [16]. So it seems logical to assume that majority of future rooftop PV installation would occur at or near Jakarta. The annual electricity generation each year from rooftop PV installation can be calculated from equation 3.11

$$E_{RTPV,i} = RTPV_{yield}(kWh/kW_p) * RTPV_{installed,i}(kW_p) \tag{3.11}$$

where $RTPV_{yield}$ is the annual energy yield in kWh/kW$_p$ calculated from PVwatts software. $E_{RTPV,i}$ is the electricity generated from rooftop PV in year i, $RTPV_{installed,i}$ is the total rooftop PV capacity in the year i.

3.3.1 Scenario description for rooftop PV

For projecting the rooftop PV impact till 2030, three scenarios will be depicted.

1. Business as usual scenario - In this scenario, it is assumed that growth rate of rooftop PV observed in 2020 to 2021 will continue till 2030. The rooftop PV growth rate of 32% in the year (2020-2021) is taken as the compound growth rate until 2030, and the rooftop PV electricity generation from 2023 to 2030 is found out. In this scenario, the rooftop PV capacity could reach to 100 MW by 2030.

2. Government policy scenario - Indonesian government has set a rooftop PV target of 3.6 GW [101] in 2025 and 13 GW [102] in 2030. This scenario is used to simulate these growth targets set by government by taking linear growth rate from 2023 to 2025 and then from 2025 to 2030.

3. Ambitious scenario - This scenario is used to imitate Vietnam's rooftop PV growth in Indonesia. Given that Vietnam is an ASEAN nation and has similar electricity consumption (15% difference) [28] it is interesting to investigate Vietnam's rooftop PV growth model in Indonesia to comprehend the lessons learnt from Vietnam's solar experience. The growth of rooftop PV is estimated for Indonesia to be 10 GW in 2023 and 2024, followed by 5 GW each year from 2025 until 2030. Limited grid capability to accommodate the enormous increase in rooftop PV is the reason for reducing power added from rooftop sources in the years after 2025. The installed rooftop PV power will be close to 50 GW by the end of 2030.

Chapter 4

Results

The results from the research methodology are discussed in this section. The section 4.1 examines the stock growth, energy use of appliance stock, energy saved and carbon dioxide mitigated under various scenarios. The electricity generated by rooftop PV under various scenarios is then investigated in section 3.3 results.

4.1 Appliances

4.1.1 Projected stock and energy use till 2030

The projected energy consumption and stock growth of air conditioner, refrigerator, rice cooker, and LED lamp are depicted in the figures below. In the case of air conditioners as shown in Figure 4.1, the government policy scenario will help reduce energy demand by 9.6 TWh in 2030, which is close to 8% of current household electricity consumption. By revising the MEPS by one level every two years (ambitious scenario), energy savings increases by 1.5 times and energy use stabilizes at the end of 2030. If all new residential buildings are constructed with efficient building envelope design from 2025 and are equipped with best available technology (BAT) for cooling (Efficient envelope scenario), cooling energy demand will be stabilized by 2027 and will begin to decline gradually thereafter.

Refrigerators, as shown in Figure 4.2, save no energy until 2025 in government policy scenario due to the government's relaxed energy performance standards. Following the revision of standards in 2025 and 2029, the rate of energy use from refrigerators decreases, resulting in a 1 TWh energy savings by 2030. By revising the MEPS every two years (ambitious scenario), the energy usage of refrigerator stock decreases rapidly, stabilizing in 2027 and then decreasing. The energy saving from the ambitious scenario is 3.7 TWh, which is nearly four times the energy saved in the government policy scenario.

In the case of electrical rice cookers, as shown in Figure 4.3, the database available may not be completely accurate because old stock is rapidly depleting. The energy savings from government mandated MEPS (government policy scenario) result in 1.4 TWh savings in 2030. The energy savings from revising MEPS every two years (ambitious scenario) will result in 3.5 TWh energy savings, which is more than double the energy savings from the government policy scenario.

The same trend is also observed in case of LED lamps as shown in Figure 4.4. As the lifetime of LED lamps is low, so the old stock will decrease to zero before 2030. The MEPS for LED lamps, which is under consideration will save close 3 TWh by 2030. The ambitious scenario could save upto 4.5 TWh which is 1.5 times more than government policy scenario by 2030.

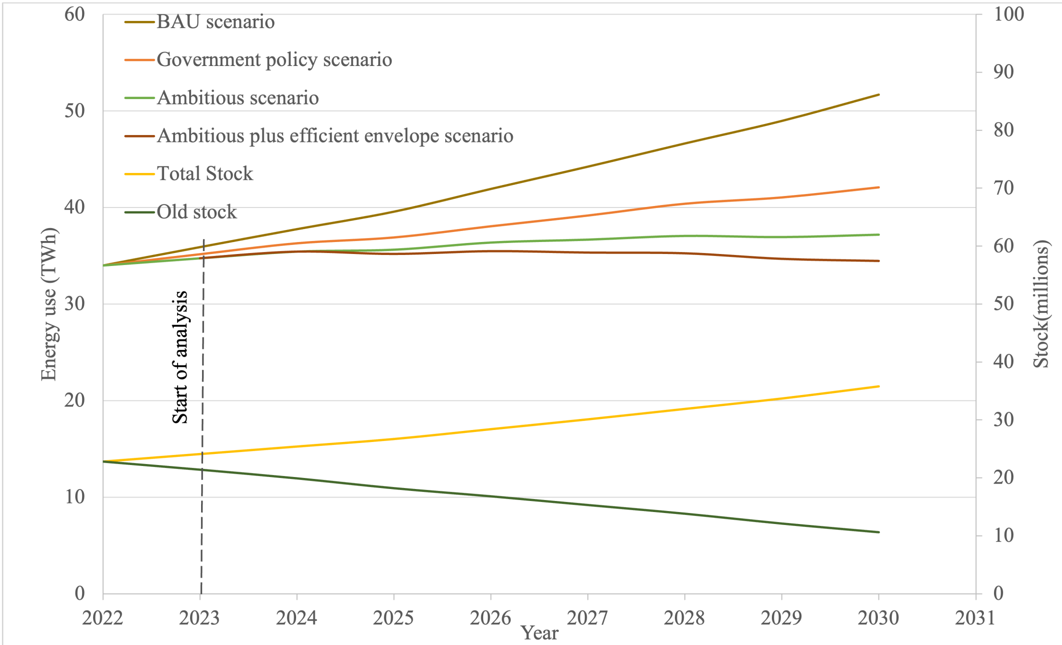

Figure 4.1: Stock growth and energy use of AC stock under different scenarios

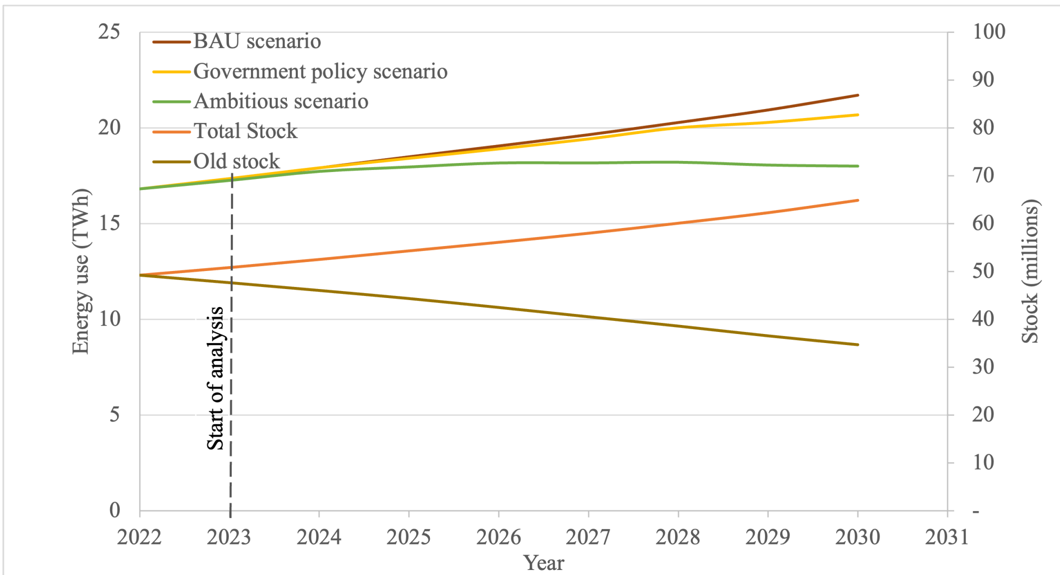

Figure 4.2: Stock growth and energy use of refrigerator stock under different scenarios

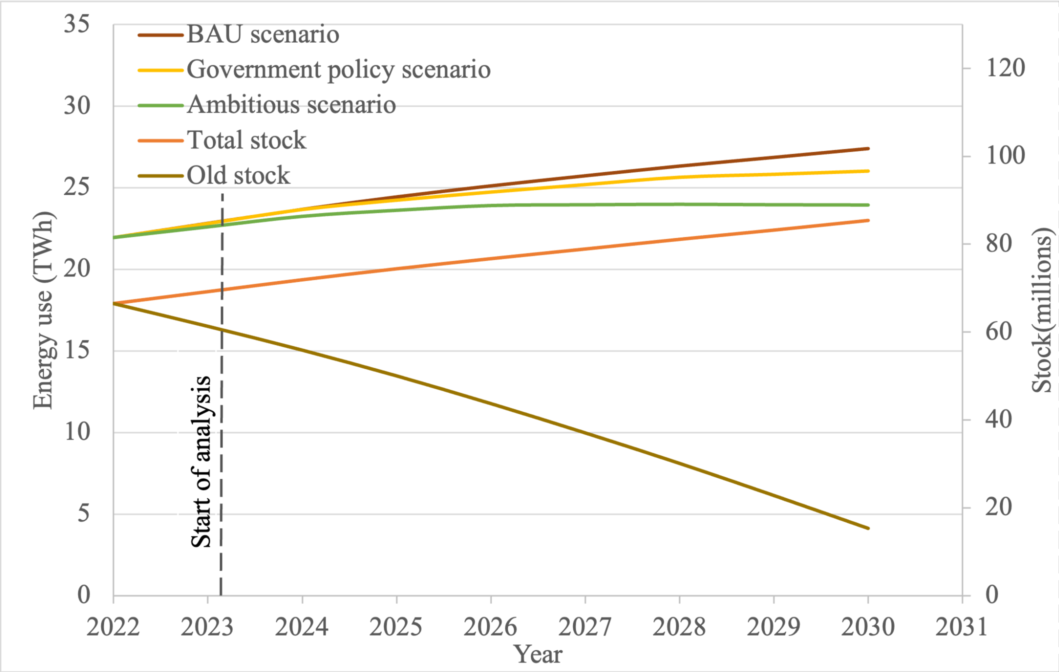

Figure 4.3: Stock growth and energy use of rice cooker stock under different scenarios

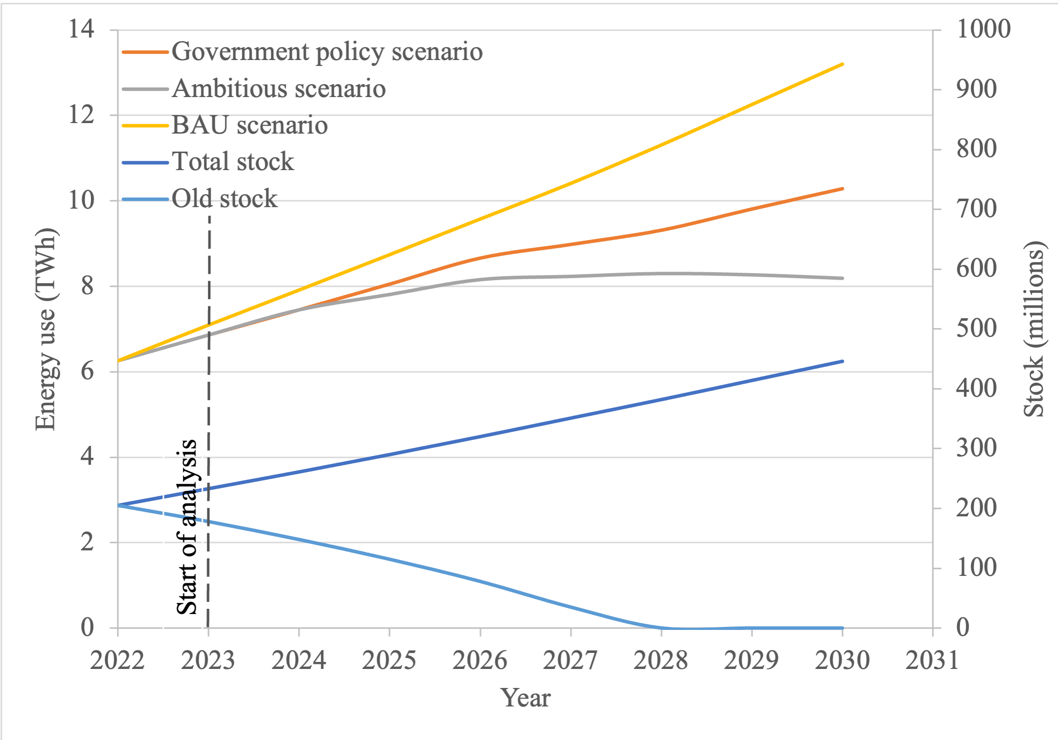

Figure 4.4: Stock growth and energy use of LED lamps stock under different scenarios

In the business as usual scenario, the total energy consumption of these appliances will increase from 79 TWh in 2020 to 114 TWh in 2030, an increase of 1.5 times. This rise appears reasonable given that household electricity use has doubled over the past decade [31]. As depicted in Figure 4.5, energy efficiency can cut this demand by 25% in the optimistic scenario, limiting energy consumption to only 85 TWh in 2030. Additionally, it is possible to stabilise the demand of these appliances by 2030, if aggressive energy efficiency measures are implemented. This results in reduction of power capacity increase, decrease in pollution, and reduced financial strain on nation as a whole. In contrast, under the government policy scenario, just 13 percent of this demand curtailment is feasible.

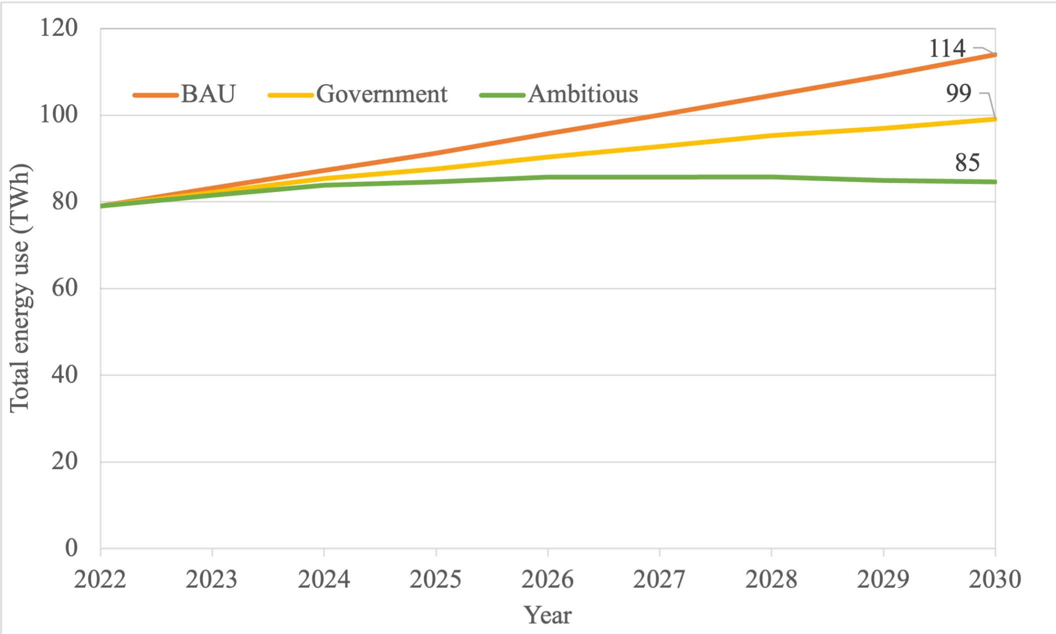

Figure 4.5: Total energy use of the four household appliances in different scenarios

Figure 4.6 and Figure 4.7 compare the share of energy consumed by these four household appliances between 2022 and 2030. The comparison reveals no discernible difference in the energy share between these years. Over the course of eight years (2022 to 2030), the proportion of electricity consumed by air conditioning and lighting rises marginally, while the proportion consumed by the refrigerator and rice cooker declines slightly. In both time periods, air conditioners continue to have the largest energy share, accounting for more than 40 percent, followed by rice cookers, which account for approximately 25 percent.

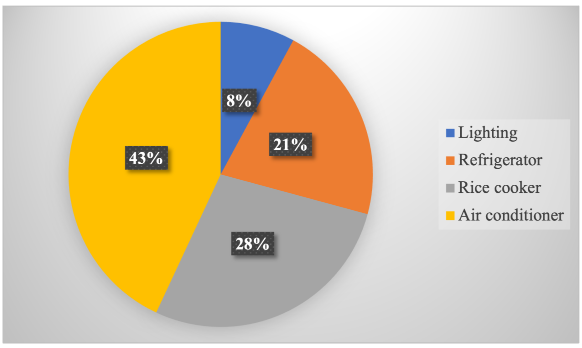

Figure 4.6: Energy share of appliances in 2022

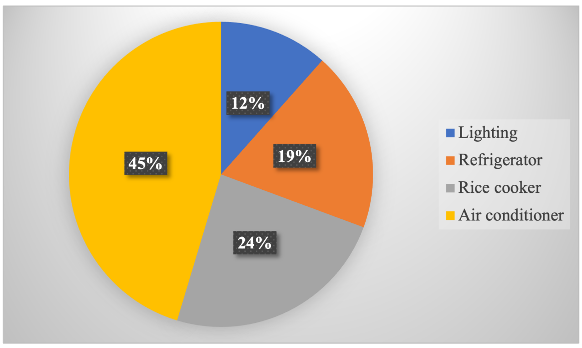

Figure 4.7: Energy share of appliances in 2030 under BAU scenario

4.1.2 Total energy savings

The total annual energy savings and emissions mitigated in 2030 under government policy and ambitious scenario from all the four household appliances are depicted in Figure 4.10 and Figure 4.11. Both figures highlight that ambitious scenario could lead to two times more impact than the present government trend. As shown in Figure 4.8 and Figure 4.9, AC forms the highest share of the savings amongst appliances probably in each scenario because of the high energy usage, urbanization and more demand in the future. As shown in Table 4.1, the government policy of AC and LED lamps (to be launched next year) fare better than current MEPS of refrigerator and rice cooker when compared with corresponding ambitious scenario. It is clear that refrigerator MEPS has no significant impact and has alteast 2.5 times more potential to save energy than current regulation. Therefore, amongst all the launched MEPS the government should prioritise revising the MEPS of refrigerator and soon launch MEPS of LED lamps.

The emission reduction also show similar trend for both scenarios as visible in Figure 4.11. The Indonesian government's NDC objective for the energy sector is 446 $MTCO_2$ reduction by 2030 relative to 2010 baseline. If the government follows the current path, it can meet 3 percent of the NDC objective by 2030 through the energy efficiency of appliances. By adhering to the aggressive policy in appliances, alteast 6 percent of the NDC target could be met.

Table 4.1: Head to head comparison of energy savings under scenarios

Appliances	Energy savings in 2030 "government policy"	Energy savings in 2030 "ambitious scenario"	% increase of savings in "ambitious scenario"
AC	10	17	79%
Refrigerator	1	4	258%
Rice cooker	1	3	150%
LED lamps	3	5	72%

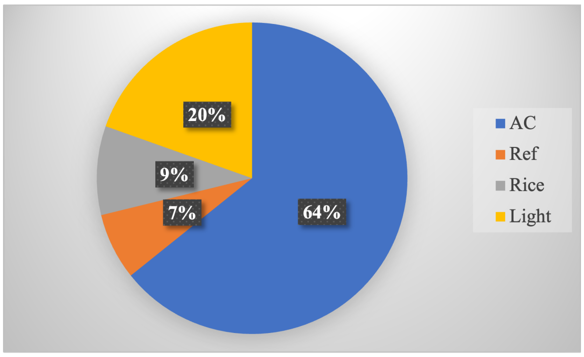

Figure 4.8: Energy savings share under government policy scenario

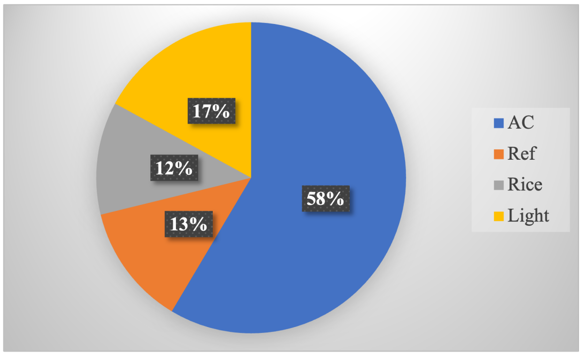

Figure 4.9: Energy savings share under ambitious scenario

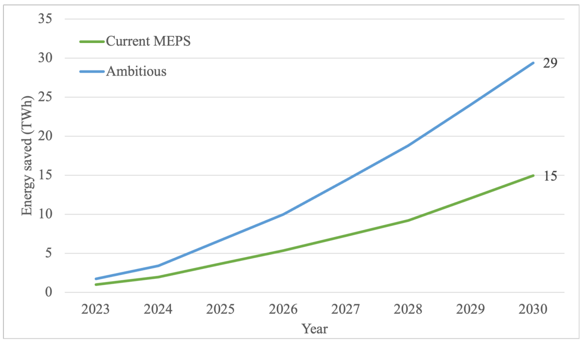

Figure 4.10: Total energy savings from appliances under government policy and ambitious scenario

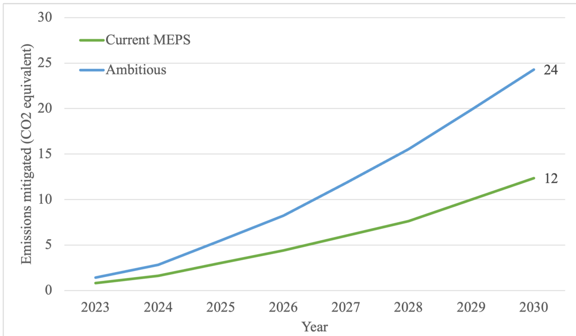

Figure 4.11: Total emissions mitigated from appliances under government policy and ambitious scenario

4.1.3 Penetration and ownership rate of appliances

Penetration rate of an appliance is the percentage of households possessing that particular appliance in a country. Ownership rate, on the other hand is the number of appliances in such households. A comparison between ownership rate of appliances per households in 2020 and 2030 is shown in Figure 4.13. The penetration rate of each appliance with their respective stock is provided in Figure 4.12. As expected the penetration rate of appliances in 2030 does not exceed 100%. The penetration rate of lights remained at 100% meaning that all households of Indonesia have access to lamps. Amongst the 4 appliances analysed, air conditioners saw the highest growth growth in its penetration rate followed up by rice cooker. Access of households to air conditioners increased significantly to 34% in 2030 from 24% in 2020. This outcome is in agreement with the finding of "Future of Cooling report" by IEA. In this report , IEA [2] analysed 500 data points across 68 countries to model penetration of AC in countries as a function of climate and wealth. It was found that in countries with cooling degrees days more than 3000 like that of Indonesia, AC ownership rises very steeply with income as cooling is crucial in such countries for consumers to live and work in comfort. According to the results in Figure 4.12, the stock of air conditioner would nearly double in coming decade, from 20 million in 2020 to 36 million in 2030. Similar estimates is also reported by IEA, wherein IEA projects that by 2050 50% of the air conditioner stock in ASEAN region will be from Indonesia [60]. It may be noted that IEA's policy reports considers both residential and commercial air conditioners, but in this study only residential air conditioners is considered. Furthermore, the penetration rate and stock of some appliances could be little high probably because of presence of these equipment in commercial buildings. No sources were discovered that indicated the proportion of appliances in Indonesia's business and residential structures.

The Figure 4.14 highlights the annual energy consumption of appliances in kWh/year. By pursuing the ambitious scenario, the annual energy consumption of new air conditioners, refrigerators, and lights can be cut in half by 2030. The Figure 4.14 shows that best air conditioner in current markets has presently available in the 2030 market, so the government could revamp the standards to transform the market toward these efficient technologies, resulting in significant energy savings. It is interesting to notice that despite the availability of high-performing appliances on the market, the government has set inferior MEPS for most of the appliances. For instance, the best available air conditioner, refrigerator, and LED will consume at least 50 percent less energy than the government's current MEPS. This demonstrates the huge energy-saving potential existing in the appliance sector, which may be leveraged successfully.

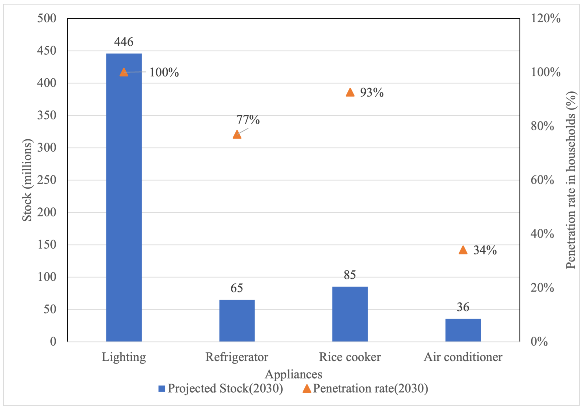

Figure 4.12: Penetration rate and estimated stock of appliances in 2030

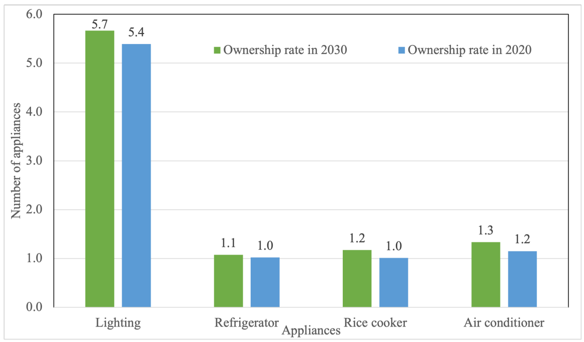

Figure 4.13: Ownership rate of appliances

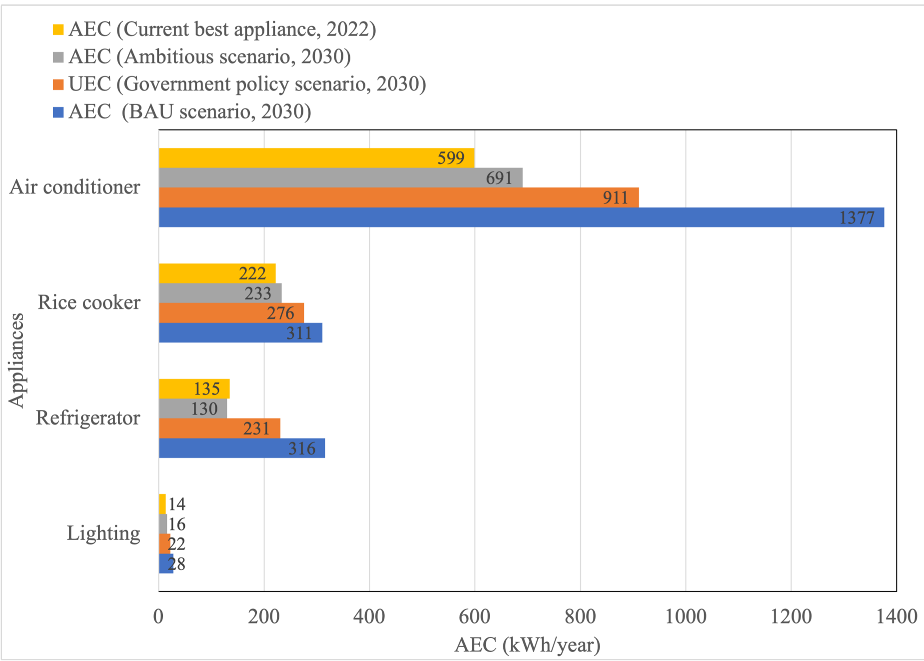

Figure 4.14: Annual energy consumption (AEC) of appliances under various scenarios.

4.2 Rooftop PV

In this section, the results obtained from the scenarios of rooftop PV growth in Indonesia is discussed. Under BAU scenario as shown in Figure 4.15, the rooftop PV installed power will reach to 100 MW by 2030. For the government policy scenario as shown in Figure 4.16, the rooftop PV growth is projected linearly and it reaches 13 GW at the end of 2030. In the ambitious scenario as shown in Figure 4.17, the initial years show a high slope followed by reduced slope. The reduced growth of rooftop PV is due to grid limitation of Indonesia. The steep rise in the initial years could be simulated by generous FiTs as was the case of Vietnam. The installed rooftop PV in ambitious scenario stands at 50 GW, which is close to 4 times the government policy scenario in 2030.

As seen by the result of rooftop PV in Figure 4.18 and Figure 4.19, the renewable rooftop PV share of the household electricity supply will be 12% and 48% in 2030 under the government policy and ambitious scenario respectively. In the two scenarios, with this level of decarbonized supply, approximately 17 and 65 metric tons of carbon dioxide can be reduced. This emission mitigated could help in reaching 4% and 15% share of NDC target of Indonesia in the respective scenarios. Taking into account households installing 1 kWp per home, the Figure 4.20 depicts the penetration of rooftop PV amongst the total households (78.6 million) in 2030. Similarly, considering that 5 square meters of roof area required for 1 kWp, the amount of roof area for rooftop PV is determined in Figure 4.21.

It should be mentioned that the current rooftop PV installation in 2021 is only 8.3 MW for 3208 homes. The government has set a goal of achieving 13 GW of installed capacity of rooftop PV by 2030, which is more than thousand times the current installed capacity, within the next seven years. Both the scenarios described are fairly ambitious, but nevertheless realizable, as Vietnam demonstrated in its rooftop PV growth.

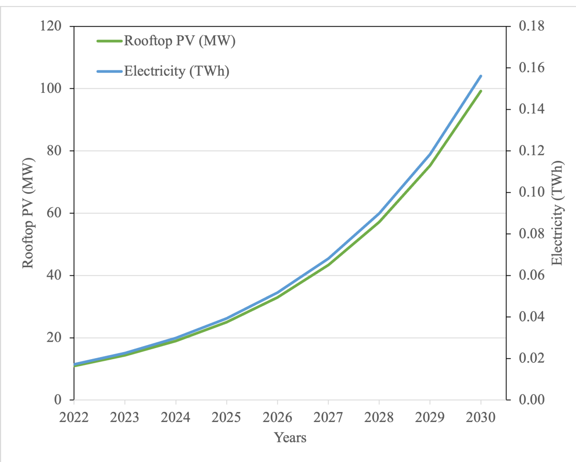

Figure 4.15: Rooftop PV growth in Indonesia under *Business as Usual scenario*

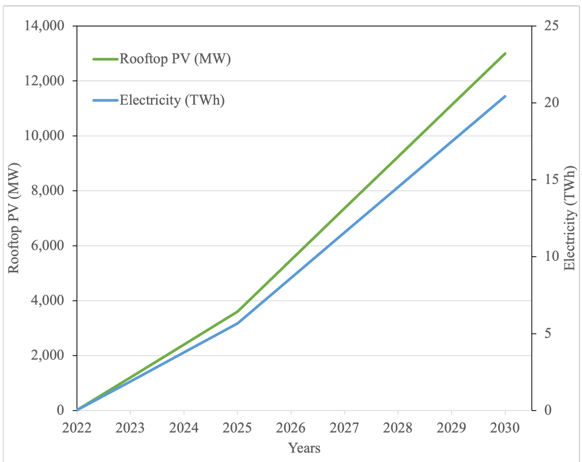

Figure 4.16: Rooftop PV growth in Indonesia under *Government policy scenario*

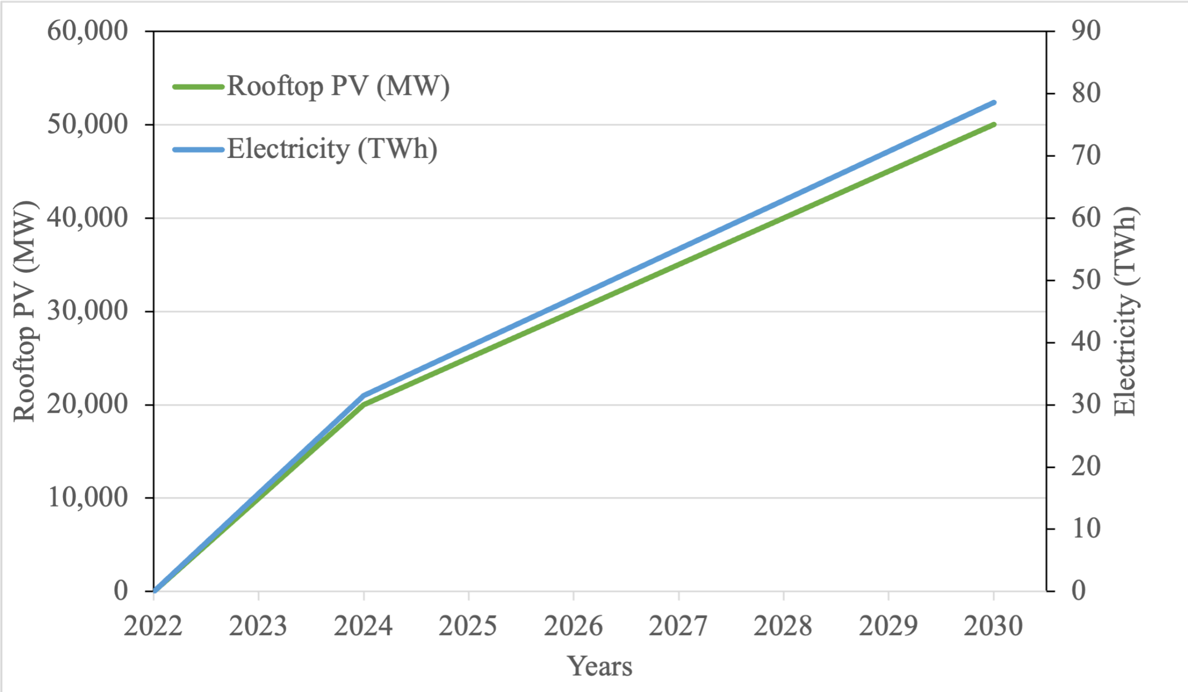

Figure 4.17: Rooftop PV growth in Indonesia under *Ambitious scenario*

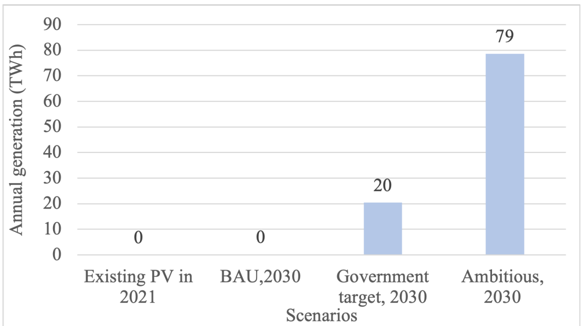

Figure 4.18: Comparison of total electricity from rooftop under various scenarios

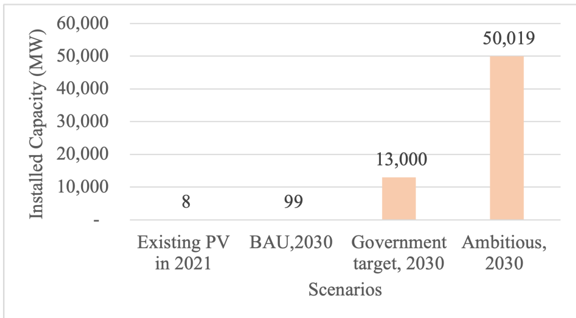

Figure 4.19: Comparison of total rooftop PV installed capacity under various scenarios

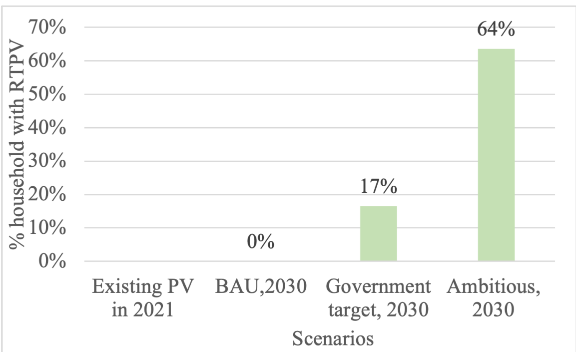

Figure 4.20: Comparison of households share(%) with rooftop PV under various scenarios

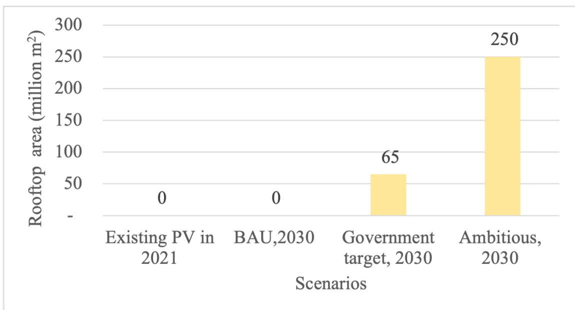

Figure 4.21: Comparison of total roof area used by rooftop PV under various scenarios

4.3 Summary of results

The four appliances taken into account in this study account for 70% of home electricity demand [57]; and it is expected that this will continue till 2030. The residential electricity consumption projection from PLN's RUPTL document matches the total household demand of 165 TWh in 2030 under the BAU scenario [32]. It is evident from the Table 4.2 that efficient appliances, building envelopes, and rooftop PV in ambitious scenario cause the net hosuehold electricity demand to be met from grid to drop to 1/3rd of the demand in BAU scenario's demand. Similarly, it was discovered that the emission mitigation potential in the ambitious scenario is triple that of the government scenario. Indonesia has a conditional NDC target of reducing 446 MT GHG emissions in 2030 in the energy sector [30]. The emission reduction potential under government and ambitious scenarios will be 7 and 20 percent, respectively, of the NDC target. Given that the emissions from buildings currently account for 16% of all energy-related emissions in Indonesia, this mitigation potential is crucial [31]. However. the share of emissions reduction potential determined could be inflated as Indonesia's NDC emission reduction target is set by comparing the emission of 2030 with 6.7% energy growth from 2010 baseline [30] whereas the historical total energy source growth of Indonesia in the period 2000 to 2019 was only 3.7% [28] and electricity demand growth of Indonesia in the decade 2021-2030 is expected to be 5% as per PLN [32]. Therefore, the emission reduction target stated in NDC is inflated because of reduced energy demand growth of Indonesia and higher BAU projection as compared to current energy growth. Climate action tracker also rates the NDC targets to be "critically insufficient" due to higher projection of BAU growth, large share of commitment from forestry which leads to reduced targets for energy sector, high reliance on coal and setting percentage reduction targets relatively to BAU instead of absolute emission commitments [103].

Table 4.2: Summary of projected savings in 2030

Scenarios	**Household demand (TWh)**	**Rooftop PV supply (TWh)**	**Net household demand to be met from grid (TWh)**	**Emissions mitigated (MtCO2)**	**NDC share achieved (%)**
BAU	165	0	165	0	
Government policy	150	20	130	29	7%
Ambitious	136	79	57	89	20%

Table 4.3: Summary of energy saved and emissions mitigated

Scenarios	**Energy saved from efficient appliances & envelope (TWh)**	**Energy saved as % of BAU**	**Rooftop PV (TWh)**	**Total emission mitigated (MtCO2)**	**Electricity generation cost saved (Billion US$**
Government policy	15	13%	20	29	2
Ambitious	29	26%	79	89	8

In this study, three strategies namely efficient appliances, efficient envelope and rooftop PV were employed to decarbonise the residential sector of Indonesia. On comparing the share of decarbonising potential as illustrated in 4.22, it is reported that rooftop PV has the highest potential (71%), followed up closely by high performing appliances (26%). The high upfront cost of rooftop PV and efficient appliances is a major impediment in the uptake of these solutions in residential sector. The low emission mitigation potential of building envelope could be due to the fact that only cooling load reduction potential of new residential buildings was considered in this study. The results could differ if the energy saving potential in renovation of existing buildings is also taken into account. However, the rate of renovation of existing buildings is quite low all around world. In the EU, for example, only 1% of buildings are renovated each year to make them more energy efficient [104].

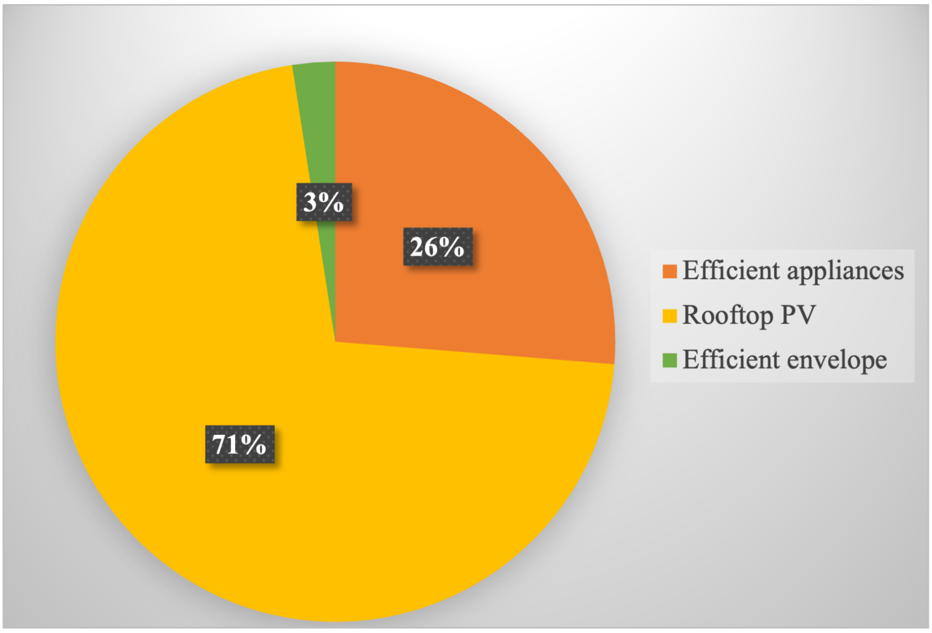

Figure 4.22: Decarbonising potential share of each strategy

Apart from savings in energy, the reduced energy demand has financial and societal impact too. For estimating the financial savings, the electricity generation costs reported by PLN were taken into account. The cost for PLN to generate electricity is indicated in BPP value (cost of power generation) The cost of obtaining electricity is divided into two parts by PLN; the cost of producing it through its own power plants and the cost of purchasing it from outside suppliers like IPPs (Independent power producers) and power rental companies. The average generation cost across the country is 7 US$ cents per kilowatt hour in 2020 [105]. The financial savings accrued due to energy saved by efficient appliances and rooftop PV electricity generation amounts to 2 billion US$ and 8 billion US$ in government policy and ambitious scenario. The total financial savings amount to 0.8% of the GDP of Indonesia in 2021 [33]. However, these savings exclude the investment cost for rooftop PV and energy efficient technologies in appliances. The societal benefits from reduced fossil power generation can include reduced air pollution and increased well being of the citizens [106]. Furthermore, the emission reduction strategies highlighted in this research could augment Indonesia's efforts to achieve its NDC targets, thereby mitigating the effects of climate change recently being witnessed by Indonesia.

Chapter 5

Discussion

In this section of the report, the previously obtained results from appliance energy usage projection are compared with relevant policy databases and reports. Following that, an analysis of the shortcomings of the methodology is undertaken, and a strategy to briefly address it is discussed.

5.1 Comparison of results

In this section, the research findings of appliance energy usage are first compared with the results of the MEPSy database, U4E (United For Efficiency) database, and other research publications. After that, the reasons for the difference in results obtained are examined.

5.1.1 UNEP database

One of the objective of the United Nations Environment Programme's (UNEP) United for Efficiency (U4E) is to augment energy saving gains through appliance by assisting nations in establishing high energy efficiency appliance standards. U4E database has collated the potential energy usage and energy savings associated with the deployment of energy-efficient air conditioners, lights, and refrigerators (rice cooker database was not available) in Indonesia for 2020 to 2050 period. The energy saving results from this report's ambitious scenario are compared to those obtained from U4E's ambitious scenario to examine the difference between the two. As observed in the Table 5.1, the disparity between the estimated savings is substantial.

Before comparing the energy saving results, it is important to understand that energy savings are calculated based on the difference of energy use of a scenario with respect to business as usual scenario. Therefore, the difference in energy savings depends greatly on the modelling of BAU scenario. U4E projects the total energy usage of three major Indonesian appliances (lights, air conditioners and refrigerators) in 2030 to be around 192 TWh, which is 1.2 times the result obtained in this report. While investigating the energy use projection appliance wise, it was found that largest difference noted is in case of residential AC. U4E projects 150 TWh of energy usage from air conditioner while the corresponding figure obtained in this report is only one third at 52 TWh. The figure projected by U4E for AC alone, is very close to total expected residential electricity demand of Indonesia by 2030 which is 165 TWh. The result obtained by this report highlights that AC will constitute about 30% of the total electricity demand of residential sector by 2030 [32]. Although the approach used in projecting AC demand was similar (bottom up approach), but it appears that U4E's representative model of AC was 3.5 kW as compared to 2.6 kW which was taken in this study [5]. Two studies found that small capacity air conditioners were more common in Indonesia [58], [57]. The energy usage in 2030 estimated by U4E in case of lights is double the value reported in this research. This is expected as U4E considers residential, commercial and outdoor lights, whereas this research focuses only on Indonesian residential sector. U4E approach for modelling lighting energy considers floor space projection to estimate a 50% increase in lighting demand. Another difference lies in the fact that U4E took all types of lighting technologies during the analysis whereas in this report, only residential LED lamps is considered. In case of refrigerators, the energy use result obtained is 38% higher than corresponding U4E's forecast. This is little surprising as the modelling approach, AEC value, natural efficiency improvement values taken in both studies are similar [5]. The reason for the deviation observed could be due to U4E's conservative approach towards ownership rate of refrigerators. However, the ownership rate and stock projection data for the appliances was not available in the U4E's repository. All these reasons could have resulted in the difference of energy savings figure. It is interesting to note that under the ambitious scenario of U4E, the energy consumption of the refrigerator and lighting stabilized, similar to what was seen in in Figure 4.2 . Unlike this report's findings, U4E projects that under ambitious scenario, energy consumption of air conditioner would continue to increase after 2030. The difference observed in the ambitious scenarios projections of both the analysis could be due to different ambitious MEPS considered and absence of MEPS revision in U4E approach.

5.1.2 MEPSy database

MEPSy is the climate effect calculator for appliances and equipment developed by CLASP. Using this online tool, it is possible to assess the benefits of policies for various products and determine the effects of different policy options on a national or international level [92]. According to MEPSy, the BAU overall electricity demand in 2030 from Indonesia's major household appliances is almost 177 TWh, which is just 7% more than the Indonesia's estimated residential electricity demand, as determined by RUPTL [32]. The discrepancy between energy savings determined in the results and MEPSy's energy savings as shown in Table 5.1 could be due to different efficiency levels, operating hours, and stock model data. A higher MEPS used by MEPSy for predicting the energy savings and non- consideration of revision of efficiency standards could have lead to the estimated savings to be on the higher side. Just like the this report's results, stabilisation of energy usage for the three appliances (air conditioner, refrigerator, lighting) is also observed in the projected MEPSy's ambitious scenario. Similar to U4E, MEPSy also anticipates that air conditioners saves the highest energy in 2030 (almost 70% of total savings) which is in agreement with this report's findings.

5.1.3 Other policy reports

CLASP and LBNL have done appliance level market survey to estimate energy savings from efficient policy standards in Indonesia. The total energy savings have a variation of 16% from the calculated results. The energy savings reported by CLASP in lighting report is zero in 2030 which might not be entirely correct. CLASP states that by 2030 all lights in the market will be most efficient LED lights, which might not be true as average efficacy of LED is only 65 lumen/watt and the best available technology LED lamps has almost double the present efficacy i.e. 130 lumen/watt. Significant variation in energy savings is observed in rice cooker and moderate variation is observed in air conditioner and refrigerator. Calculated energy savings of these three appliances are on a higher side as regular revision of standards was taken into account. In CLASP and LBNL report, however, a higher MEPS is taken and is applied for the rest of the years. In the method followed by CLASP and LBNL, the projected energy savings will depend on the MEPS level taken. If the MEPS level considered is high, then high energy

Table 5.1: Comparison of obtained results with other publications

Item	**Results obtained (TWh)**	**U4E (TWh)**	**Deviation observed (%)**	**MEPSy (TWh)**	**Deviation observed (%)**	**Other reports (TWh)**	**Deviation observed (%)**
Energy saved in Lighting	5	4	-20%	9	85%	0	-100%
Energy saved in refrigerator	4	6	62%	0	-98%	4	19%
Energy saved in air conditioner	17	50	190%	28	65%	20	14%
Energy saved in rice cooker	3	NA	NA	NA	NA	1	-83%
Total energy saved	29	60	131%	38	46%	25	-16%

savings will be observed and if it is low then energy savings will be low. As seen in the MEPSy and U4E case, the maximum energy savings are also accrued from air conditioners which is in agreement with this report's finding. This result is consistent with the conclusion reached by Zhou et al. [42] where it was also determined that, among all appliances, the MEPS of air conditioners will result in the greatest savings in China.

In summary, while the three resources mentioned above and the findings of the report are distinct, there are some similarities. The use of some appliances with high energy efficiency could result in energy use saturation by 2030. In the context of Indonesia, air conditioner demand will rise dramatically and setting MEPS for AC will result in highest energy savings. Its little hard to argue which projections are more closer to reality. MEPSy and U4E could an advantage over the findings of this analysis due to their consistent use of same macroeconomic variables across all of the appliances. On the other hand, this report took the stock projections of appliances from different sources which could have used different macroeconomic indicators. Therefore, an uniform approach could be missing in this report's finding. However, some representative models chosen for U4E and MEPSy were not representing the most common model in the stock. This lacunae is addressed in this report. Another drawback addressed in this report was considering the standby energy (17% share) while modelling energy use of rice cooker which was not considered by CLASP. Standby power constitutes to about 2% of the annual electricity consumption in OECD countries [107]. Unlike other reports, this report estimates the impact of government policy in 2030 and highlight the impact of revision of MEPS which has not been considered in any of the aforementioned reports.

5.2 Limitations

In this part of the report, the various drawbacks of the currently used study methodology are analyzed, and then, some potential solutions to each drawback are briefly presented.

5.2.1 Impact of user behavior

Effect of user behaviour on energy usage
There are some studies that examine the impact of the occupants' activity schedule, the style of dwelling, and the floor size on domestic energy consumption. In one of the study, it was found that a single family's appliance electricity consumption is proportional to its floor space [108]. As a result of the sharing of appliances, it is discovered that the electricity consumption of large households is lowered when floor area is reduced. Lighting and cooling energy consumption roughly increases with floor area. However, the cooling energy consumption of a small family does not rise much with floor area. In contrast to apartments, detached houses of 50 square meters in size (the most frequent type of dwelling in Indonesia) consume 22 percent more energy. All of these conclusions are based on an examination of residential energy consumption in the Japanese city of Osaka [108]. The results may not differ significantly for Indonesia.

Rebound effect
According to book on "Introduction to energy analysis", a rise in energy consumption may result from an improvement in efficiency in certain circumstances [109]. Two types of rebound effects exist: direct and indirect. The direct rebound effect occurs when an improvement in the specific energy consumption of a piece of equipment results in a reduction in its energy cost. This may result in increased equipment usage by consumers. Indirect rebound effect, on the other hand, addresses the possibility that net savings from one process could be invested in another process, which could result in increased energy consumption. Usually rebound effect has a small impact, accounting for 10 to 30 percent of the intended energy saved [109]. Adha et al. examined the economy-wide rebound effect in Indonesia as a result of government-launched energy efficiency programs from 2002 to 2018. They found that the rebound effect is less significant in the long run and is more prominent in cities with higher energy efficiency [110].

5.2.2 Impact of urbanization and climate change

Effect of urban heat island (UHI)
Due to the dark pavements, tall buildings, and other infrastructures, urban areas typically have ambient air temperatures that are greater than those in rural environment. These structures absorb and hold onto heat, which causes the temperature to rise and affect the efficiency of the air conditioner which is known as Urban Heat Island effect. Areas in Jakarta affected by UHI phenomena rose from 37% in 2008 to 86% in 2018 in direct proportion to Jakarta's growth in built area [111]. Jakarta's afternoon UHI effect is particularly pronounced, and the districts with the highest density of residential settlements has greater temperatures than the city's commercial and industrial areas [112]. In the case of high rise buildings, which are widespread in Jakarta, UHI could become severe. Small split air conditioners with all of their outside units stacked in a column are typically installed in high rise structures. A heat column forms as a result of all these outdoor units forcing hot air outside. The temperature of the condenser coils in the outdoor unit rises as a result of this heat column, decreasing AC performance. It is discovered that, when compared to the ground floor of a high-rise building, the 10th floor uses 9–10% more electricity for cooling [113]. To evaluate impact of UHI on the scenarios considered

in this report, a simple calculation is undertaken. Considering 30% of the air conditioners sold in Indonesia are fitted above ground floor and are affected by UHI which lead to increase 5% energy use, then the change in energy use and energy savings in air conditioner was observed to be in the range of 1-2% which is insignificant.

Effect of climate change on cooling energy use
Climate change can influence the energy use of appliances especially the operational energy use of air conditioners [114]. Indonesia's yearly mean temperature is at 25.5 degrees Celsius [33]. The annual mean average temperature in Indonesia increased by 0.03 degrees Celsius per decade between 1990 and 2020 [33]. A study of Taiwanese residential dwellings revealed that, based on simulations of future climate conditions, the operating frequency of air conditioners will grow by 21% and their cooling energy consumption will increase by at least 23% between 2015 and 2040 [115]. In a similar study conducted on residential dwellings of China, it was determined that an increase in cooling degree days will result in a significant increase in air conditioning energy consumption and operation time [116]. Observations indicate that an increase in relative humidity causes an increase in perceived temperature, resulting in an increase in the power consumption of the air conditioner. Zhang et al. assert that climate change would increase cooling energy use, and he pushes for more energy-efficient air conditioners as a means of mitigating this increase [116].

5.2.3 Impact of sales, performance, and direct emissions

Impact of staggered sales of appliances
The current research method assumed that annual sales of appliances occur at the beginning of each year and did not take into account sales that occur throughout the year. Sales of one appliance could be split into 4 quarters and then impact of staggered sales on energy use could be discussed. The yearly refrigerator sale is equally divided into four quarters. The refrigerators sold in the first quarter of the calender year will run for whole year (8760 hrs), the refrigerators sold in second quarter will run for half the year (4380 hrs), similarly other refrigerators sold in rest of the quarters will run for even less hours. This will lead to reduced energy use of entire stock as newly sold refrigerators in the year are operating for reduced hours as per their sales in the quarter. The energy savings reduced by 14% when staggered sales were taken into account. Similar calculation can be done for other appliances too. Although actual energy savings could reduce when staggered sales is considered, but the trend of energy use remains the same.

Effect of performance degradation of appliance over lifetime
India cooling action plan states that energy efficiency degradation over the life time of equipment is inevitable; however, there are ways to limit the degradation through improved maintenance [117]. In absence of proper maintenance and servicing, the performance loss in air conditioner can be up to 50% over its lifespan [117]. Another study done by CLASP highlight the impact of performance of AC due to short term exposure to varying environmental conditions. The study measures the energy efficiency of air conditioners under simulated short term climatic circumstances of salinity, dust, and humidity. 18 air conditioners from India were put through three tests in this study that simulated salinity, humidity, and dust. The outcome demonstrates that short-term environmental exposure has no significant effect on the air conditioner's efficiency [118]. In another study, it was observed that 5% annual performance degradation in air conditioners installed in Florida occurred [119]. To assess its effect on the energy usage of AC stock from 2023 to 2030, the annual performance degradation value of 5% is used. In all three scenarios for 2030, the energy consumption of AC stock grew significantly,

by a factor of 21 to 27 percent. This results in another important conclusion that suggests augmenting the use of energy-efficient appliance; as energy savings from efficient situations increased by 33 to 56 percent.

Impact of direct emissions from appliances
Direct and indirect emissions are produced by refrigerators and air conditioners. The term "direct emissions" refers to emissions from refrigerants that occur during equipment operation, equipment maintenance, and equipment disposal after the equipment has served its purpose. The emission that result from the use of electricity over the course of its operation is the indirect greenhouse gas emissions. According to a study by GIZ in Indonesia, emissions related to refrigerants account for 15% of all greenhouse gas emissions in Indonesia's air conditioning industry. [120]. Similarly, Green Growth Initiative (GGI) found that close to 80% of the emissions in refrigeration and air conditioning sector in 2030 will be from indirect emissions and rest will be from direct emissions [121].

Life cycle assessment
Only operational use was taken into account in the current methodology, and energy use during the entire life cycle was not evaluated. Karkour et al. conducted a life cycle assessment for the Indonesian air conditioner market to examine the impact of emissions at its different life phases, including material extraction, product manufacturing, distribution, usage, and disposal/recycling [122]. It was observed that 90% of the emissions occurred when the air conditioner was running, which indicates that the operation phase of the air conditioner has the greatest impact on climate change in terms of GHG emissions. Accordingly, considering the entire life cycle would not lead to a significant change in the overall energy savings.

Dynamic relation between building envelope and cooling energy
Since the cooling load is a dynamic function of the ambient environment, location type, building type, occupant schedule, activity, and other factors, it is difficult to quantify the cooling energy saved by different efficient building envelope. However, some recent studies have highlighted the potential for cooling energy savings via efficient envelope design. To assess the impact of the building envelope on annual cooling load and peak cooling demand, Al-Tamami and Fadzil [65] simulated a residential home in a high rise building in Malaysia. The best building envelope strategy, according to this research, is exterior wall thermal insulation, which lowers peak and cooling loads by 10 and 26 percent, respectively. There is a 1.3 percent increase in cooling demand for every 10% increase in window to floor ratio. By using double low-emissivity glass for the base case glazing system, the yearly cooling load and peak cooling load could both be reduced by a maximum of 5.8 and 36 percent, respectively. The potential for savings from overhangs and shading is limited because, after 60 cm, they are no longer economically viable. Although, it can reduce peak load by 22.15 percent and peak cooling load by 2.56 percent, respectively. Additionally, the latest IPCC report on climate change mitigation advocates for a decrease in energy demand for buildings by promoting sufficiency, efficiency, and renewable energy [10]. The potential for energy savings from various building envelope solutions is depicted in the Figure 5.1, and ranges from 5 to 65 percent.

5.2.4 Impact of grid strength and rooftop PV costs

Grid capability to accommodate rooftop PV growth
The sudden rise in rooftop PV growth is restricted by a weak grid capacity. In Indonesia, the

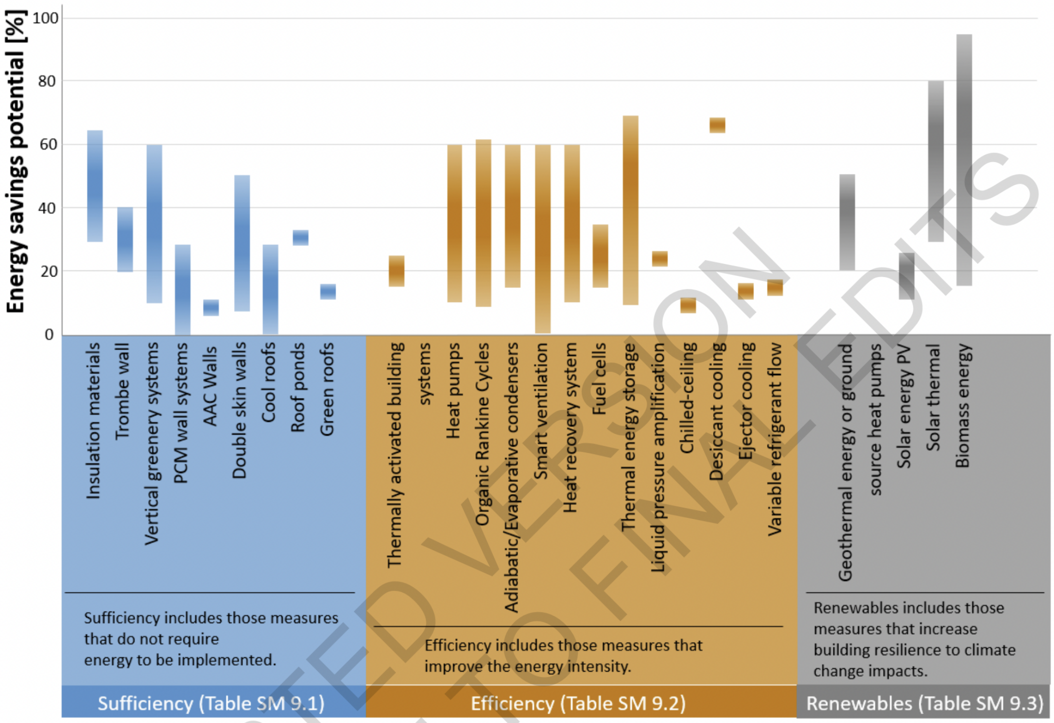

Figure 5.1: Energy savings potential of building envelope and technology strategies for climate change mitigation in buildings [10].

rooftop PV faces implementation challenges like oversupply of electricity; increased cost of generation for keeping the generators in buffer; investment cost to upgrade technologies for precise forecast of energy supply and demand; and grid strengthening as mentioned by PLN [32]. There is a limit to which a decentralised power source can be integrated into the grid. According to National Renewable Energy Laboratory (NREL), hosting capacity is the maximum capacity of decentralised power that can be integrated safely and reliably into a distribution system before control modifications or system upgrades are necessary [123]. Decentralized generation can enhance the voltage profile and ease congestion at distribution feeders, although a higher penetration could result in a decline in reliability and quality of power supply [124]. A case study done on the Putri Betung feeder in Indonesia found that a rooftop PV capacity equal to 50% of the installed capacity could be integrated to this feeder without affecting the acceptable level of electricity quality and reliability [124]. In this study, Wardana and Riady considered only overloading limit of active power in determining the hosting capacity of the feeder. It was found that Putri Betung feeder with 250 kVA (5X50 kVA)transformer capacity has a hosting capacity close to 125 kW (50% of the transformer capacity). In a different investigation for the feeders of Yogyakarta, Indonesia, it was discovered that feeders with same load curve and PV output have different hosting capacities due to different feeder characteristics [125]. The study also pointed out that with increase in deployment of rooftop PV, power factor decreases and reverse power limits and under/over voltage limits become more restrictive. Therefore, it is important to take into account the operational constraints of grid before incorporating the maximum allowable rooftop PV growth into the grid [125].

Financial implication of rooftop PV growth

Levelized cost of electricity (LCOE) is used as a financial metric to assess how economically viable electricity from a particular source is. The net present cost of producing electricity from a source over the course of its lifetime is LCOE. Budi et al. use Monte Carlo Simulation to examine the financial viability of rooftop PV in the city of Semarang [126]. 8.23 cents USD/kWh is determined to be the Semarang's average LCOE. The fact that LCOE of rooftop would be lower than Semarang's electricity tariff shows that homes (PLN's customers) would earn profit by installing rooftop PV systems. Therefore, this study infers that encouraging rooftop PV in households is the right course of action [126]. Rooftop PV penetration in local households may be impacted by the LCOE of rooftop because it varies based on the location's electricity generation price and irradiation. For example, Rooftop PV systems in Surabaya have lower LCOE values than those in DKI Jakarta due to Surabaya's greater solar energy potential; hence, customers in Surabaya should have a greater likelihood of adopting rooftop photovoltaic than those in DKI Jakarta [127]. Therefore, due to financial implications, the uptake of rooftop PV will not be uniform as depicted in the report and will vary from city to city.

To summarise, the various approach restrictions are examined in this section, and it was discovered that some factors could be quantitatively and others could be qualitatively analyzed. The most significant impact on energy savings will come from the appliances' performance degradation over its lifetime while the impact of UHI, rebound effect, indirect emissions from refrigerants will not be of great significance. The type of building design envelope utilized has different impact on the peak cooling load, annual cooling load, and air conditioner operational period. Last but not least, it is crucial to take into account the grid's operational characteristics in order to establish the maximum permissible rooftop PV capacity that may be connected to the grid without compromising the electricity supply's reliability and quality. In addition to the aforementioned shortcomings, the current methodology failed to take into account the compliance rate of the energy labeling scheme, appliance stock flow to commercial buildings, and the use of incandescent and CFL (Compact Fluorescent Lamps) lights in the lighting sector. In the absence of a high compliance rate, the market will continue selling inefficient appliances, and the potential energy savings will not be attained. According to MEPSy, a 50% compliance rate will result in a reduction of more than 40% in potential annual energy savings for air conditioners in 2030 as compared to a scenario of 100% compliance [92].

5.3 Policy Recommendations

After analyzing the results and acknowledging their limitations, this section presents the primary policy recommendations that emerged from the investigation. The sector specific policy recommendations arsing from the results obtained is listed in sections 5.3.1 and 5.3.2. Apart from this some broad policy recommendations which could improve the governance and compliance side of regulations and increase awareness amongst the end users is listed in section 5.3.3.

5.3.1 Appliances and buildings

Upgrading MEPS for refrigerator
As indicated in the results section, amongst all appliances the current MEPS of refrigerator is fairly low and is not driving the market toward energy-efficient models. The MEPS set by the government 16% lower than commonly available refrigerator in the market. As illustrated in Table 4.1, by upgrading the refrigerator MEPS and following a more aggressive approach, 4 times more energy could be saved in comparison with current government trend in 2030. Therefore, it is suggested, priority could be given in upgrading the MEPS for refrigerators next year, followed by periodic revision.

Launching MEPS for light and other appliances
Lights have penetration rate of 100% in Indianian households with ever household owning atleast 6 lights each. Inefficient CFL (50 lumens/watt) and incandescent lights (12 lumens/watt) currently occupy 70% of the residential stock. Setting a technology agnostic MEPS of 70 Lumens/watt could phase out low performing lighting products and can lead to increase in demand of efficient lighting solutions. 5 TWh of energy could be saved in 2030 by implementing MEPS of 70 lumen/watt from 2023 and continuously upgrading it every two years. Furthermore, adopting MEPS for other commonly used appliances like TV (93% penetration rate), electric iron (70%), water pump (35%), washing machine (29%) would further reduce the energy usage of residential sector.

Continuous revision of MEPS standards
The first MEPS standard of AC was launched in 2015 and was revised after 6 years. The validity of current energy performance thresholds for the four appliances (AC, rice cooker, refrigerator and fans) is 4 years [11]. Continuous revision of MEPS is crucial in transforming the market towards the energy efficient products leading to reduce the upfront cost to the consumers. By following 2 year revision cycle, atleast 26% of the BAU energy could be saved in 2030. As shown in the Figure 4.14, even after periodic MEPS revision of 2 years starting from 2023, the MEPS of the appliances in 2030 would reach only close to the performance of the current best appliance. This strategy allows the government to extract the underlying energy efficiency potential present in the existing market. After 2030, the government could adopt a more lenient revision cycle of 3 years, just as was done by India in 2020 [88].

Implementing financial incentives for buildings
Currently there are no residential building which has adopted the efficient building envelope regulation of MPWH 21/21. One of the reason could be the low awareness and non implementation of financial incentives like reduced land, permit fees. Implementing these financial incentives and providing timely approval approval of permits, the uptake of efficient building could be significantly increased in residential sector. Special focus could be given to new residential towers, as reducing the cooling demand of these buildings through efficient envelope can significantly reduce operational energy to be met with the appliances.

5.3.2 Rooftop PV

Implementation of FiT
Vietnam saw gigantic increase in rooftop PV due to its gracious FiTs [39]. The success of Vietnam advocates for relaxed local content regulation. Implementation of FiT can generate favourable results for rooftop PV and can send a strong signal for private players investing in solar PV.

Relaxed local content regulations
Considering the supply chain of rooftop PV, the current solar PV module manufacturing capacity stands at 620 MWp of which only 10% annual utilisation is noted due to low demand [40]. The Indonesian solar PV manufacturers largely focus on assembling the solar PV modules by importing the solar cells from other countries. The government's recent stance to increase the local content component from 40% to 60% in January 2019, is making it harder for supplying required quality of solar PV at the affordable rate [40]. The solar PV manufacturers of Indonesia couldn't compete with imported cheap components because of low demand of PV. It

would be better for Indonesia's PV market to presently capitalise on the efficient technology coming from China and then slowly ramp up the local production as the demand for rooftop PV increases. After few years, it is also advisable to provide production linked incentive to boost solar PV manufacturing like it was done in India [128]. India recently gave production linked incentive to local manufacturers that are producing PV modules with 20% efficiency.

Financial incentives to all rooftop PV consumers
MEMR Regulation No. 26 of 2021 states that 100% of the electricity exported to the grid (net metering scheme) can be used as credit for reducing their electricity bill. However, based on expert consultation it was found that this regulation has been stayed due to fear of financial losses to PLN. MEMR may implement this regulation as this will significantly reduce the payback period for rooftop PV for households [129].The recently launched initiative by UNDP, MEMR for rooftop PV households provide incentive to homeowners for rooftop PV installation that can provide impetus to rooftop PV [130]. But the scheme could provide a greater impact by including non-PLN customers also. Additionally, removing the current installation limit of rooftop PV capacity not exceeding 15% of the connected customer capacity could incentivize consumers to install larger rooftop PV systems.

5.3.3 Other policy recommendations

In this section some broad policy suggestions that are not a direct outcome of this study's findings are listed below. These general recommendation could enhance governance, implementation, compliance with regulations, and end-user awareness.

Bulk procurement of efficient appliances in government buildings
The government may set an example by enacting energy-saving policies and by requiring that all appliances purchased for use in government buildings meet the greatest energy efficiency standards. Such regulation may increase the demand for efficient technology and increase its affordability. India introduced a similar regulation in 2013 for high-end energy-consuming appliances like air conditioner, refrigerators and water heaters in its government buildings [131].

Reducing high upfront cost of efficient appliances
Energy Service Companies (ESCO) is a commercial entity that provides energy services, such as enhancing energy efficiency inside the premises of an energy customer, while assuming a certain level of financial risk. China and India have effectively utilized the ESCO business model to promote energy-efficient appliances [132], [133]. India's ESCO, EESL, implemented a demand aggregation method in order to cut the effective price of LED bulbs by leveraging economies of scale. EESL compiled the demand from various regions of the country, bought a significant quantity of LED bulbs through an open bidding process, and chose the technically qualified bidder with the lowest price. One year after the program's launch, the price of LED bulbs decreased from 5 USD to 1 USD. This successful intervention led to massive investments in LED manufacture assembly lines, and within a few years the lighting sector successfully transitioned from inefficient incandescent, CFL bulbs to LED lamps [24]. Indonesia launched revised regulations for promoting ESCO business model in 2017 and implemented ESCO concept in LED street light project in Semarang and Batang. In future, government of Indonesia may execute bulk procurement of energy-efficient equipment for future residential towers/commercial buildings/government offices similar to India's ESCO model, resulting in substantial financial and operational energy savings.

Financial incentives for energy saving appliances
Customers may be encouraged by financial incentives to purchase new appliances or replace old, inefficient ones with them, which would not only result in significant energy savings but also lower home peak load demand. The benefit of schemes that promote appliance replacement in households is that the old, energy intensive models will be out of stock, can be safely disposed of, and could be replaced with energy-saving alternatives. Financial incentives can include tax deductions at consumer level or subsides directly to manufacturers . Other nations have successfully implemented similar schemes, like China's upstream subsidy scheme to manufacturers and Mexico's incentive scheme to homeowners to replace inefficient refrigerators and air conditioners with modern ones. Italy offers a 50% tax reduction on high-end home equipment and UK offers a reduced VAT rate for certain appliances [134]. The financial incentives could be derived with partnership with developing economies like GIZ, UNDP, GEF or another way is to impose energy labeling fees to manufacturers for each labeled product sold in the market.

Implementing cooling as a service for new residential towers
In developed nations like EU, heating is billed as a service, and as a result of the network's centralized distribution of heat, losses are greatly reduced. In developing nations, usually only commercial buildings use centralized cooling. To assess the viability of district cooling for residential towers in new cities (especially in the new capital), techno-economic feasibility study for few pilot plants might be conducted. However greater coordination and planning will be required for execution of a district cooling plant, which might be a challenge.

Capacity building for appliance maintenance
In California, it was observed that performance of air conditioners can have 6% annual degradation in its performance [76]. Indonesia faces shortage of qualified AC service technicians and during higher temperature the demand for technicians increases by 30 to 40 % in Jakarta alone. By giving an air conditioner proper maintenance and servicing, it is predicted that energy will be saved throughout the course of its lifetime [117]. Therefore, it would be a good idea to enhance the capacity building of trained technicians who are certified to provide proper maintenance.

Lab capacity building, compliance checks and database for energy efficient products
Energy efficiency programs' true potential for energy savings may be realized with robust execution of these regulations. It is crucial that the government has sufficient number of accredited testing agencies for verifying these energy efficiency criteria for appliances. It is necessary that these institutions be independent and capable of doing random inspections of the appliances available on the market for monitoring and compliance checks. It is further advised to provide consumers with ability to verify the energy labels validity so that they can closely monitor whether the product is actually meeting the energy requirements mentioned on the label. One method is that consumers can request manual verification of certified energy label through the MEMR website. For strong compliance, some nations, including China and India, have incorporated QR codes into the labels. Indonesia could contemplate on launching the similar QR code on pilot basis for one appliance to enable stronger verification checks from consumer side.

Campaigns, workshops to increase consumer awareness about energy efficiency
In addition to mandating top-level norms, it would be advisable to push for bottom-up level initiatives such as awareness campaigns to spread awareness amongst consumers about financial benefits, energy savings from efficient appliances, and urging consumers to prioritize thermal comfort over cooling. Japan's "Cool biz" and "cool share" campaigns and India's "AC@24"

campaign are examples of awareness campaigns from which Indonesia can take some inspiration [135], [136]. According to Japan government, these initiatives mitigated 2.2 million ton of emissions in 2012 alone and government was successful in making 95% of the general public aware of this initiative by 2017. Such awareness campaigns will eventually lead to cooling demand reduction from consumer side which can be comfortably met with the efficient technology present in the market owing to strict appliance efficiency standards. However, in Indonesia only less than 7% of Indonesians are aware of energy labeling [57]. Launching energy-saving labels on widely used household products like lights and televisions can increase the program's awareness and boost demand for products with energy labels. The IPCC claims that the demand for energy-efficient appliances is higher in developing economies than it is in developed economies [93]. Increased customer awareness and education about the benefits of the energy label can augment this high demand. As the EU did for its 25 products [75], complete information about payback period, annual energy savings, and other relevant information might be published for each certified model in the MEMR database which can further make consumers empowered to choose the suitable product for themselves.

In addition to the above suggestions, it is advised that MEMR establish a central database that can track the production of renewable energy, the impacts of energy savings regulations in appliances and buildings in order to continuously assess, confirm, and evaluate the effects of these initiatives at the national level. Apart from focusing on the regulation at central level, the provincial government can bring a lot of impact at local level. For instance, Jakarta has set a "30:30" target of reducing energy by 30% by 2030. Similar energy road map plans at city/ provincial level could make a greater impact in curtailing the energy demand at grass root level.

Chapter 6

Conclusions

The main research questions will be discussed by answering the following sub questions.

Sub-question 1. What is the status of existing research and current regulations of Indonesia's energy efficiency and rooftop solar PV policies in residential sector?

Most research on Indonesian household appliances employed either the bottom-up stock model or LEAP model to predict the energy demand of appliances in various scenarios to compute the energy savings, emissions mitigated, and payback period for consumers. The research articles on energy-efficient building envelope focused on green building implementation, anticipated energy savings using life cycle assessment, and analysis of pilot green building projects in Indonesia to determine its energy-saving potential. Research on rooftop PV in Indonesia consists of estimating the technical potential of rooftop PV, analysing the payback duration of solar PV under net metering scheme, and determining the impact of PV price reductions and subsidies on the rooftop PV adoption rate. A research gap was noted in the analysis of the impact of current appliance performance standards fixed by the government and the impact of continuous revision appliance standards on residential energy use. Understanding the implications of stringent efficiency standards in the residential sector is essential for assessing the contribution of energy efficiency in decarbonising the Indonesian economy.

So far, the Indonesian government has established MEPS or efficiency standards for four appliances: air conditioners (in 2015), refrigerators (in 2021), fans (in 2021), and rice cookers (in 2021). The validity of these efficiency standards is four years. New green building laws were also released in 2021. Although over 300 buildings have passed green building requirements, most are commercial structures, with no residential buildings meeting any efficient building envelope norms mandated by these regulations. The green building regulation mandates a lower window-to-wall ratio, an OTTV of less than 35 W/m^2, and optimum ventilation and shading. For rooftop PV, the net metering scheme revised in 2021 could accelerate its deployment in households. Recently, MEMR started providing financial incentives to households for rooftop PV installation. However, the local content regulations that require that 60% of rooftop PV components be obtained locally act as a barrier.

Sub-question 2. What is the impact of the current appliance standards, stringent appliance standards and efficient building envelope design on energy use of household sector in 2030?

From this research, it was clear that current energy efficiency regulations are not adequate in accelerating the Indonesian economy towards net zero by 2060. Especially the green building regulations have failed to generate any impact in the residential sector. The coverage of appliances under current MEPS regulation is low, and refrigerator MEPS especially is ineffective in pushing the consumers towards efficient products. The rising cooling demand in the residential sector presents a formidable challenge for Indonesia which can be effectively tackled with smart energy efficiency regulations in the space cooling sector. However, Indonesia being the fourth most populous country in the world, has significant untapped potential in energy efficiency. It is estimated that in 2030, current efficiency policies of the residential sector could reduce energy use by 10% in 2030 and mitigate 12 $MTCO_2$ in 2030. Considering aggressive efficiency policy measures, Indonesia can reduce energy use by up to 18%, save energy by 29 TWh, and mitigate 24 $MTCO_2$, which corresponds to 6% of Indonesia's NDC mitigation target for the energy sector in 2030. The highest energy savings, accounting for almost 60% of the total savings, is from air conditioners, highlighting the need for stringent energy efficiency standards for cooling equipment. The fact that energy savings in ambitious scenario are twice the government policy scenario illustrates the significant untapped energy saving potential in the household sector, waiting to be realized.

Sub-question 3. What is the projected rooftop PV electricity generation in 2030 under various scenarios?

The clean energy policies of Indonesia, in general, have not been successful in fostering the growth of renewable energy, especially rooftop PV, with the current total installation standing at only 8.3 MW in households. The government has set ambitious targets of attaining 13 GW rooftop PV by 2030, but the existing regulations and their implementation are not conducive enough to support this massive expansion. The rise of rooftop is also hindered by stringent local content regulations, low demand and weak implementation of financial incentives. However, similar to the tremendous rooftop PV growth of Vietnam, Indonesia could enact feed-in tariffs to even overachieve the above mentioned targets set by the government. It is estimated that under ambitious scenario the rooftop PV installation in Indonesia could reach upto 50 GW as compared to the government target of 13 GW in 2030. However, limited grid capacity to accommodate the increase in rooftop PV could act as a barrier. The renewable rooftop PV share of household supply could become 12% and 48% by 2030 under the government policy and ambitious scenario respectively. The decarbonising potential of rooftop PV in both scenarios stands around 17 and 65 metric tons of carbon dioxide respectively. The penetration rate of rooftop PV in households for both scenarios is projected to be 17% and 64% respectively by 2030, considering 1kWp per household. In terms of the NDC target, ambitious rooftop PV expansion can achieve 15% of the NDC target of Indonesia by 2030, whereas the government targets can achieve only 4% of NDC.

Sub-question 4. What are the policy constraints of current regulations, and what policy interventions can be recommended to enhance the impact of these policies?

The Indonesian policymakers have successfully imposed several regulations on rooftop PV, buildings, and appliances to regulate their energy use, but the objectives of these mandates are severely curtailed due to constraints arising from design, implementation, monitoring & compliance issues. The limited coverage of the regulation, lenient performance standards, longer revision cycles and high upfront cost are few impediments to the market transformation towards efficient products. The main hurdles in the building sector include its poor implementation and lack of financial incentives. The barriers to rooftop PV penetration in the residential sector are high requirement of local content in PV, low PV demand, low financial incentive and high upfront cost. Realising the full potential of current laws is also hampered by ineffective execution, inadequate cooperation between ministries and provincial governments, and limited consumer awareness.

Despite these shortcomings, Indonesia could still achieve significant energy savings because there are already efficient models in the market that use only half the energy of a typical appliance. To effectively utilise this potential, it is suggested to revise the current performance standards of refrigerators and adopt efficiency standards for lights. Energy savings in the tune of 26% of business as usual could be attained in 2030 if biennial revision of performance standards is done. Implementing more robust implementation and adequate verification checks would increase the reliability of energy labels. For rooftop PV, it is recommended to relax local content regulation and adopt Feed in Tariffs to boost the rooftop PV uptake in the residential sector. In addition, grid strengthening and technological upgrades to handle the intermittent nature of the grid could be undertaken simultaneously to accommodate the increase in PV capacity in the grid.

Main research question: What is the impact of energy efficiency and rooftop PV policies on Indonesia's residential sector and what policy interventions can be recommended to further increase its impact in 2030?

Globally there is a renewed sense of push toward clean energy sources to satisfy consumers' growing energy demand. Indonesia is the fastest growing economy in South East Asia and its energy use is closely related to its GDP growth. Energy efficiency is an effective approach to reduce Indonesia's energy intensity and rooftop PV on the other hand is a clean, decentralised source of energy for Indonesia. Indonesia's consistent and growing energy demand, coupled with the high potential for solar, makes it ideal for Indonesia to utilise these strategies to decarbonise its supply and demand side. Together, these two strategies alone could achieve 20 percent of Indonesia's NDC target in 2030, which is significant considering the current emission from residential buildings at 16%. Both these strategies could accelerate Indonesia's journey toward energy security and ultimately toward the net-zero objective by 2060.

This report aimed to comprehend the decarbonising potential in the residential sector from the supply and demand side. For decarbonising supply and demand side of the residential sector, rooftop PV and efficient appliances coupled with efficient building envelope were considered. By combining rooftop PV and energy efficiency policies, the household demand to be met from the grid can be significantly reduced by 65% in 2030. The energy efficiency schemes in appliances can lead to stabilisation of electricity usage for respective appliances by 2030. Similarly, in the supply side, rooftop PV could transform consumers into prosumers and decarbonise household demand by 50% in 2030. The maximum energy savings on the demand side (close to 60%) is attributed to air conditioner. The total decarbonisation potential of the residential sector in 2030 is 89 $MtCO_2$, with 29% share from the demand side due to energy efficiency and the remainder coming from the supply side due to rooftop PV. In addition to carbon reduction, these techniques might save up to 8 billion US dollars in 2030 by reducing conventional power generation, which is close to 0.8% of the GDP. This research also demonstrates that current Indonesia's household energy regulations are insufficient, and if rigorous and effective policies are implemented, at least twice as much energy can be saved in 2030. The current regulations suffer from weak implementation and high upfront costs for efficient appliances and rooftop PV. These barriers could be overcome by designing and implementing energy efficiency and rooftop PV policies hand in hand. Some policy recommendations include biennial revision of efficiency standards, financial incentives for efficient building, and adoption of FiTs for rooftop PV. Strong regulations coupled with robust implementation and compliance framework could further assist Indonesia in decarbonising its residential sector through these strategies and could decouple Indonesia's energy growth with its GDP growth in the long run.

Chapter 7

Recommendations for further research

There were some aspects that could be further explored in the context of Indonesia to complement this research. Some recommendations for further research are listed below.

Investigate financial impact of energy efficiency on residential consumers
This thesis examined, from a national perspective, the energy saved and greenhouse gas emissions reduced as a result of energy-efficient appliances and building envelopes. However, in a developing economy such as Indonesia, the high upfront cost of energy-efficient products may prevent their widespread adoption. Therefore, it is suggested to evaluate the financial savings and economical impact of energy-efficient solutions from residential end-users' perspective.

Explore the impact of other household appliances
It is advised that the impact of establishing energy efficiency standards for other extensively used household appliances such as CFL lamps, televisions, and fans can be explored. The study of CFL can be particularly interesting because of the adverse effect on the environment caused by the presence of mercury in CFL. It is also advised to study and compare impact of energy efficiency in rural and urban households.

Evaluate the impact of local content regulations
The ministry of industry has established local content regulations for specific products on the grounds that doing so may result in the creation of green jobs. Examining the impact of mandating local content in rooftop PV and other home appliances on the supply chain, energy savings, and job development may be of interest.

Investigate impact of setting MEPS for solar PV panels
The possible effects of enforcing a minimum efficiency for solar PVs in Indonesia could be the subject of additional investigation. The analysis can evaluate the market investment necessary, the emission-mitigating potential of such regulation, and the LCOE of an efficient PV and low efficient PV system.

Impact of geothermal based cooling in households
For the purpose of reducing household carbon emissions, geothermal based cooling systems might be worth investigating. It is proposed to study the decarbonising potential, economic potential for geothermal based cooling in Indonesian households.

Study to determine hosting capacity of cities

There is a maximum amount of rooftop PV that can be integrated into each Indonesia's feeder. Investigating this capacity (hosting capacity) for each feeder of Indonesia might be beneficial to ascertain the rooftop PV penetration limits of each city and then accordingly prioritize rooftop PV adoption in these cities.

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Appendix A

Appendix

A.1 Literature review of energy efficiency in other sectors

This subsection summarizes the literature review of energy efficiency policy papers in various sectors like industries, transport of Indonesia. A brief literature review of the research on energy efficiency in these sectors is listed below:-

1. *Transport*- For transport sector, especially in electric vehicles (EV), there are many research papers focusing about the electrifying transport in tourist sectors, research challenges to EV, feasibility study to explore grid supporting capability of electric vehicles, social acceptance of electric vehicles, techno- economic feasibility study of Vehicle to Grid (V2G) technology [67, 137–140].

2. *Industry*- In industry sector, each research is focused on energy efficiency strategies in particular segment of industries of sugar, palm oil, steel, Information, and communication technologies (ICT), energy auditing in oil and gas industry [141–145]. A study also focuses in general on energy conservation polices for industries but explores an interesting relation between Islamic religion with energy conservation in industries by using Maqasid Alshariah framework [146].

3. *Streetlighting*- Several research papers are published highlighting energy efficiency in streetlighting system.Irsyad et al. [147] explores streetlighting projects by Energy Service Companies (ESCO) and investigates the financing side of energy efficiency measures via ESCO. It builds a strong case for PLN to become a super ESCO and proposes some policy measures for building an energy efficiency market for ESCO. In an another study by Irsyad et al. examine energy efficiency potential of streetlighting in Indonesia [148]. Presently PLN charges the municipalities a fixed contract irrespective for energy used. This paper suggests five energy efficiency measures to save energy in streetlighting. It estimates the cost, and impact of such energy efficiency measure via cost benefit analysis.

4. *Energy Intensity inequality and Sustainable Development Goal (SDG) -7 indicators*- Setywan et al. [149] highlightes the importance of energy intensity inequality in several Indonesian regions. Setyawan et al. [149] analyses the energy intensity, energy consumption, energy consumption per capita for 33 provinces of Indonesia. It is found that, the energy intensity is gradually decreasing and the energy intensity amongst provinces is converging. Santika et al. [150] tracks the three indicators of Sustainable Development Goal (SDG)-7 related to energy access, renewable energy deployment and energy efficiency. The paper scrutinizes all the regulations related to energy and qualitative analyse its

impact on energy use. After analysis, it gives brief recommendations. Fragkos et al. [151] the low carbon pathway for Indonesia is analysed using Asia Pacific Integrated Model (AIM) and backcasting approach is used to highlight the most cost-effective measures to reach the nationally determines contributions (NDC) targets set by Indonesia.

5. *Energy Diversity*- Apart from energy efficiency, energy diversity would also play an important role in clean energy transition. According to Nibed et al. [152], energy efficiency is low-cost mitigation strategy and along with energy diversity it could achieve the sustainable targets of developing countries. This research paper focuses on energy efficiency and energy diversity's role in mitigating CO2 in the 7 developing economies of world.

6. *Energy consumption and corona pandemic*- There are close to five research papers which analyses effect of corona pandemic on energy use in Indonesia. Hartono et al. [153] explore the energy pattern use before and during the pandemic in different regions of Indonesia [153]. Hartono et al. also analyse the current policy stimulus from the government and finally proposes Indonesia to adopt energy efficiency, low carbon technologies for achieving green recovery [153].

A.2 Testing capacity of Indonesian laboratories

Table A.1: Testing capacity of Indonesia laboratories appliance wise [24–26]

Item	**Labs**	**Labs with accreditation**	**Annual testing capaciy**	**Annual sales in 2020 (include commercial and residential)**	**Testing capacity (%)**
Fans	5	5	1,860	15,000,000	0.01%
Lights	5	5	91,200	180,000,000	0.05%
Refrigerators	10	2	4,800	2,730,000	0.18%
Rice cookers	12	9	NA	13,800,000	NA

A.3 Estimation of energy usage of residential refrigerator stock

In this section, the energy use calculation of refrigerator stock during the time period 2022 to 2030 is shown. Similar calculation is done for the other three appliances; air conditioner, LED lamps and rice cooker. The estimated stock data and sales data for refrigerator was obtained from MEPSy database of 2022 [92] and was verified from CLASP market survey report of 2020 [25], and UNESCAP report for Indonesia of 2021 [91]. The annual stock retirement rate of refrigerators as a percentage of the existing stock was found to be in the 3%. After obtaining the stock data, the energy use of the stock was calculated. The most commonly available refrigerator model of 165 litre of storage volume was taken as the representative model for entire stock of the refrigerator. The annual energy consumption (AEC) of this model was found to be 342 kWh/year [5] in year 2022. Multiplying the AEC with the stock of 2022 provides the energy consumption of the entire stock in 2022. In the BAU scenario there will be 1% improvement in the energy performance of the refrigerator due to autonomous market improvement. The MEPS prescribed by the government for refrigerators as per the Table 2.2 leads to annual energy consumption of 410 kWh/year for 165 litre volume (0.85*165+270). In the ambitious scenario, AEC for new refrigerators sold in year 2023 would be reduced by 25% at 308 khW/year as compared with BAU scenario. In ambitious scenario, a reduction of 25% in energy use of the new refrigerators would take place every two years in 2025, 2027 and 2029. Whereas in government policy scenario, this improvement in the new refrigerators would be after every four years in 2025 (4 years after launched year 2021) and 2029. It may be noted that in any given year, the energy consumption of the stock will be sum of the energy consumption of the old stock plus the energy consumption of new appliances sold in that year. The energy saved is calculated in government policy and ambitious scenario with respect to business as usual scenario. The emission mitigated is calculated by multiplying the energy saved with 0.826 tCO_2/kWh. The generation cost saved is found out by product of energy saved and cost of unit electricity generation (7 USD cent/kWh). The AEC values, stock estimation and energy use forecast of Indonesian residential refrigerators in various scenarios is given in Table A.2, Table A.3 and Table A.4.

Table A.2: Annual Energy Consumption values for refrigerator

	AEC value (kWh/year)		
Year	BAU	Government policy	Ambitious scenario
2022	342	410	342
2023	339	410	308
2024	335	410	308
2025	332	308	231
2026	329	308	231
2027	325	308	173
2028	322	308	173
2029	319	231	130
2030	316	231	130

Table A.3: Refrigerator stock projection (in millions)

Year	Total Stock	Old Stock	Sales	Retired stock	Retirement rate
2022	49	49.20			
2023	51	47.64	3.16	1.6	3%
2024	53	46.02	3.32	1.6	3%
2025	54	44.34	3.48	1.7	3%
2026	56	42.48	3.66	1.9	3%
2027	58	40.54	3.84	1.9	3%
2028	60	38.60	4.03	1.9	3%
2029	62	36.57	4.24	2.0	3%
2030	65	34.72	4.45	1.8	3%

Table A.4: Energy saved, emission mitigated and generation cost saved from refrigerator

Year	Energy use (TWh)			Energy Saved (TWh)		Emission Mitigated ($MTCO_2$)		Generation cost saved (Billion US Dollar)	
	BAU	Govern ment	Ambitious	Govern ment	Ambitious	Govern ment	Ambitious	Govern ment	Ambitious
2022	17	17	17	0	0	0	0	0.0	0.0
2023	17	17	17	0	0	0	0	0.0	0.0
2024	18	18	18	0	0	0	0	0.0	0.0
2025	19	18	18	0	1	0	0	0.0	0.0
2026	19	19	18	0	1	0	1	0.0	0.1
2027	20	19	18	0	1	0	1	0.0	0.1
2028	20	20	18	0	2	0	2	0.0	0.1
2029	21	20	18	1	3	1	2	0.0	0.2
2030	22	21	18	1	4	1	3	0.1	0.3

A.4 MEPS regulations in ASEAN countries

Existing Appliance energy performance regulations in major ASEAN countries (from CLASP Policy database [1])

Country	Products Type	Policy Approach	Policy Instrument	Adopted
Indonesia	Variable Speed Drives	Voluntary	Minimum Performance Standard, Comparative Label	
Indonesia	Non-Directional lamps, Directional Lamps	Not applicable	Comparative Label, Minimum Performance Standard	
Indonesia	Televisions	Not applicable	Comparative Label, Minimum Performance Standard	
Indonesia	Washing Machines	Not applicable	Comparative Label, Minimum Performance Standard	
Indonesia	Pumps Other	Not applicable	Comparative Label, Minimum Performance Standard	
Indonesia	Portable Fans	Mandatory	Comparative Label, Minimum Performance Standard	2021
Indonesia	Refrigerators-Freezers	Mandatory	Comparative Label, Minimum Performance Standard	2021
Indonesia	Rice Cookers	Mandatory	Comparative Label, Minimum Performance Standard	2021
Indonesia	Rice Cookers, Lamps, Portable Fans, Room ACs - Stationary ACs, Refrigerators-Freezers	Mandatory	Comparative Label, Minimum Performance Standard	2021
Indonesia	Non-Directional lamps, Directional Lamps	Mandatory	Comparative Label	2013

Indonesia	Room ACs - Stationary ACs	Mandatory	Comparative Label, Minimum Performance Standard	2015
Malaysia	Washing Machines	Mandatory	Comparative Label, Minimum Performance Standard	2018
Malaysia	Room ACs - Stationary ACs	Mandatory	Comparative Label, Minimum Performance Standard	2015
Malaysia	Ceiling Fans, Portable Fans	Mandatory	Comparative Label, Minimum Performance Standard	2013
Malaysia	Microwaves	Mandatory	Comparative Label, Minimum Performance Standard	2020
Malaysia	Refrigerators-Freezers	Mandatory	Comparative Label, Minimum Performance Standard	2015
Malaysia	Rice Cookers	Mandatory	Comparative Label, Minimum Performance Standard	2020
Malaysia	Televisions	Mandatory	Comparative Label, Minimum Performance Standard	2015
Malaysia	Tubular Lamps, Non-Directional lamps, Directional Lamps	Mandatory	Minimum Performance Standard	2015

Singapore	Televisions, Clothes Dryers, Non-Directional lamps, Directional Lamps, Fluorescent and HID Lighting, 3-Phase Motors, Room ACs - Stationary ACs, Refrigerators-Freezers	Mandatory	Comparative Label	
Singapore	Non-Directional lamps, Directional Lamps	Voluntary	Endorsement Label	2012
Singapore	Streetlighting, Non-Directional lamps, Directional Lamps	Voluntary	Endorsement Label	2012
Singapore	Televisions	Voluntary	Endorsement Label	2012
Singapore	Coffee Machines	Voluntary	Endorsement Label	2012
Singapore	Dishwashers	Voluntary	Endorsement Label	2013
Singapore	Electric Kettles	Voluntary	Endorsement Label	2017
Singapore	Cooktops or Hobs	Voluntary	Endorsement Label	2017
Singapore	Storage Water Heaters	Voluntary	Endorsement Label	2017
Singapore	Small-Solar Powered Electronics	Voluntary	Endorsement Label	2017
Singapore	Refrigerators-Freezers	Voluntary	Endorsement Label	2012
Singapore	Small-Solar Powered Electronics, Solar Energy Kits	Voluntary	Endorsement Label	2017
Thailand	Lighting, Lamps, Tubular Lamps	Voluntary	Minimum Performance Standard	2013
Thailand	Lighting, Lamps, Non-Directional lamps	Voluntary	Minimum Performance Standard	2007

Thailand	Kitchen, Electric Hot Pots	Voluntary	Endorsement Label	2012
Thailand	Laundry, Washing Machines	Mandatory	Minimum Performance Standard	1997
Thailand	Air Cleaners	Voluntary	Comparative Label	2021
Thailand	Cooktops or Hobs	Voluntary	Comparative Label	2014
Thailand	Cooktops or Hobs	Voluntary	Comparative Label	2015
Thailand	Irons	Voluntary	Comparative Label	2012
Thailand	Non-Directional lamps	Voluntary	Comparative Label	2012
Thailand	Microwaves	Voluntary	Comparative Label	2014
Thailand	Refrigerated Cabinets	Voluntary	Comparative Label	2015
Thailand	Televisions	Voluntary	Comparative Label	2014
Thailand	Washing Machines	Voluntary	Comparative Label	2013
Thailand	Water Coolers	Voluntary	Comparative Label	2017
Thailand	Pumps Other	Voluntary	Comparative Label	2016
Thailand	Fluorescent and HID Lighting	Voluntary	Endorsement Label	2003
Thailand	Motors and Motor Driven Equipment, Motors, 1-Phase Motors	Voluntary	Comparative Label	2022
Thailand	Motors and Motor Driven Equipment, Motors, 3-Phase Motors	Voluntary	Comparative Label	2022
Thailand	Building Materials, Envelopes	Voluntary	Comparative Label	2022
Thailand	Fryers	Voluntary	Comparative Label	2022
Thailand	Building Materials, Insulations	Voluntary	Comparative Label	2022
Thailand	LPG Stoves	Voluntary	Comparative Label	2022

Thailand	Kitchen, LPG Stoves	Voluntary	Comparative Label	2022
Thailand	Cooktops or Hobs	Voluntary	Comparative Label	2022
Thailand	Building Materials, Roof Materials and Coatings	Voluntary	Comparative Label	2022
Thailand	Motors and Motor Driven Equipment, Motors, Variable Speed Drives	Voluntary	Comparative Label	2022
Thailand	Insulations	Voluntary	High Energy Performance Standard	2018
Thailand	Space Heating and Space Cooling, Air Conditioning, Chillers - Cooler Towers	Voluntary	High Energy Performance Standard	2009
Thailand	Tubular Lamps	Voluntary	High Energy Performance Standard	2015
Thailand	Space Heating and Space Cooling, Ventilation, Portable Fans	Voluntary	High Energy Performance Standard	2009
Thailand	Rice Cookers	Voluntary	High Energy Performance Standard	2009
Thailand	Lighting, Drivers/ Controls, Fluorescent and HID Lighting	Voluntary	High Energy Performance Standard	2015
Thailand	Non-Directional lamps	Voluntary	Minimum Performance Standard	2015
Thailand	Lighting, Drivers/ Controls, Fluorescent and HID Lighting	Voluntary	High Energy Performance Standard	2015
Thailand	Kitchen, Electric Kettles	Voluntary	High Energy Performance Standard	2015
Thailand	Kitchen, Electric Hot Pots	Voluntary	High Energy Performance Standard	2009

Thailand	Lighting, Drivers/ Controls, Fluorescent and HID Lighting	Voluntary	High Energy Performance Standard	2015
Thailand	Electronics, Audio-Visual, Home Theater Equipment	Voluntary	High Energy Performance Standard	2015
Thailand	Electronics, Information Technology, Imaging Equipment	Voluntary	High Energy Performance Standard	2015
Thailand	Electronics, Audio-Visual, Televisions	Voluntary	High Energy Performance Standard	2015
Thailand	3-Phase Motors	Voluntary	High Energy Performance Standard	2015
Thailand	Motors and Motor Driven Equipment, Motors, Variable Speed Drives	Voluntary	High Energy Performance Standard	2015
Thailand	Kitchen, Cooktops or Hobs	Voluntary	High Energy Performance Standard	2015
Thailand	Laundry, Washing Machines	Not applicable	High Energy Performance Standard	2021
Thailand	Laundry, Washing Machines	Voluntary	High Energy Performance Standard	2021
Thailand	Water Coolers	Voluntary	High Energy Performance Standard	2021
Thailand	Kitchen, Ovens	Voluntary	High Energy Performance Standard	2021
Thailand	Boilers and Furnaces	Voluntary	High Energy Performance Standard	2009
Thailand	Pumps, Pumps Other	Voluntary	High Energy Performance Standard	2021
Thailand	Refrigerators-Freezers	Voluntary	High Energy Performance Standard	2009

Thailand	Room ACs - Stationary ACs	Mandatory	High Energy Performance Standard	2009
Thailand	Electronics, Information Technology, Computers	Voluntary	High Energy Performance Standard	2015
Thailand	Ceiling Fans, Portable Fans	Voluntary	High Energy Performance Standard	2015
Thailand	Kitchen, Cooktops or Hobs	Voluntary	High Energy Performance Standard	2015
Thailand	Cooktops or Hobs	Voluntary	High Energy Performance Standard	2015
Thailand	Kitchen, Microwaves	Voluntary	High Energy Performance Standard	2015
Thailand	Electronics, Audio-Visual, Displays	Voluntary	Minimum Performance Standard	2015
Thailand	Electronics, Information Technology, Imaging Equipment	Not applicable	High Energy Performance Standard	2015
Thailand	Electronics, Information Technology, Imaging Equipment	Voluntary	High Energy Performance Standard	2015
Thailand	Electronics, Other-Electronics, Air Cleaners	Voluntary	Endorsement Label	2014
Thailand	Insulations	Voluntary	Endorsement Label	1997
Thailand	Washing Machines	Voluntary	Endorsement Label	2007
Thailand	Computers	Voluntary	Endorsement Label	1997
Thailand	Projectors	Voluntary	Endorsement Label	2013
Thailand	Dishwashers	Voluntary	Endorsement Label	2013

Thailand	Doors, Windows	Voluntary	Endorsement Label	2012
Thailand	Space Heating and Space Cooling, Ventilation, Ceiling Fans, Window Fans, Portable Fans	Voluntary	Endorsement Label	2011
Thailand	Fryers	Voluntary	Endorsement Label	2013
Thailand	Irons	Voluntary	Endorsement Label	2013
Thailand	Rice Cookers	Voluntary	Endorsement Label	2012
Thailand	Imaging Equipment	Voluntary	Endorsement Label	2003
Thailand	Taps or Faucets	Voluntary	Endorsement Label	2011
Thailand	Tubular Lamps	Voluntary	Endorsement Label	2002
Thailand	Hair Dryers	Voluntary	Endorsement Label	2013
Thailand	Hand Dryers	Voluntary	Endorsement Label	2012
Thailand	Space Heating and Space Cooling, Space Heating, Heat Pumps	Voluntary	Endorsement Label	2001
Thailand	Instantaneous Water Heaters	Voluntary	Endorsement Label	2014
Thailand	Non-Directional lamps	Voluntary	Endorsement Label	2013
Thailand	Microwaves	Voluntary	Endorsement Label	2011
Thailand	3-Phase Motors	Voluntary	Endorsement Label	1998
Thailand	Imaging Equipment	Voluntary	Endorsement Label	2018
Thailand	Imaging Equipment	Voluntary	Endorsement Label	2018
Thailand	Refrigerated Cabinets	Voluntary	Endorsement Label	2013
Thailand	Refrigerators-Freezers	Voluntary	Endorsement Label	2002
Thailand	Room ACs - Stationary ACs	Voluntary	Endorsement Label	2003

Thailand	External Power Supply	Voluntary	Endorsement Label	2012
Thailand	Televisions	Voluntary	Endorsement Label	2004
Thailand	Kitchen, Toasters	Voluntary	Endorsement Label	2014
Thailand	Uninterruptable Power Supply	Voluntary	Endorsement Label	2015
Thailand	Vacuum Cleaners	Voluntary	Endorsement Label	2012
Thailand	DVD|Blu-Ray Players	Voluntary	Endorsement Label	2004
Thailand	Water Coolers	Voluntary	Endorsement Label	2015
Thailand	Pumps Other	Voluntary	Endorsement Label	2014
Thailand	Non-Directional lamps	Voluntary	Comparative Label	2001
Thailand	Room ACs - Stationary ACs	Voluntary	Comparative Label	1995
Thailand	Electric Kettles	Voluntary	Comparative Label	2014
Thailand	Instantaneous Water Heaters	Voluntary	Comparative Label	2012
Thailand	Space Heating and Space Cooling, Ventilation, Ceiling Fans, Window Fans, Portable Fans	Voluntary	Comparative Label	2001
Thailand	Rice Cookers	Voluntary	Comparative Label	2011
Thailand	Refrigerators-Freezers	Voluntary	Comparative Label	1995
Thailand	Electric Hot Pots	Voluntary	Comparative Label	2004
Thailand	Room ACs - Stationary ACs	Mandatory	Minimum Performance Standard	2003
Thailand	Refrigerators-Freezers	Mandatory	Minimum Performance Standard	2004
Thailand	Fluorescent and HID Lighting	Mandatory	Minimum Performance Standard	1978

Thailand	Lighting, Drivers/ Controls, Fluorescent and HID Lighting	Voluntary	Minimum Performance Standard	2014
Thailand	Lighting, Drivers/ Controls, Fluorescent and HID Lighting	Mandatory	Minimum Performance Standard	2017
Thailand	Electronics, Power Supply and Power Conversion, Power strips	Voluntary	Minimum Performance Standard	2012
Thailand	Kitchen, Rice Cookers	Voluntary	Minimum Performance Standard	2013
Thailand	Kitchen, Microwaves	Voluntary	Minimum Performance Standard	2013
Thailand	Kitchen, Electric Kettles	Voluntary	Minimum Performance Standard	2013
Thailand	Kitchen, Cooktops or Hobs	Voluntary	Minimum Performance Standard	2013
Thailand	Laundry, Irons	Voluntary	Minimum Performance Standard	2014
Thailand	Pumps, Pumps Other	Voluntary	Minimum Performance Standard	2014
Thailand	Kitchen, Fryers	Voluntary	Minimum Performance Standard	2016
Thailand	Kitchen, Ovens	Voluntary	Minimum Performance Standard	2016
Thailand	Refrigeration, Water Coolers	Voluntary	Minimum Performance Standard	2016
Thailand	Motors and Motor Driven Equipment, Motors, 3-Phase Motors	Voluntary	Minimum Performance Standard	2007
Vietnam	3-Phase Motors	Mandatory	Minimum Performance Standard	2005

Vietnam	Ceiling Fans, Portable Fans	Mandatory	Comparative Label, Minimum Performance Standard	2007
Vietnam	Imaging Equipment, Televisions, Displays, Rice Cookers, Electric Kettles, Washing Machines, Tubular Lamps, Fluorescent and HID Lighting, Motors, 3-Phase Motors, Ceiling Fans, Room ACs - Stationary ACs, Storage Water Heaters, Power Transformers, Refrigerated	Not applicable	Comparative Label, Endorsement Label	2011
Vietnam	Refrigerators-Freezers, Freezers-only	Mandatory	Minimum Performance Standard	2007
Vietnam	Room ACs - Stationary ACs	Mandatory	Minimum Performance Standard	2007
Vietnam	Streetlighting	Mandatory	Minimum Performance Standard	2008
Vietnam	Tubular Lamps	Mandatory	Minimum Performance Standard	2008
Vietnam	Fluorescent and HID Lighting	Mandatory	Minimum Performance Standard	2008
Vietnam	Storage Water Heaters	Mandatory	Minimum Performance Standard	2009
Vietnam	Fluorescent and HID Lighting	Mandatory	Minimum Performance Standard	2009
Vietnam	Tubular Lamps	Mandatory	Minimum Performance Standard	2009

Vietnam	Storage Water Heaters	Mandatory	Minimum Performance Standard	2009
Vietnam	Power Transformers	Mandatory	Minimum Performance Standard	2010
Vietnam	Washing Machines	Mandatory	Minimum Performance Standard	2010
Vietnam	Boilers and Furnaces	Mandatory	Minimum Performance Standard	2010
Vietnam	Non-Directional lamps	Mandatory	Minimum Performance Standard	2011
Vietnam	Displays	Mandatory	Minimum Performance Standard	2012
Vietnam	Imaging Equipment	Mandatory	Minimum Performance Standard	2012
Vietnam	Imaging Equipment	Mandatory	Minimum Performance Standard	2012
Vietnam	Televisions	Mandatory	Minimum Performance Standard	2012
Vietnam	Refrigerated Cabinets	Mandatory	Minimum Performance Standard	2014
Vietnam	Rice Cookers	Mandatory	Minimum Performance Standard	2015
Vietnam	Non-Directional lamps, Directional Lamps	Mandatory	Endorsement Label	2017
Vietnam	Directional Lamps	Mandatory	Minimum Performance Standard	2017
Vietnam	Computers	Mandatory	Minimum Performance Standard	2017