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Title: Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia

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Abstract: Energy is a key enabling factor within the Sustainable Development Goals (SDGs), which include eradicating poverty and hunger, improving human well-being, and protecting the environment. Countries intending to incorporate SDGs in their development programs should expect an increase in energy consumption, and therefore, need to review their energy planning. The objective of this paper is to anticipate the additional energy requirements of Indonesia with the implementation of SDGs compared to business as usual (BAU) and current policy (CP) scenarios. Assuming all SDG targets were to be implemented in the Indonesian national development plan, the additional energy demand for each target by 2030 was calculated. It was found that 18 out of 169 SDGs targets required additional energy in the Indonesian context. Overall, more energy will be needed to achieve those 18 SDGs targets compared to the BAU scenario. Fortunately, the full realisation of the current energy policies will cover the additional energy required under the SDGs scenario.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
The authors use secondary data from published reports and documents (see the reference section).

December 13, 2019

To: Professor Henrik Lund
Editor-in-Chief of Energy (The International Journal)

Subject: Submission of Revised Manuscript

Dear Professor Lund,

Please find the revised version of the paper entitled, **'Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia'**.

This work is a part of a PhD research undertaken at Murdoch University, Western Australia. It examines the impact of the Sustainable Development Goals (SDGs) implementation in Indonesia on national energy demand and compares the results with those under business as usual and current energy policy scenarios. The objective of the study is to estimate the additional energy demand if Indonesia is to achieve all SDG targets by 2030 and to assess if the current energy policy environment will be adequate for meeting the expected energy demand.

The scientific community acknowledges that the SDGs implementation will put pressure on the energy sector but does not fully understand what this means to energy demand at the national and local levels. This study offers a procedure to estimate additional energy requirement under the SDGs scenario, which will benefit a wider audience.

I declare on behalf of all the authors that it has not been published and is not considered for publication elsewhere.

Thank you very much for your kind consideration.

Sincerely Yours,

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Response to Reviewers

Reviewer #1

It can be accepted for publication after adding a new section "Policy Implications"

Response:

We add it under the Conclusions and Policy Implications section. Please see the manuscript (with changes marked) on Page 28 Line 52 (P28 L52).

> The findings of this study have policy implications. First, Indonesia should continue the execution of its national energy plan (RUEN) to ensure that the additional energy demand under the SDGs regime will be met by 2030. The implementation of RUEN in the national development plan will satisfy Indonesia's final energy demand.
>
> Next, Indonesia should increase efforts to improve energy efficiency and conservation in the transportation sector as the sector will show a remarkable increase in energy demand by 2030. The National Energy Board, through RUEN, has proposed fuel conversion programs from petroleum-based fuels to electricity, natural gas, biodiesel, and ethanol. It also suggests the acceleration of efficient public transport and services. A coherent transportation policy is needed to ensure effective inter-ministerial coordination and non-conflicting strategies [94]. Active transportation (walking and bicycling) policies should also be promoted as they will reduce energy use and emissions, improve health and well-being, and may create safer and more sustainable cities and human settlements.
>
> In addition, to achieve the ambitious RUEN target of increasing per capita electricity consumption, Indonesia should maintain high economic growth, improve people's living standard, and accelerate the adoption of electric vehicle and cooking stove technologies. These are some factors associated positively with electricity consumption [81]. Furthermore, as fossil-based electricity consumption is a source of emissions, policy on electricity generation should ensure the adoption of low carbon technology.

Reviewer #2

The authors propose, in the submitted paper EGY-D-19-05689, a paper about "Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia". The objective of this paper is to anticipate the additional energy requirements of Indonesia with the implementation of SDGs compared to business as usual (BAU) and current policy (CP) scenarios.

I have carefully reviewed the paper and the literature in the field and the proposed research is interesting but there is a similar approach in the literature, so that I suggest some improvements in the paper, although no similar studies are reported for the case of Indonesia:

1. The model lacks an environmental and/or emissions analysis because nowadays it is mandatory including this aspect in any research proposing an energy improvement.

Response:

We greatly appreciate the comment and note it for our future study.

The objectives of our study are to provide a way to estimate national energy demand under the SDG scenario, to demonstrate that the SDGs implementation will increase national energy demand, and to find out if the current national energy policy has anticipated the extra energy demand as a consequence of the SDGs implementation. Environmental or emissions analysis, therefore, is beyond the scope of the study.

Please see P27 L22.

Future studies should also include a detailed analysis of emissions or environmental impacts. Approximate estimates of carbon emissions calculated using Indonesia's carbon intensity of 2.058 kg of CO_2 per kg of oil equivalent primary energy use [92] shows that CO_2 emissions may reach 863 million tonnes (or about 2.91 tonnes per capita) if low-carbon transitions are not undertaken, assuming 70% final to primary energy ratio (see Table 1). In comparison, the average CO_2 emissions of Indonesia and the lower-middle-income countries were only 1.82 and 1.47 tonnes per capita in 2014, respectively [93]. While a summary of GHG emissions has been provided, a detailed emissions analysis is beyond the scope of this paper.

Table 1. Estimates of CO_2 emission in 2030

Scenarios in 2030	BAU	SDGs	CP
Energy use (billion GJ)	10.29	10.76	12.302
CO_2 emissions (million tonnes)	722.63	755.88	863.39

2. According to Equation 1 and Equation 2, the increase in the energy demand is supposed to follow the equations. This is a key aspect in the research, the authors should clearly justify that the growth will follow this tendency. In many reported studies and case studies, energy demand increases not linearly and it the rate changes among years.

Response:

We discuss this comment in the discussion section, P26 L41.

The CAGRs were used to estimate energy demand under the BAU and SDGs scenarios. The CAGRs assumed smooth exponential growth, and growth rates in the next 15 years would be similar to those in the last 14 years. Many studies, however, have found that energy demand and growth fluctuate. Even the International Energy Agency (IEA), with its vast amount of knowledge and data on the subject, admits that energy demand is very hard to predict, in part because there are large uncertainties in economic prospects, energy prices, and government policies [81, 91]. According to IEA, the purpose of developing energy scenarios is not to forecast future energy demand but to show how energy demand may evolve under certain circumstances.

3. Section conclusions is too short and does not summarize the main findings of the paper.

Response:

We rewrite the conclusion and summarise the main findings (see P27 L44)

Mainstreaming the SDGs in national development plans requires energy. Countries setting targets to ensure access to food, water, energy, health care, education, and other services to the public should anticipate an increase in their national energy demand. Activity levels and energy intensities of the SDG targets that require energy in their implementation can be identified and estimated to predict energy demand at the national level under the SDGs scenario. While the Indonesian final energy demand under the BAU scenario in 2030 will be almost double that in 2015, the demand under the SDGs scenario is expected to be 4.51% higher relative to the demand under the BAU scenario in 2030. It implies that national energy planning in Indonesia should tolerate about 5% more energy demand than the routine estimates if the SDGs are to be accommodated in the national development programs. Fortunately, the full implementation of the current energy policy scenario will cover the additional demand as a result of the SDGs implementation.

The sectoral comparison shows that the transportation sector will consume more energy than the industrial sector under the BAU and SDGs scenarios by 2025. Under the current energy policy scenario, however, the industrial sector will still use more energy than the transportation sector by a small margin in 2030 due to the ambitious target of increasing electricity consumption. It will significantly increase energy use in the industrial, commercial and household sectors.

The energy demand analysis (by fuel) reveals that:

- Gasoline, electricity, and diesel oil use will increase the most under the BAU scenario.
- Natural gas, non-energy, and coal consumption will also increase significantly by 2030 under the BAU scenario.
- Under the SDGs scenario, the use of electricity, natural gas, gasoline, diesel oil, biodiesel, and LPG will only be slightly higher than that under the BAU scenario.
- The current energy policy scenario, on the other hand, calls for a dramatic increase in electricity use.
- A notable increase in natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use should also be expected under this scenario in order to reduce gasoline, diesel, and LPG imports.

Finally, this study translates Target 7.3 to a global energy intensity benchmark of 3.422 MJ/2011 PPP $ of GDP and combines Targets 7.3 and 8.1 to set a global primary energy use target of less than 73,083 MJ/cap by 2030. Under the current energy policy scenario, Indonesia's energy use may reach 3.057 MJ/2011 PPP $ or 57,616 MJ/cap, which will be less than the predicted global average consumption in 2030. The per capita energy consumption in 2030 will also be less than the minimum per capita energy use associated with a very high human development index.

4. Include a brief sensibility analysis or at least, mention the key parameters that would modify the results.

Response:

We discuss the key modifying variables on P21 L33.

3.5. Key modifying variables

Energy demand estimates under the BAU scenario assume that future energy demand growth (CAGR) equals past growth (see Eq. 1 and 2). Based on the equations, the CAGR is the key variable that will modify the energy demand estimate under the BAU. Variables that are positively associated with energy demand and its growth include population and GDP [81, 82]. Since GDP and its growth fluctuates, energy demand and its growth are also likely to vary. Therefore, the accuracy of demand estimates also depends on how good the CAGR is predicted. For instance, the 2030 BAU energy demand will increase by 33% to 13,687.22 million GJ if sectoral energy demand CAGRs increase by 2% (see Appendices, Table A.1).

Under the SDGs scenario, the key parameters for energy demand are SDGs activity level gaps and activity level energy intensities (see Figure 1 and Eq. 3-7). If we assume zero growth of the activity level CAGR of target T, or $G_T = 0$ (see Eq. 3), then

$$A_{T,BAU} = A_{T,2015} \qquad \text{(see Eq. 4)}$$

and

$$A_{T,Gap} = |A_{T,SDGs} - A_{T,2015}| \qquad \text{(see Eq. 5)}$$

Solving Eq. 7 for each SDG target *T*, we found that the energy demand estimate under the SDGs scenario will be 943.85 million GJ in 2030, more than twice the previous estimate, or about 9.17% higher than that under the BAU (see Appendices, Table A.2).

On the other hand, energy demand under the current policy scenario depends largely on the national energy policy and plan. Different countries will have different objectives and priorities; therefore, different demands for energy.

Reviewer #4

Sustainable development goals are a very broad topic and are very interlinked. Energy being one of the SDG's I believe if you could further draw the line away from the conflicting aspects.

Response:

The interlinkages between energy (SDG7) and other SDGs have been discussed on P26 L9.

> The scope of SDGs is very broad, from ending poverty and hunger, providing universal access to healthcare, education, water, and energy to delivering equality, good infrastructure, healthy environment, peace, justice, and partnerships. The SDGs are also, directly and indirectly, interlinked as a network of goals and targets [14]. These complex interactions of targets make the corresponding energy demand more difficult to quantify [15]. In the present study, only the direct first-degree interactions of the SDGs and energy demand are calculated. It does not take into consideration second-degree interactions.
>
> It should be noted that energy demand also interacts with the energy goal (SDG 7), but energy demand, per se, is not SDG 7. Some of the SDG targets may overlap, and, in some cases, there are second and third-degree interactions between the target and energy demand all of which add complexity to the calculation. For example, halving food losses (Target 12.3) in Indonesia requires energy for food processing and storing. Yet, it also will save enough food to feed the undernourished people (Target 2.1). Consequently, less food must be farmed, and less energy will be needed.

Highlights

- Energy demand in Indonesia under the SDGs will increase by 5% of the BAU in 2030
- Under the national energy plan, the energy demand will be 19% higher than the BAU
- The national energy plan has anticipated energy demand under the SDGs scenario
- In 2030, the transport energy demand will be higher than that of industries
- The current energy policy scenario calls for a dramatic increase in electricity use

Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia

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The funding source had no involvement in any stages of the study.

Declaration of interest: None.

Abstract

Energy is a key enabling factor within the Sustainable Development Goals (SDGs), which include eradicating poverty and hunger, improving human well-being, and protecting the environment. Countries intending to incorporate SDGs in their development programs should expect an increase in energy consumption, and therefore, need to review their energy planning. The objective of this paper is to anticipate the additional energy requirements of Indonesia with the implementation of SDGs compared to business as usual (BAU) and current policy (CP) scenarios. Assuming all SDG targets were to be implemented in the Indonesian national development plan, the additional energy demand for each target by 2030 was calculated. It was found that 18 out of 169 SDGs targets required additional energy in the Indonesian context. Overall, more energy will be needed to achieve those 18 SDGs targets compared to the BAU scenario. Fortunately, the full realisation of the current energy policies will cover the additional energy required under the SDGs scenario.

Keywords: Sustainable Development Goals; energy; energy demand; energy intensity; LEAP; Indonesia.

1. Introduction

In September 2015, the United Nations introduced the Sustainable Development Goals (SDGs) as a global plan of action for people, environment, and economy [1]. The SDGs incorporated 17 goals with 196 associated targets. They replaced the Millennium Development Goals, which expired in the same year. The SDGs are global goals achievable only through implementation in local and national development agendas [2]. Most countries have adopted the SDGs into their development agendas [3], and by 2019, 144 countries have presented their voluntary national reviews (VNRs) on SDGs at the UN's High-level Political Forum [4].

There are many studies related to individual SDG targets and their implementation, but few discuss this implementation impact on energy demand. Büyüközkan, Karabulut and Mukul [5], for instance, presented an integrated multi-criteria decision-making (MCDM) method to determine the most suitable renewable energy source by addressing SDG7, while Schwerhoff and Sy [6] worked on SDGs by considering how an increase in the production of renewable energy would affect the likelihood of achieving these goals in a given amount of time. Caiado *et al*. [7] mention some of the problems and barriers related to SDGs implementation, and dos Santos and Balestieri [8] tried to understand the relationship between a group of socioeconomic and environmental factors linked with the SDGs for some cities in Brazil.

Other studies discuss energy efficiency actions in achieving SDGs, including Puig, Farrell, and Moner- Girona [9] who worked on the significance of energy efficiency enhancements to meet the SDGs. They observed that besides SDG7, which aspires to double the global rate of improvement in energy efficiency by 2030, energy efficiency improvement could also contribute to SDG2, SDG3, SDG6, and SDG8. Di Foggia [10] studied energy efficiency in the residential sector and found that energy-efficient buildings can make a significant positive contribution in achieving SDG 11 and SDG 13. Alawneh *et al*. [11] studied the contribution of water and energy efficiency to SDGs (SDGs 6−9, 12–13, and 15) in the residential sector in Jordan.

Interlinkages and cross impacts of the SDGs are also discussed in the literature. Some studies applied a nexus approach to analyse the SDGs interactions [12-14]. This approach provides a more comprehensive explanation of the interactions, yet it also will add complexity to the analysis of the corresponding energy demand [15]. Both positive and negative links between the SDG targets and energy were found by McCollum *et al*. [16], and their analysis suggested that the positive interactions outweigh the negative ones. Nerini *et al*. [17] assessed the interactions between SDG7 (related to energy access, renewable energy, and energy efficiency) and the other SDGs and found similar results. These studies, however, did not take into account the impact of the interactions on energy demand. Recently, Santika *et al*. [15] mapped the linkages between 25 SDG targets and energy demand and found that additional energy is required, compared to the business-as-usual, to achieve these targets.

Should the SDGs be nationally mainstreamed, higher energy demand should be anticipated, and energy planning and policy may require reconsideration. Santika *et al*. [18] simulated the impact of SDG7 on household sector energy demand in Indonesia and found that providing clean energy access to everyone would indeed increase demand for commercially sourced energy. Subsequently, Santika *et al*. [15] estimated that 599.5 MJ/person per year would be needed to end hunger in Indonesia (Target 2.1)[1]. They also identified SDG targets related to energy demand and offered a method for estimating the energy intensity of each target should it be realised in a development agenda. Further study on how it would work at a country level, however, was greatly required. This paper has addressed this research gap and built on their work [15] by quantifying the additional energy requirement at the country level. In doing so, it has tried to answer the question about the full impact of the implementation of SDGs on Indonesia's national energy demand.

As a part of the 193 countries ratifying the SDGs in 2015, Indonesia agreed to implement them in its national development agendas. Its 2015-2019 national medium-term development plan (locally known as RPJMN) explicitly states that Indonesia would embed the SDGs into the post-2015 national development agendas. In 2017, Indonesia released its voluntary national review (VNR) report on SDGs [19]. The report claims that Indonesia has 320 national indicators to measure the level of achievement in reaching the SDGs. Some are similar to the 241 global indicators of the SDGs, and others are additional and proxy indicators [19]. Subsequently, Presidential Regulation 59/2017, passed in July 2017, provides the legal basis for the implementation of SDGs in Indonesia. The regulation provides national targets that have been matched and synchronised with the SDG targets. In fact, Indonesia is committed to becoming the world pioneer and role model in SDGs implementation, as stated in its national action plan on SDGs (under the National Development Planning Ministerial Regulation 7/2018).

[1]Target 2.1 means the first target of SDG2

Earlier in 2017, the Government of Indonesia (GOI) released the National Energy General Plan (locally known as RUEN). RUEN is the extension of the national energy policy, which has targets as shown in Table 1.

Table 1. Indonesian national energy policy targets [20]

Targets	**2015**	**2020**	**2025**	**2050**
Primary energy (MTOE)			400	1000
Primary energy (TOE/capita)			1.4	3.2
Power generation (GW)			115	430
Electricity consumption (kWh/capita)			2500	7000
Energy elasticity (%)			< 1	
Reduction of final energy intensity (% per year)	1	1	1	1
National energy mix:				
Renewable energy (%)			>23	>31
Oil (%)			<25	<20
Coal (%)			>30	>25
Natural gas (%)			>22	>24
Electrification ratio (%)	85	100		

Additionally, Indonesia's national energy outlook is annually released by the Agency for the Assessment and Application of Technology (locally known as the BPPT). However, the outlook omits the impact of the SDGs implementation on energy demand. The latest outlook, for instance, exercises only demographic and economic variables under the RUEN implementation scenarios [21]. These scenarios do not necessarily reflect the SDGs.

The above discussions suggest that there is a need to estimate energy demand to meet the SDGs in Indonesia by 2030 and compare the results with the demand under the current energy policy (CP) scenario. In the absence of an integrated plan that accounts for this additional energy demand, Indonesia's ambition to achieve all SDGs by 2030 is likely to fail. In this context, this study aims at estimating the additional energy requirement under the context of full implementation of the SDGs in Indonesia and compares the result with those under BAU and CP scenarios. This study aims to answer the following research questions:

a. What would be the national energy demand, in different sectors and by fuel, in 2030 if Indonesia achieves all of the SDGs?
b. What is the gap in energy demand between the SDGs scenario, BAU scenario, and current energy policy scenario?
c. How adequate is the current energy policy environment for meeting energy demand under the SDGs implementation?

This study also provides examples of how country-level energy demand is estimated under the SDGs regime and ensures that the procedure is applicable to other countries.

2. Methods

This study compared a complete implementation of SDGs scenario against business as usual (BAU) and current energy policy (CP) scenarios. The BAU scenario assumes no new policy will be implemented in the national development plan by 2030. In this case, the historical growth of sectoral fuel consumption was assumed to continue into the future. In contrast, the CP scenario considers all demand-side targets imposed by the RUEN. The availability of useful data directed the choice of 2015 as a baseline year and 2016 as the first year of the SDGs implementation. Figure 1 shows the data collection and analysis steps taken in this research.

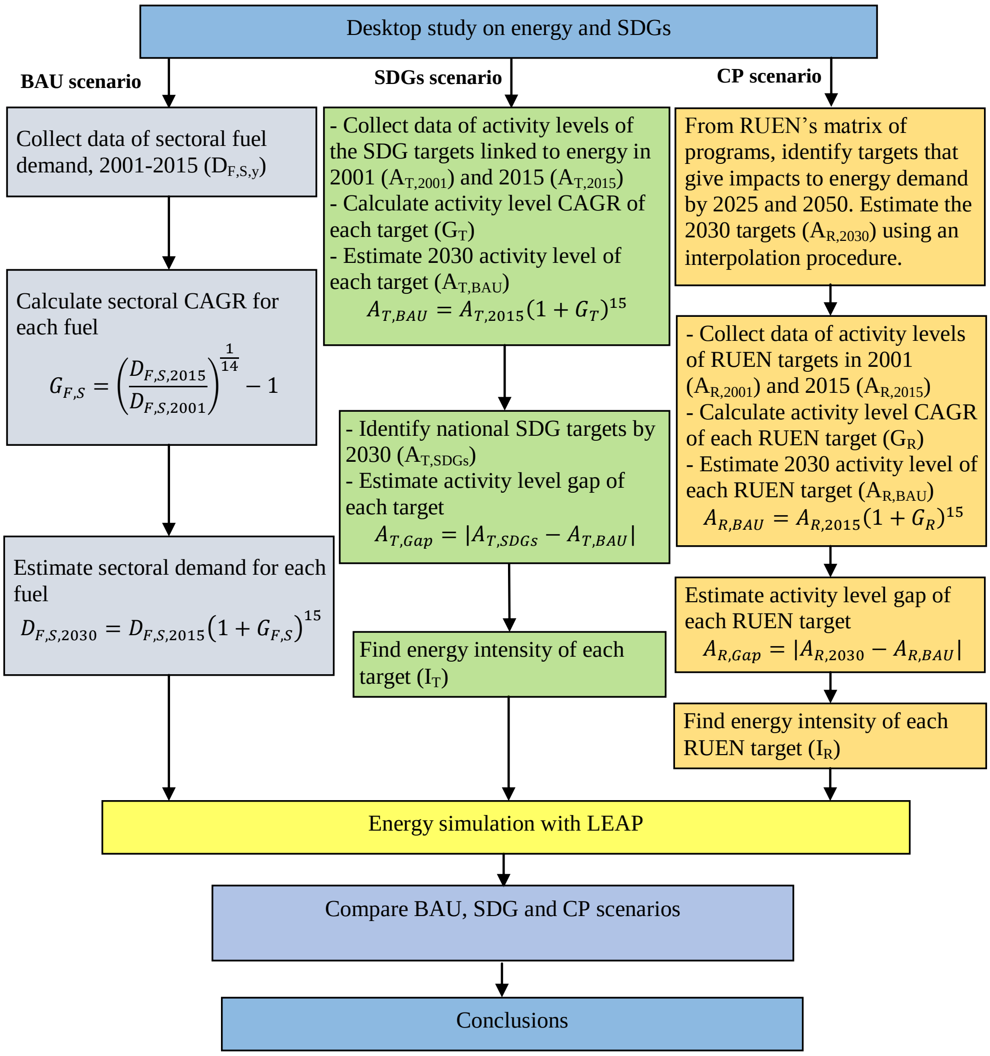

Figure 1. Flowchart of the methodology for estimating energy demand under BAU, SDGs, and CP scenarios

(2-collumn fitting image, print in colour)

The desktop study provided comprehensive information on links between SDGs and energy demand. Under the BAU scenario, data of sectoral energy demand from 2001 to 2015 was collected from the Indonesian Ministry of Energy and Mineral Resources (MEMR) reports. Next, the compound annual growth rate (CAGR) of sectoral energy consumption of each fuel was calculated [18],

$$G_{F,S} = \left(\frac{D_{F,S,2015}}{D_{F,S,2001}}\right)^{\frac{1}{n}} - 1 \qquad \text{(Eq. 1)}$$

$G_{F,S}$ represented the CAGR of the energy demand of fuel *F* in sector *S*, *n* indicated the total years between 2001 and 2015, while $D_{F,S,2001}$ and $D_{F,S,2015}$ represented energy demand for fuel *F* in sector *S* in 2001 and 2015, respectively.

The future energy consumption growth rates were assumed to equal $G_{F,S}$, and demand of fuel *F* of sector *S* by 2030 was estimated as

$$D_{F,S,2030} = D_{F,S,2015}\left(1 + G_{F,S}\right)^{m} \qquad \text{(Eq. 2)}$$

where *m* is the total years between 2015 and 2030.

An exception was made for the household and transport sectors, as the energy demand in these sectors is strongly linked to the population size. For these sectors, the energy use intensity (EI) of each fuel in 2001 and 2015 (in MJ/household for the household sector, and MJ/person for the transportation sector) was determined. Next, the CAGR of energy use intensity of each fuel ($G_{F,S}$) was calculated. Based on the $G_{F,S}$, the EI of each fuel in 2030 was estimated and the future energy demand of these sectors was projected based on the 2030 EIs.

Under the SDGs scenario, secondary data from the body of literature was obtained of the activity levels of the SDG targets linked to energy in 2001 and 2015. The activity levels include population, GDP, and other economic and socio-demographic activities that consume energy [22]. $A_{T,2001}$ and $A_{T,2015}$ represented the activity level of target *T* in 2001 and 2015, respectively. Next, the activity level CAGR of target *T* (G_T) was calculated as

$$G_T = \left(\frac{A_{T,2015}}{A_{T,2001}}\right)^{\frac{1}{n}} - 1 \qquad \text{(Eq. 3)}$$

The following step was to estimate the activity level of target *T* by 2030 ($A_{T,BAU}$), assuming the activity level CAGR of target *T* in the coming years will equal G_T. Therefore,

$$A_{T,BAU} = A_{T,2015}(1 + G_T)^{15} \quad \text{(Eq. 4)}$$

$A_{T,BAU}$ is the 2030 activity level of target T before the implementation of the SDGs. The next step was to identify the 2030 national SDG targets ($A_{T,SDGs}$). For example, some countries may consider 100% electrification ratio (Target 7.1) as too ambitious and difficult to achieve and set a target of 95% electricity access instead. In this case, we assumed Indonesia fully implements all of the SDG targets in its development plan.

After that, the activity level gap of target T by 2030 ($A_{T,Gap}$) was estimated

$$A_{T,Gap} = |A_{T,SDGs} - A_{T,BAU}| \quad \text{(Eq. 5)}$$

In order to calculate the energy demand of target T (D_T), the energy intensity of target T (I_T) was estimated using a similar procedure to that offered by Santika *et al*. [15]. For example, the energy intensity of providing a mobile phone for everyone ($I_{T5.b}$) was calculated as

$$I_{T5.b} = \frac{E_P}{t_{op}} \quad \text{(Eq. 6)}$$

where E_P and t_{op} are energy use per phone and phone operating time, respectively. Eq. 6 was solved using an energy use of 16 kJ/phone for an operating time of 27 hours [23], which gave energy intensity of 5.19 $\text{MJ}\cdot\text{phone}^{-1}\cdot\text{year}^{-1}$.

Once I_T was identified, D_T could be determined by

$$D_T = I_T . A_{T,Gap} \quad \text{(Eq. 7)}$$

D_T estimates, however, were automatically computed using the Long-range Energy Alternative Planning System (LEAP) once data such as activity levels, energy intensities, growth rates, the total energy of the base year and end year were entered into the modelling software. LEAP is an energy modelling software developed at the Stockholm Environment Institute to analyse energy policy and climate change [22]. It has been used especially in developing countries for integrated resource planning and emission assessment [24-28]. The Government of Indonesia also utilizes LEAP for the national energy projection and GHG emission assessment [29]. Other Indonesia's energy assessments using the LEAP model in their analyses include studies on Java-Bali power capacity expansion [30], long-term electricity planning [31], and renewable electricity for energy security and emission reduction [32].

Note that D_T might be made up of different fuels and different fuel consumption patterns across sectors. For instance, ensuring adequate food for everyone to end hunger (Target 2.1) required energy for farming (the agriculture sector), food distribution (the transportation sector) and retailing (the commercial sector). These sectors use various fuels (energy sources), including electricity, gasoline, diesel fuel, and natural gas. The approach used by this study was to consult the literature for the sectoral share of D_T and the fuel share of sectoral D_T. Otherwise, it was assumed that the shares were directly proportional to the baseline year's sectoral share and fuel share of national demand.

Next, the procedure for estimating energy demand under the CP scenario RUEN targets provided a large matrix of (planned) national energy programs with targets set for 2025 and 2050. Under the current energy policy scenario, RUEN targets having an impact on energy demand were identified, and their 2030 activity level of RUEN's target R ($A_{R,2030}$) was estimated based on the 2025 and 2050 RUEN targets. The next steps were similar to those under the SDGs scenario.

In the following section, yearly energy demand for the three different scenarios are presented, along with an analysis of energy demand by sector and fuel. Finally, these results are discussed and followed by a conclusion.

3. Results

The Ministry of Energy and Mineral Resources of Indonesia (MEMR) divides energy consumers into six sectors:

- industrial,
- household,
- commercial,
- transportation,
- other, and
- non-energy sectors.

The other sector includes mining, fishery, and construction sub-sectors. The non-energy sector is the sector that consumes fuels without releasing their energy content, which includes lubricant oil, gas, and petrochemicals used to produce substances such as ammonia and methanol [33]. Sources of energy (referred to as fuels in the texts) vary across sectors including biomass, coal, natural gas, briquette, oil, LPG, and electricity. The present study omitted the traditional use of biomass in the household sector.

3.1. BAU Scenario

Table 2 provides examples of estimates in industrial sector energy demand, by fuel, under the BAU scenario. The 2001-2015 consumption data were used to calculate future growth (CAGR), which, in turn, was used to estimate future consumption. The industrial sector total energy consumption is estimated to be 3,428.20 million GJ by 2030.

Table 2. Industrial sector energy demand by 2030 under the BAU scenario. Data sources: [34, 35].

Year	**Industrial Sector (million GJ)**									
	Biomass	Coal	Briquette	Gas	Kerosene	Diesel Oil	Fuel Oil	Other Petroleum Product	LPG	Electricity
2001	320.91	215.28	0.45	476.02	24.19	274.43	155.14	149.52	5.65	126.88
2015	260.67	408.38	0.29	709.89	1.52	301.70	56.50	276.29	4.58	228.42
CAGR	-0.015	0.047	-0.031	0.029	-0.179	0.007	-0.070	0.045	-0.015	0.043
2030	208.62	810.93	0.18	1,089.31	0.08	333.93	19.15	533.46	3.66	428.86
Total consumption projection in 2030: 3,428.20 million GJ										

The projection of the transportation sector's energy demand by 2030 under the BAU scenario using the energy intensity (EI) approach is shown in Table 3. Once the 2030 EIs were obtained, the energy consumption was determined by multiplying each EI with the 2030 projected population of 296.4051 million [36].

Table 3. Transportation sector energy demand by 2030 under the BAU scenario. Data sources: [34, 35].

Transportation sector								
	Gas	Avgas	Avtur	Gasoline	Kerosene	Fuel Oil	Diesel	Electricity
EI 2001 (MJ/cap)	3.90	0.52	241.90	2,063.57	0.76	14.48	1,806.02	0.81
EI 2015 (MJ/cap)	5.58	0.41	581.50	4,071.02	0.06	4.30	2,555.98	2.85
EI CAGR	0.02667	-0.02215	0.06465	0.04973	-0.18369	-0.08297	0.02512	0.09204
EI 2030 (MJ/cap)	8.31	0.28	1,488.13	8,430.74	0.0023	1.17	3,708.23	10.75
2030 Energy use (million GJ)	2.46	0.08	441.09	2,498.92	0.0006	0.35	1,099.14	3.18
Total consumption projection in 2030: 4,045.22 million GJ								

Sectoral energy demand estimations for 2030 under the BAU scenario are shown in Table 4. The transportation sector will consume the most energy, followed by the industry and household sectors. Overall, about 10,291.7 million GJ energy demand should be anticipated under the BAU scenario by 2030.

Table 4. Estimates of sectoral energy consumption by 2030 under the BAU scenario.

	Industry	Household	Commercial	Transportation	Other	Non-	Total

						Energy	
Million GJ	3,428.20	989.89	705.95	4,045.22	259.09	863.35	10,291.70

3.2. SDGs Scenario

An example of how to estimate additional energy demand under the implementation of the SDGs at the national level is provided below. Target 2.1 of the SDGs calls for zero hunger by 2030. The prevalence of undernourishment is an indicator of Target 2.1. The activity levels of Target 2.1 in 2001 and 2015 ($A_{T,2001}$ and $A_{T,2015}$) were 37,973,754 and 18,648,726 undernourished persons, respectively (see Table 5). Next, the CAGR of the undernourishment (G_T) and the number of undernourished people by 2030 ($A_{T,BAU}$) were calculated using the Eq. 3 and Eq. 4, which gave an estimate of 8,704,728 undernourished persons by 2030 under the BAU.

Table 5. Prevalence of undernourishment in Indonesia. Data source: [37]

Year	**Total population**	**Prevalence of undernourishment**	
		%	Persons (A_T)
2001	208,647,000	18.2	37,973,754
2015	255,462,000	7.3	18,648,726
CAGR (G_T)			-0.04953
2030	296,405,100	2.94%	8,704,728

The target ($A_{T,SDGs}$) is to reach zero undernourished people by 2030, and the undernourishment gap between the SDG target and the BAU estimate ($A_{T,Gap}$) becomes |8,704,728| undernourished persons (absolute value). Consequently, addressing the gap with SDGs implementation requires energy, and according to Santika, *et al*. [15], the energy required to provide food for the undernourished people in Indonesia (I_T) is 599.33 MJ·person^{-1}·year^{-1}. Therefore, the additional energy demand (D_T) as a consequence of Target 2.1 implementation in Indonesia by 2030 is approximately 5,217,004.64 GJ.

Due to a lack of data for some targets, calculations based on relevant associated information were made. For instance, Target 6.3 is to improve water quality by halving the proportion of untreated wastewater by 2030. According to the 2014-2019 Indonesian Medium-term development plan (locally known as RPJMN), wastewater treatment facilities should reach 34 million urban people by 2019. By 2030, the facilities were assumed to reach 50 million urban people. BAPPENAS *et al*. [36] estimated that Indonesia's urban population would be 187,920,833 persons (63.4%) by 2030, so about 137,920,833 urban people will remain without wastewater treatment facilities by 2030. Wastewater generation in urban Indonesia was about 0.12 $m^3 \cdot person^{-1} \cdot day^{-1}$ [38]. Therefore, untreated urban wastewater will be approximately 6,040,932,503 m^3/year by 2030. Halving this figure means treating 3,020,466,251.46 m^3/year more wastewater by 2030, which will consume more energy. Table 6 shows a summary of the procedure used to calculate the amount of extra wastewater that needs to be treated per annum by 2030.

Table 6. An example of the improvised procedure applied to Target 6.3

Variables	**Amount**	**Units**
Total population, 2030	296,405,100	Persons
Urban population 2030	63.4	%
Urban population, 2030	187,920,833	Persons
RPJMN target 2014-2019	34,000,000	Persons
Assumed 2030 access	50,000,000	Persons
Urban people without access	137,920,833	Persons
Wastewater generation	0.12	m^3 person^{-1} day^{-1}
Wastewater untreated	6,040,932,503	m^3/year
Halving the untreated wastewater ($A_{T,Gap}$)	3,020,466,251	m^3/year

Once $A_{T,Gap}$ is determined, the additional energy demand as a consequence of Target 6.3 implementation can be estimated. The energy intensity of wastewater treatment in Indonesia was assumed to be 0.5 kWh/m^3 considering that the intensity ranged from 0.05 to 0.15 and from 0.95 to 1.25 kWh/m^3 in India and China, respectively [39, 40]. The extra energy consumption will, therefore, be 1,510,233,126 kWh or 5,436,839 GJ by 2030.

Table 7 summarises the results of the calculations of Indonesia's additional energy requirement under the SDGs regime by 2030. Twenty-four out of 25 SDG targets linked to energy as proposed by Santika *et al*. [15] were assessed (Target 1.4 about access to basic services was excluded as the achievement of other targets would contribute to it). The results reveal that 18 targets will require additional energy by 2030. Target 2.4 was omitted due to a lack of national data on land areas under sustainable agriculture, and the target also lacked a precise number making it difficult to assume a national target (Indonesia has not set one). Targets 4.3 and 17.8 were considered to be achievable under the BAU scenario; hence, no additional energy will be needed. Target 7.2, concerning the substantial increase in the renewable energy share, was assumed to transform energy sources from fossil fuel to renewables and thus affect energy supply only. The target will not change energy demand. Finally, Targets 7.3 and 8.1 should be calculated together, and the figure reflects the maximum allowable energy demand by 2030. This issue has been further elaborated in the discussion section.

Overall, SDGs implementation will require approximately 464.27 million GJ more energy on top of the BAU scenario by 2030. Figure 2 shows that Target 9.1 (access to quality infrastructure) will consume the most energy (about 169.41 million GJ) by 2030, followed by Target 11.2 (access to safe urban transport systems for all; 87.44 million GJ), Target 7.1 (access to clean fuels and technology for cooking; 83.23 million GJ), and Target 12.3 (food losses and waste; 76.03 million GJ). The energy demand for the other targets will be about 10 million GJ or less. Targets 5.b (equal access to mobile phones) and 13.1 (resilience to disasters) will consume the least energy (about 0.22 and 0.55 million GJ), respectively. The negative value of Target 12.5 (waste reduction) indicates a potential saving of energy.

Table 7. Summary of the additional energy requirement for SDGs implementation in Indonesia

SDG Targets	Description	Activity levels (A_T)	SDGs Gap	Energy Intensity, annually		Additional Energy demand	Data and reference	Remarks
			($A_{T,Gap}$)	(I_T)	Unit	(GJ)		
2.1	Zero hunger	Undernourish people	8,704,728 persons	599.33	MJ/person	5,217,005	[15, 37, 41]	
2.3	Double small farmer productivity	Small farmer households	8,722,526 households	1,611.99	MJ/household	14,060,598	[41-43]	2003-2013 Data
2.4	Sustainable agriculture	Land area under sustainable agriculture	NA	-	-	-		Data and target are not available
3.8	Universal healthcare access	Persons with unmet needs for healthcare	4,674,884 persons	475.63	MJ/person	2,223,495	[15, 44]	2011-2015 Data
4.1	Access to primary and secondary education	Elementary school students	1,512,505 students	798.34	MJ/student	1,207,487	[15, 45-48]	2014-2016 Data
		Junior high school students	2,224,973 students	991.87	MJ/student	2,206,888	[45-48]	2014-2016 Data
		Senior high school students	2,605,210 students	1,330.56	MJ/student	3,466,388	[45-48]	2014-2016 Data
4.2	Access to early childhood education	Kindergarten students	2,161,635 pupils	598.75	MJ/student	1,294,283	[15, 45-48]	2014-2016 Data
4.3	Access to tertiary education	Students of tertiary education	0	-	-	0	[49, 50]	The trend shows that the 40% target of gross enrolment rate will be achieved by 2030 under the BAU
5.b	Equal access to enabling technology	Persons with a mobile phone	42,328,459 persons	5.19	MJ/person	219,685	[15, 23, 51]	2015-2016 Data
6.1	Access to safe drinking water	Persons with drinking water access	56,148,718 persons	92.16	MJ/person	5,174,666	[39, 52-54]	2015-2017 Data
6.3	Halving the proportion of untreated Wastewater	Cubic meters untreated wastewater	3,020,466,251 m^3	1.8	MJ/m^3	5,436,839	[36, 38-40]	Improvised procedure
7.1	Access to electricity and clean cooking fuels	Households with electricity	0	1,314	MJ/household	-	[18, 34, 35, 55, 56]	100% of electricity access will be achieved by 2020
		Households cooking with LPG	12,095,286 households	7,087.26	MJ/household	85,722,464	[18, 34, 35, 57, 58]	Biomass and kerosene were replaced by LPG

SDG Targets	Description	Activity levels (A_T)	SDGs Gap	Energy Intensity, annually		Additional Energy demand	Data and reference	Remarks
		Households cooking with kerosene	304,519 households	-8,200.314	MJ/household	-2,497,151	[18, 34, 35, 57, 58]	Avoided kerosene use after conversion to LPG. Traditional biomass use was never included in the calculation since only commercial energy was considered.
7.2	Renewable energy share	Renewable energy does not change energy demand						
7.3	Energy efficiency	Targets 7.3 and 8.1 should be calculated together using national data, and the result should be regarded as a benchmark for maximum national energy consumption. See the discussion section and Santika, et al. [15].						
8.1	Sustainable economic growth							
9.1	Access to road infrastructure	Toll road length	3,261.04 km	10	TJ/km	32,610,400	[59-61]	Improvised procedure
		National road length	6,000 km	7.5	TJ/km	45,000,000		
		Provincial road length	6,000 km	5.4	TJ/km	32,400,000		
		Sub-provincial road length	18,000 km	3.3	TJ/km	59,400,000		
9.c	Access to information and communication technology	Persons in areas without mobile network cover	6,372,602 persons	1,702.94	MJ/user	10,852,184	[15, 62, 63]	2011-2014 Data
11.1	Access to adequate housing	Persons in urban slums	5,970,911 persons	864.00	MJ/person	5,158,867	[15, 64, 65]	2015-2016 Data
11.2	Access to convenient public transport	Persons with convenient public transport	29,640,510 persons	2,950.00	MJ/person	87,439,505	[66, 67]	Improvised procedure
11.6	Urban solid waste	Urban solid waste not collected	2,732,669.80 tonnes	588.07	MJ/t (diesel)	1,607,014	[68, 69]	2015-2016 Data
				432	MJ/t (electricity)	1,180,513		
12.3	Food losses and waste	Total population	296,405,100 persons	256.5	MJ/cap	76,027,908	[70-72]	Improvised procedure
12.5	Waste reduction	Waste recycled	5,188,000 tonnes	-1,640	MJ/t	-8,508,320	[69, 72-74]	Improvised procedure
13.1	Resilience to disasters	Relocated persons	403,441 persons	1,353.07	MJ/person	545,882	[65, 75]	Improvised procedure
17.6	Access to science	Fixed broadband subscriptions	23,074,583 subscriptions	315.36	MJ/subscription	7,276,800	[76, 77]	Improvised procedure
17.8	Access to the internet	Persons using internet	0	113.7	MJ/user	-	[78-80]	All Indonesian will have access to

SDG Targets	Description	Activity levels (A_T)	SDGs Gap	Energy Intensity, annually		Additional Energy demand	Data and reference	Remarks
								the internet by 2030
Total additional energy demand (MJ)						**464,268,084,283**		

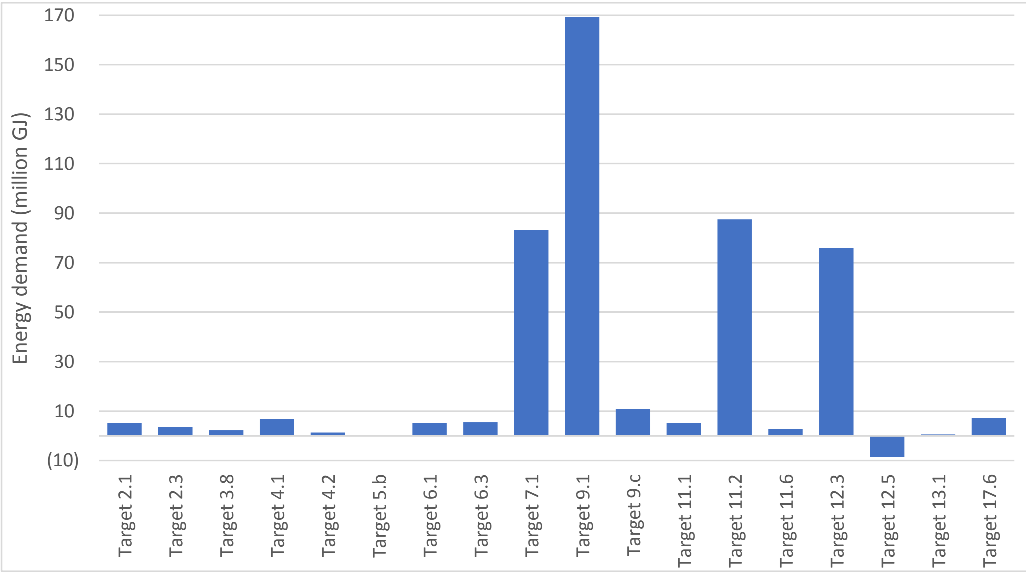

Figure 2. Additional energy demand as a consequence of SDGs implementation

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3.3. Current Policy Scenario

Nine RUEN targets related to energy demand were identified, as shown in the second column of Table 8. Since the targets need to be achieved by 2025 and 2050, RUEN targets for 2030 were also estimated (the third column of the table). It was assumed that only targets R1 and R3 would require more energy compared to the BAU scenario. Both targets anticipate about 2.05 billion GJ more energy in 2030. The other targets would not add or reduce energy demand as they replace one energy source with another. This analysis did not consider the potential to reduce energy demand as a result of added efficiencies of the substituting energy sources. LEAP results show that the total energy demand in 2030 will be about 12.29 billion GJ, which is approximately 2.00 billion GJ higher than the BAU. The discrepancy between this figure with the total demand calculated in Table 8 is accounted for by the assumption relating to target R8. The assumption in R8 will offset the transport demand under the BAU and CP scenarios at 3.11 billion GJ by 2025. The same assumption, however, will create less demand under the CP scenario by 2030 (see Table 9).

Table 8. Summary of RUEN targets and additional energy requirement under the current policy scenario in Indonesia

No	RUEN Targets	RUEN Targets	Additional	Remarks

		adjusted for 2030	Energy demand	
R1	Electricity consumption: 2,500 and 7,000 kWh/cap by 2025 and 2050	3,400 kWh/cap	2,036.07 million GJ	Assumption: this target is proportionally shared across sectors; the share is equal to the baseline year share
R2	Pipeline natural gas for cooking: 4.7 million households by 2025	10% of total households	It would not add or reduce energy demand	It was assumed to replace LPG
R3	Biogas for cooking: 1.7 million households by 2025	3.4% of total households	17.03 million GJ	It was assumed to replace solid biomass, which was omitted in the household sector
R4	Dimethyl ether (DME) production: 1 million ton by 2025 (about 10% of the estimated total LPG consumption in 2025)	It replaces 15% of total LPG consumption	It would not add or reduce energy demand	Assumption: mixed with LPG; 60% produced from coal, 40% from biomass
R5	Electrification ratio: 100% by 2020	-	-	Achieved under the BAU
R6	Natural gas use in the transport sector: 282.1 mmscfd by 2025 (about 372.77 MJ/cap)	552.4 MJ/cap	It would not add or reduce energy demand	This target supports the achievement of Target R8
R7	Electric vehicle energy use: 2.3 TWh by 2025 (about 26.55 MJ/cap)	37.8 MJ/cap	It would not add or reduce energy demand	This target supports the achievement of Target R8
R8	Petroleum-based fuels for transport: 75.3 million kilolitres or less by 2025 (about 2.55 billion GJ). Our estimate shows that it will be about 3.01 billion GJ by 2025 under the BAU	2.55 billion GJ or less by 2025	It would not add or reduce energy demand	The gasoline and diesel energy intensity growths were assumed to decrease to 4.45% and 2.3135% to achieve this target. 30% biodiesel and 15% bioethanol blends by 2025 were also assumed.
R9	Biodiesel for transport: 13.9 million kL by 2025 (524.3 million GJ)	319.67 million GJ	It would not add or reduce energy demand	This RUEN target was constrained by the B30 biodiesel blend target. This target supports the achievement of Target R8.
		Sum of R1 and R3 energy demand	2,053.1 million GJ	

Table 9. LEAP estimates of transport sector energy demand under the BAU and CP scenarios (in million GJ). Target R8, which is to be achieved by 2025, combined with Targets R6, R7, and R9, requires equal demand under the BAU and CP scenarios by 2025. Those targets create a demand discrepancy between the BAU and CP scenarios in 2020 and 2030.

Scenarios	2015	2020	2025	2030
BAU	1,844.78	2,392.82	3,108.55	4,045.08
Current Policy	1,844.78	2,402.82	3,108.56	4,002.50

3.4. Scenario comparison

Figure 3 shows the LEAP result of energy demand under the BAU, CP, and SDGs scenarios. Under the BAU scenario, energy demand will rise from 5.66 to 10.29 billion GJ between 2015 and 2030. Under the SDGs scenario, the demand will increase further from the same baseline point in 2015 to 10.76 billion GJ in 2030. The demand will increase even further to 12.30 billion GJ in 2030 under the CP scenario. These results indicate that mainstreaming the SDGs in the national development plan of Indonesia will increase national energy demand. However, the full realisation of its national energy plan (RUEN) will be more than enough to anticipate the rise of energy demand under the SDGs scenario.

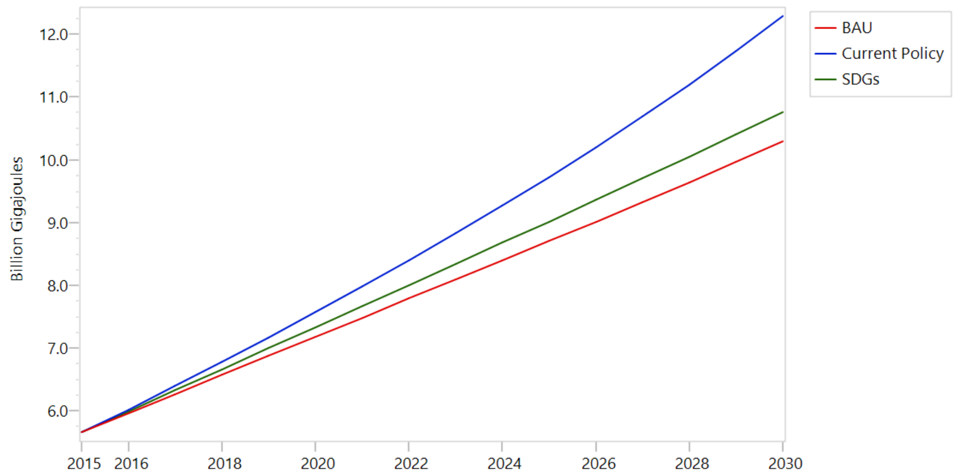

Figure 3. LEAP results of energy demand under three different scenarios

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The scenarios are also compared based on their sectoral energy demand, as shown in Figure 4. The 2030 BAU energy demand will almost be double the base year demand. Under this scenario, the transport sector will consume the most energy by 2030, followed by industrial and household sectors. Transport sector energy demand will grow about 5.37% annually from 1.84 billion to 4.04 billion GJ between 2015 and 2030 (see also Table 4). The other sectors' energy demand will also increase significantly, contributing to the overall energy demand of 10.29 billion GJ.

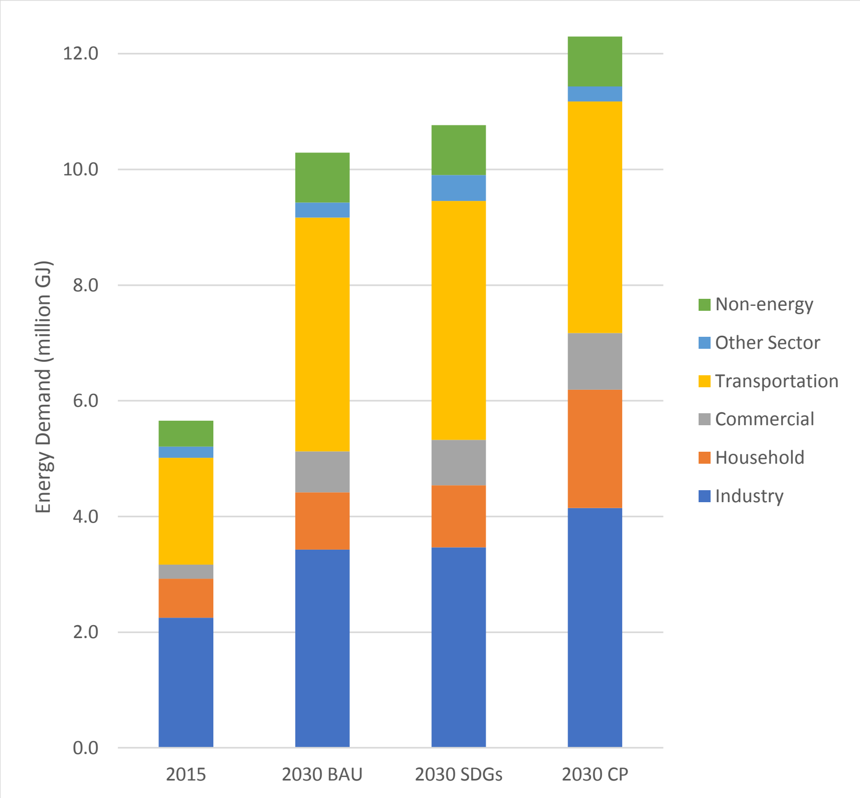

Figure 4. Comparison of Indonesian sectoral energy demand in 2030 under the BAU, SDGs, and CP scenarios

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Under the SDGs scenario, total energy demand will rise 4.51% above the BAU total demand to 10.76 billion GJ by 2030. This rise is a result of slight increases in energy demand of all sectors except the non-energy sector. Mainstreaming the SDGs in the developmental agenda of Indonesia will produce a small increase in sectoral energy demand.

The current policy scenario calls for 2 billion GJ more electricity by 2030 in order to reach 2.5 and 7.0 MWh/cap electricity by 2025 and 2050, respectively. The target is assumed to be distributed across sectors in proportion to the sectoral shares of electricity consumption in 2015, which is calculated from the MEMR data [33]. As a result, the energy demand of the industrial, household, and commercial sectors will increase significantly compared to BAU demand. This result suggests that the current energy policy in Indonesia anticipates higher energy demand from these sectors.

Figure 5 shows the scenario comparison of Indonesian energy demand in 2030 by fuel. Under the BAU scenario, gasoline, electricity, and diesel oil will contribute most of the rise in energy demand followed by natural gas, non-energy use, and coal. Incorporating the SDGs into the national development agendas will slightly increase the consumption of electricity, natural gas, gasoline, diesel oil, biodiesel, and LPG. The sharp increase in the 2030 electricity consumption under the CP scenario is much more significant. Electricity will, therefore, be the major contributor to increased energy demand in 2030 when following the Indonesian energy plan (RUEN, see Target R1 of Table 8). The rise of electricity use under the CP scenario will be more than double that under the BAU. The rise of natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use was also notable in the CP scenario; however, it will compensate the planned decline in gasoline, diesel, and LPG use in transport and household sectors (see also Table 10).

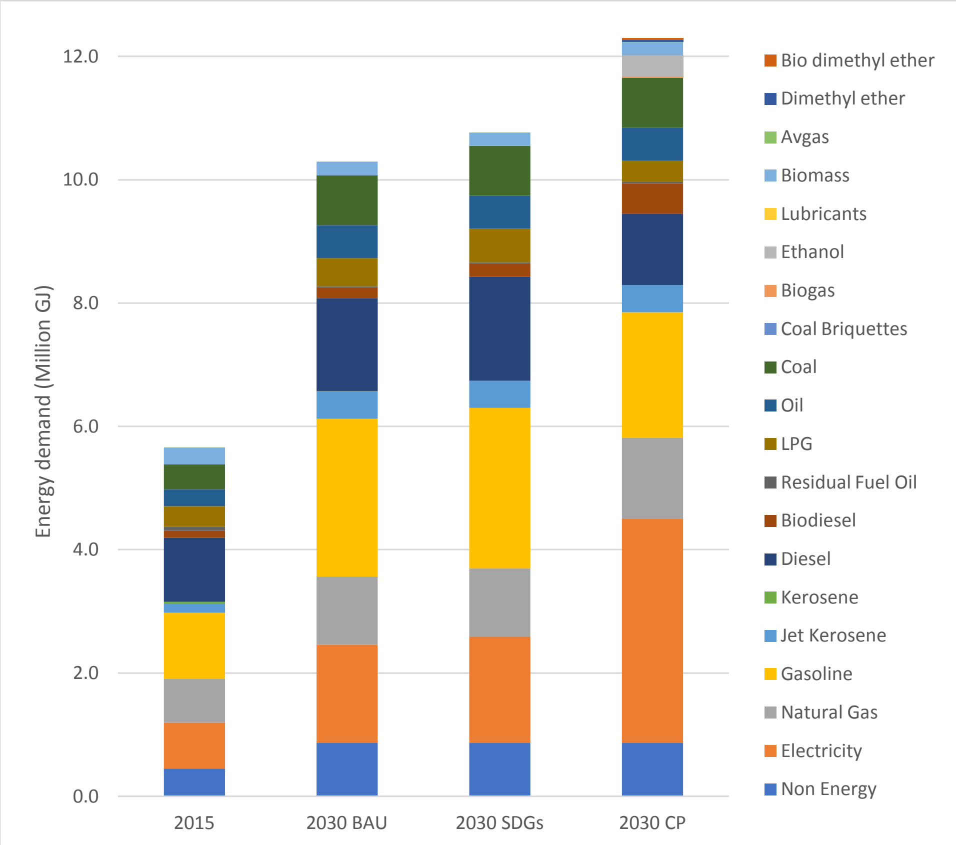

Figure 5. Comparison of Indonesian energy demand in 2030 under the BAU, SDGs, and CP scenarios, by fuel

(2-column fitting image, print in colour)

Table 10. Comparison of energy demand under the BAU and current policy scenarios

Fuel Type (Million GJ)	**2030 BAU**	**2030 CP**
Non Energy	863.35	863.35
Electricity	1,591.93	3,635.41
Natural Gas	1,105.83	1,315.51
Gasoline	2,563.12	2,034.98
Jet Kerosene	441.07	441.07
Kerosene	2.69	2.68
Diesel	1,513.64	1,155.23
Biodiesel	168.18	495.10
Residual Fuel Oil	22.58	22.58
LPG	458.53	343.66
Oil	533.44	533.44
Coal	810.89	810.89
Hard Coal Briquettes	0.18	0.18
Biogas	-	17.03
Ethanol	-	347.77
Biomass	215.88	215.88
Avgas	0.08	0.08
Dimethyl ether	-	36.39
Bio dimethyl ether	-	24.26
Total	10,291.38	12,295.91

3.5. Key modifying variables

Energy demand estimates under the BAU scenario assume that future energy demand growth (CAGR) equals past growth (see Eq. 1 and 2). Based on the equations, the CAGR is the key variable that will modify the energy demand estimate under the BAU. Variables that are positively associated with energy demand and its growth include population and GDP [81, 82]. Since GDP and its growth fluctuates, energy demand and its growth are also likely to vary. Therefore, the accuracy of demand estimates also depends on how good the CAGR is predicted. For instance, the 2030 BAU energy demand will increase by 33% to 13,687.22 million GJ if sectoral energy demand CAGRs increase by 2% (see Appendices, Table A.1).

Under the SDGs scenario, the key parameters for energy demand are SDGs activity level gaps and activity level energy intensities (see Figure 1 and Eq. 3-7). If we assume zero growth of the activity level CAGR of target T, or $G_T = 0$ (see Eq. 3), then

$$A_{T,BAU} = A_{T,2015} \quad \text{(see Eq. 4)}$$

and

$$A_{T,Gap} = |A_{T,SDGs} - A_{T,2015}| \quad \text{(see Eq. 5)}$$

Solving Eq. 7 for each SDG target *T*, we found that the energy demand estimate under the SDGs scenario will be 943.85 million GJ in 2030, more than twice the previous estimate, or about 9.17% higher than that under the BAU (see Appendices, Table A.2).

On the other hand, energy demand under the current policy scenario depends largely on the national energy policy and plan. Different countries will have different objectives and priorities; therefore, different demands for energy.

Comment [IS1]: Reviewer #2, Comment #4: Include a brief sensibility analysis or at least, mention the key parameters that would modify the results

4. Discussion

The results of this investigation reveal an expected energy demand of 10,291 million GJ by 2030 under the BAU scenario. This value is very close to that estimate by Indonesia's Agency for the Assessment and Application of Technology (locally known as BPPT). According to BPPT, 10,350.2 million GJ (1780 million BOE) energy will be needed by 2030 under the BAU scenario [21]. Results also show that 464.27 million GJ more energy should be added by 2030 if Indonesia is to mainstream the SDGs in its national development programs. The final energy demand under the SDGs scenario will be about 4.51% higher than the 2030 energy demand under the BAU scenario. For comparison, final energy demand in Indonesia grew about 3.05% annually between 2007 and 2017 [33].

Furthermore, if the current policy scenario can be realised, the anticipated demand will cover the demand needed under the SDGs scenario. Published in 2017, the RUEN, on which the Indonesian current policy environment is based, is well-developed and would easily satisfy the extra energy demand under the SDGs scenario. The additional energy demand of 464.27 million GJ under the SDGs scenario might appear modest compared to Indonesia's total energy demand (TFEC), but it is comparable to Nepal's TFEC in 2014, which was about 482.91 million GJ [83]. It will be interesting to see the impact of the SDGs implementation on energy demand in the least developed countries as the gaps between the current situation and the SDG targets are more likely to be wider. As the TFEC of these countries is relatively low, a substantial increase in energy demand (relative to the TFEC) will be necessary for them to fully implement all SDGs.

Under the SDGs scenario, some estimates were negative, which indicate that the implementation of targets in the national development plan will save energy. For instance, replacing kerosene with LPG to ensure access to clean cooking fuels (Target 7.1) will save energy because cooking with LPG is more efficient than cooking with kerosene. Similarly, waste recycling programs have a net energy saving potential, which will reduce overall energy demand [69, 72].

Target 7.3 was to double the global rate of improvement in energy efficiency. The target was translated as a 2.6% reduction in the global primary energy intensity of GDP (World EI) between 2010 and 2030 [84]. Since the World EI was 5.796 MJ/2011 PPP $ in 2010 [85], applying a 2.6% annual reduction gave a World EI of 3.422 MJ/2011 PPP $ by 2030. Therefore, Target 7.3 will be achieved if global energy intensity is less than or equal to 3.422 MJ/2011 PPP $ by 2030.

The 2030 world GDP was estimated using 2001 and 2015 per capita GDP data provided by the World Bank [86], which had a GDP CAGR of 2.48 % between 2001 and 2015. If this per capita global GDP growth is sustained by 2030 (i.e., Target 8.1 is achieved), the global primary energy consumption will be 73,083 MJ/cap by 2030. Table 11 provides the quantification summary of Targets 7.3 and 8.1.

Table 11. Global quantification of Targets 7.3 and 8.1

Variables	Amounts	Units
2010 World EI	5.796	MJ/2011 PPP$
Target 7.3 (CAGR)	-0.026	
2030 World EI	3.4222	MJ/2011 PPP$
2001 World GDP	10,504	$ 2011 PPP/cap
2015 World GDP	14,795	$ 2011 PPP/cap
World GDP CAGR	0.02477	
2030 World GDP (assuming the CAGR is maintained)	21,355	$ 2011 PPP/cap
2030 Primary energy use	73,083	MJ/cap

This annual primary energy use of 73,083 MJ/cap should be considered a new target designated especially for high-income countries in order to reduce energy inequality and CO_2 emissions. For comparison, the average primary energy use in high-income countries was 4,605.54 tonnes of oil equivalent per capita (or 192,825 MJ/cap) in 2015 [87]. In contrast, energy use was only 27,059 MJ/cap in the lower-middle-income countries in 2014. Primary energy consumption of as low as 60,000 MJ/cap has been associated with a high human development index [88].

In the Indonesian energy context, the primary energy intensity of GDP was 3.525 MJ/2011 PPP $ in 2015 [85], and reaching the global target of 3.422 MJ/2011 PPP $ by 2030 will not be difficult, especially when the energy intensity annual growth of -2.79% between 2001 and 2015 is to be maintained by 2030 (calculation based on the World Bank data). Table 12 provides the key variables required to quantify energy demand in Indonesia by 2030 under the SDG Targets 7.3 and 8.1. The GDP data of the World Bank [86] were used to calculate the CAGR of the GDP between 2001 and 2015. If the same economic growth is sustained by 2030 (Target 8.1), the 2030 GDP will be about 18,850 2011 PPP $/cap. Multiplying this value by the 2030 primary energy intensity (2030 EI) gave a total primary energy supply (2030 TPES) of 64,505 MJ/cap which is less than the 73,083 MJ/cap benchmark previously discussed. If the population reaches 296.4 million by 2030 [36], the TPES will be 19,120 million GJ by 2030. Assuming 72% TPES to total final energy consumption (TFEC) conversion efficiency by 2030 [18], it was found that the energy demand by 2030 (2030 TFEC) will be about 13,766 million GJ. In other words, if Targets 7.3 and 8.1 are achieved by 2030, the TPES will be no more than 19,120 million GJ, and the TFEC will be about 13,766 million GJ or less, given that the TPES to TFEC ratio of 72% is also achieved.

Table 12. Quantification of Targets 7.3 and 8.1 in Indonesia

Variables	Amount	Units
2001 GDP	5,934	2011 PPP $/cap
2015 GDP	10,367	2011 PPP $/cap
CAGR of GDP	4.066	%
2030 GDP (assuming the CAGR is maintained)	18,850	2011 PPP $/cap
2030 EI (Target 7.3)	3.422	MJ/2011 PPP $
2030 TPES	64,505	MJ/cap
2030 TPES	19,120	Million GJ
Assumed TPES to TFEC conversion ratio	72	%
2030 TFEC	13,766	Million GJ

For comparison, total energy demand under the current policy scenario will be 12.30 billion GJ in 2030, which is equivalent to the primary energy supply of 57,616 MJ/cap or 3.057 MJ/2011 PPP $ of GDP. Under the current policy scenario (RUEN), Indonesia will consume less energy per capita compared to the world average in 2030. Indonesian production systems will also use less energy per dollar it produces compared to the global economy. The ambitious RUEN target to boost electricity consumption to 2,500 and 7,000 kWh/cap by 2025 and 2050, respectively, will increase primary energy consumption in 2030 from 48,225

MJ/cap (under the BAU) to 57,616 MJ/cap. Table 13 summaries the estimated energy demand under different scenarios and benchmarks.

Table 13. Summary of primary and final energy demand under different scenarios and benchmarks

Scenarios and benchmarks	Primary energy demand in 2030 (MJ/cap)	Energy demand in 2030 (billion GJ)
BAU	48,225	10.29
SDGs	50,449	10.76
Current policy	57,616	12.30
Minimum energy associated with a high human development index	60,000	12.80
National energy use if Targets 7.3 and 8.1 achieved nationally	64,505	13.77
Global energy use as suggested under Targets 7.3 and 8.1	73,083	-

Finally, RUEN targets related to energy demand (identified in Table 8) reflect Indonesia's commitment to provide access to electricity and clean cooking fuel for everyone (SDG Target 7.1) and to improve energy efficiency (Target 7.3). The renewable energy target (Target 7.2) is beyond the scope of the present study as renewable energy is related to the supply side of energy and does not change energy demand. It is anticipated that electricity access will reach everyone by 2020 under the BAU. The 100% clean cooking access, however, is more likely to be missed by 2030 under the RUEN. The calculations done in this study using World Bank data [89] suggests that more than 50 million people (17% of the population) will still be without access to clean cooking fuels and technology by 2030 (those mostly cooking with solid biomass). Providing urban households with pipeline natural gas will mostly replace LPG use, which is also a clean fuel. Biogas for cooking might be a solution, but the target is only 3.4% of the population, and the program cannot reach non-farming communities. Programs that directly address solid biomass use should also be introduced. For instance, programs to replace traditional stoves with improved cookstoves (ICS) could be implemented [90].

Energy efficiency measures under RUEN are represented mostly by fuel conversion programs which have more efficient fuels than the replaced ones (see targets R2, R3, R6, and R7 of Table 8). Target R8 shows Indonesia's commitment to reduce the use of petroleum-based fuels with either renewable energy or natural gas. RUEN offers many more programs and activities related to energy efficiency, but they lack precise numbers (difficult to quantify the targets to energy demand). For example, programs enforcing mandatory energy management for buildings and industries consuming 6,000 tonnes of oil equivalent or more, implementation of ISO 50001 on energy management, and promoting the use of efficient power plant technology. If these programs are fully implemented, a further reduction in energy demand is possible.

Research limitations and further study

The scope of SDGs is very broad, from ending poverty and hunger, providing universal access to healthcare, education, water, and energy to delivering equality, good infrastructure, healthy environment, peace, justice, and partnerships. The SDGs are also, directly and indirectly, interlinked as a network of goals and targets [14]. These complex interactions of targets make the corresponding energy demand more difficult to quantify [15]. In the present study, only the direct first-degree interactions of the SDGs and energy demand are calculated. It does not take into consideration second-degree interactions.

It should be noted that energy demand also interacts with the energy goal (SDG 7), but energy demand, per se, is not SDG 7. Some of the SDG targets may overlap, and, in some cases, there are second and third-degree interactions between the target and energy demand all of which add complexity to the calculation. For example, halving food losses (Target 12.3) in Indonesia requires energy for food processing and storing. Yet, it also will save enough food to feed the undernourished people (Target 2.1). Consequently, less food must be farmed, and less energy will be needed.

Comment [IS2]: Reviewer #4: Sustainable development goals are a very broad topic and are very interlinked. Energy being one of the SDG's I believe if you could further draw the line away from the conflicting aspects

As is common in this kind of research, many assumptions have been made about such things as equal past and future growths of activity levels, proportionally distributed energy demand across different fuels, future population size, and GDP. Literature and historical data were consulted as the basis for these assumptions to ensure the values used were as close as possible to reality.

The CAGRs were used to estimate energy demand under the BAU and SDGs scenarios. The CAGRs assumed smooth exponential growth, and growth rates in the next 15 years would be similar to those in the last 14 years. Many studies, however, have found that energy demand and growth fluctuate. Even the International Energy Agency (IEA), with its vast amount of knowledge and data on the subject, admits that energy demand is very hard to predict, in part because there are large uncertainties in economic prospects, energy prices, and government policies [81, 91]. According to IEA, the purpose of developing energy scenarios is not to forecast future energy demand but to show how energy demand may evolve under certain circumstances.

Comment [IS3]: Reviewer #2 Comment #2: According to Equation 1 and Equation 2, the increase in the energy demand is supposed to follow the equations. This is a key aspect in the research, the authors should clearly justify that the growth will follow this tendency. In many reported studies and case studies, energy demand increases not linearly and it the rate changes among years

For some SDG activity levels, however, data only covered a few years. For example, data on collected urban solid waste (Target 11.6) was available only for 2015 and 2016. Using the CAGR from a very short time span to estimate a long-term future might be problematic since a small change in the data might create a large variation in the final result. An interesting comparison could be made between the results of this paper and other methods of estimating future activity levels, such as regression and (excel-based) trendline methods. However, it is beyond the scope of this paper.

The above discussion indicates that this research framework can be extended to other countries to evaluate if their current energy policy environment will be sufficient to meet their energy demand under the SDGs regime. Another area of future investigation is energy supply, which should be evaluated for better policy responses related to energy access and security, sustainable energy technology applications, and emission reduction.

Future studies should also include a detailed analysis of emissions or environmental impacts. Approximate estimates of carbon emissions calculated using Indonesia's carbon intensity of 2.058 kg of CO2 per kg of oil equivalent primary energy use [92] shows that CO2 emissions may reach 863 million tonnes (or about 2.91 tonnes per capita) if low-carbon transitions are not undertaken, assuming 70% final to primary energy ratio (see Table 14). In comparison, the average CO2 emissions of Indonesia and the lower-middle-income countries were only 1.82 and 1.47 tonnes per capita in 2014, respectively [93]. While a summary of GHG emissions has been provided, a detailed emissions analysis is beyond the scope of this paper.

Comment [IS4]: Reviewer #2 Comment #1: The model lacks an environmental and/or emissions analysis because nowadays it is mandatory including this aspect in any research proposing an energy improvement

Table 14. Estimates of CO_2 emission in 2030

Scenarios in 2030	BAU	SDGs	CP
Energy use (billion GJ)	10.29	10.76	12.302
CO_2 emissions (million tonnes)	722.63	755.88	863.39

5. Conclusions and Policy Implications

Mainstreaming the SDGs in national development plans requires energy. Countries setting targets to ensure access to food, water, energy, health care, education, and other services to the public should anticipate an increase in their national energy demand. Activity levels and energy intensities of the SDG targets that require energy in their implementation can be identified and estimated to predict energy demand at the national level under the SDGs scenario. While the Indonesian final energy demand under the BAU scenario in 2030 will be almost double that in 2015, the demand under the SDGs scenario is expected to be 4.51%

higher relative to the demand under the BAU scenario in 2030. It implies that national energy planning in Indonesia should tolerate about 5% more energy demand than the routine estimates if the SDGs are to be accommodated in the national development programs. Fortunately, the full implementation of the current energy policy scenario will cover the additional demand as a result of the SDGs implementation.

The sectoral comparison shows that the transportation sector will consume more energy than the industrial sector under the BAU and SDGs scenarios by 2025. Under the current energy policy scenario, however, the industrial sector will still use more energy than the transportation sector by a small margin in 2030 due to the ambitious target of increasing electricity consumption. It will significantly increase energy use in the industrial, commercial and household sectors.

The energy demand analysis (by fuel) reveals that:

- Gasoline, electricity, and diesel oil use will increase the most under the BAU scenario.
- Natural gas, non-energy, and coal consumption will also increase significantly by 2030 under the BAU scenario.
- Under the SDGs scenario, the use of electricity, natural gas, gasoline, diesel oil, biodiesel, and LPG will only be slightly higher than that under the BAU scenario.
- The current energy policy scenario, on the other hand, calls for a dramatic increase in electricity use.
- A notable increase in natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use should also be expected under this scenario in order to reduce gasoline, diesel, and LPG imports.

Finally, this study translates Target 7.3 to a global energy intensity benchmark of 3.422 MJ/2011 PPP $ of GDP and combines Targets 7.3 and 8.1 to set a global primary energy use target of less than 73,083 MJ/cap by 2030. Under the current energy policy scenario, Indonesia's energy use may reach 3.057 MJ/2011 PPP $ or 57,616 MJ/cap, which will be less than the predicted global average consumption in 2030. The per capita energy consumption in 2030 will also be less than the minimum per capita energy use associated with a very high human development index.

Comment [IS5]: Reviewer #2 Comment #3: Section conclusions is too short and does not summarize the main findings of the paper

The findings of this study have policy implications. First, Indonesia should continue the execution of its national energy plan (RUEN) to ensure that the additional energy demand under the SDGs regime will be met by 2030. The implementation of RUEN in the national development plan will satisfy Indonesia's final energy demand.

Next, Indonesia should increase efforts to improve energy efficiency and conservation in the transportation sector as the sector will show a remarkable increase in energy demand by 2030. The National Energy Board, through RUEN, has proposed fuel conversion programs from petroleum-based fuels to electricity, natural gas, biodiesel, and ethanol. It also suggests the acceleration of efficient public transport and services. A coherent transportation policy is needed to ensure effective inter-ministerial coordination and non-conflicting strategies [94]. Active transportation (walking and bicycling) policies should also be promoted as they will reduce energy use and emissions, improve health and well-being, and may create safer and more sustainable cities and human settlements.

In addition, to achieve the ambitious RUEN target of increasing per capita electricity consumption, Indonesia should maintain high economic growth, improve people's living standard, and accelerate the adoption of electric vehicle and cooking stove technologies. These are some factors associated positively with electricity consumption [81]. Furthermore, as fossil-based electricity consumption is a source of emissions, policy on electricity generation should ensure the adoption of low carbon technology.

Comment [IS6]: Reviewer #1: It can be accepted for publication after adding a new section "Policy Implications"

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Implications of the Sustainable Development Goals on national energy demand: The case of Indonesia

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Abstract

Energy is a key enabling factor within the Sustainable Development Goals (SDGs), which include eradicating poverty and hunger, improving human well-being, and protecting the environment. Countries intending to incorporate SDGs in their development programs should expect an increase in energy consumption, and therefore, need to review their energy planning. The objective of this paper is to anticipate the additional energy requirements of Indonesia with the implementation of SDGs compared to business as usual (BAU) and current policy (CP) scenarios. Assuming all SDG targets were to be implemented in the Indonesian national development plan, the additional energy demand for each target by 2030 was calculated. It was found that 18 out of 169 SDGs targets required additional energy in the Indonesian context. Overall, more energy will be needed to achieve those 18 SDGs targets compared to the BAU scenario. Fortunately, the full realisation of the current energy policies will cover the additional energy required under the SDGs scenario.

Keywords: Sustainable Development Goals; energy; energy demand; energy intensity; LEAP; Indonesia.

1. Introduction

In September 2015, the United Nations introduced the Sustainable Development Goals (SDGs) as a global plan of action for people, environment, and economy [1]. The SDGs incorporated 17 goals with 196 associated targets. They replaced the Millennium Development Goals, which expired in the same year. The SDGs are global goals achievable only through implementation in local and national development agendas [2]. Most countries have adopted the SDGs into their development agendas [3], and by 2019, 144 countries have presented their voluntary national reviews (VNRs) on SDGs at the UN's High-level Political Forum [4].

There are many studies related to individual SDG targets and their implementation, but few discuss this implementation impact on energy demand. Büyüközkan, Karabulut and Mukul [5], for instance, presented an integrated multi-criteria decision-making (MCDM) method to determine the most suitable renewable energy source by addressing SDG7, while Schwerhoff and Sy [6] worked on SDGs by considering how an increase in the production of renewable energy would affect the likelihood of achieving these goals in a given amount of time. Caiado *et al*. [7] mention some of the problems and barriers related to SDGs implementation, and dos Santos and Balestieri [8] tried to understand the relationship between a group of socioeconomic and environmental factors linked with the SDGs for some cities in Brazil.

Other studies discuss energy efficiency actions in achieving SDGs, including Puig, Farrell, and Moner- Girona [9] who worked on the significance of energy efficiency enhancements to meet the SDGs. They observed that besides SDG7, which aspires to double the global rate of improvement in energy efficiency by 2030, energy efficiency improvement could also contribute to SDG2, SDG3, SDG6, and SDG8. Di Foggia [10] studied energy efficiency in the residential sector and found that energy-efficient buildings can make a significant positive contribution in achieving SDG 11 and SDG 13. Alawneh *et al*. [11] studied the contribution of water and energy efficiency to SDGs (SDGs 6−9, 12–13, and 15) in the residential sector in Jordan.

Interlinkages and cross impacts of the SDGs are also discussed in the literature. Some studies applied a nexus approach to analyse the SDGs interactions [12-14]. This approach provides a more comprehensive explanation of the interactions, yet it also will add complexity to the analysis of the corresponding energy demand [15]. Both positive and negative links between the SDG targets and energy were found by McCollum *et al*. [16], and their analysis suggested that the positive interactions outweigh the negative ones. Nerini *et al*. [17] assessed the interactions between SDG7 (related to energy access, renewable energy, and energy efficiency) and the other SDGs and found similar results. These studies, however, did not take into account the impact of the interactions on energy demand. Recently, Santika *et al*. [15] mapped the linkages between 25 SDG targets and energy demand and found that additional energy is required, compared to the business-as-usual, to achieve these targets.

Should the SDGs be nationally mainstreamed, higher energy demand should be anticipated, and energy planning and policy may require reconsideration. Santika *et al*. [18] simulated the impact of SDG7 on household sector energy demand in Indonesia and found that providing clean energy access to everyone would indeed increase demand for commercially sourced energy. Subsequently, Santika *et al*. [15] estimated that 599.5 MJ/person per year would be needed to end hunger in Indonesia (Target 2.1)[1]. They also identified SDG targets related to energy demand and offered a method for estimating the energy intensity of each target should it be realised in a development agenda. Further study on how it would work at a country level, however, was greatly required. This paper has addressed this research gap and built on their work [15] by quantifying the additional energy requirement at the country level. In doing so, it has tried to answer the question about the full impact of the implementation of SDGs on Indonesia's national energy demand.

As a part of the 193 countries ratifying the SDGs in 2015, Indonesia agreed to implement them in its national development agendas. Its 2015-2019 national medium-term development plan (locally known as RPJMN) explicitly states that Indonesia would embed the SDGs into the post-2015 national development agendas. In 2017, Indonesia released its voluntary national review (VNR) report on SDGs [19]. The report claims that Indonesia has 320 national indicators to measure the level of achievement in reaching the SDGs. Some are similar to the 241 global indicators of the SDGs, and others are additional and proxy indicators [19]. Subsequently, Presidential Regulation 59/2017, passed in July 2017, provides the legal basis for the implementation of SDGs in Indonesia. The regulation provides national targets that have been matched and synchronised with the SDG targets. In fact, Indonesia is committed to becoming the world pioneer and role model in SDGs implementation, as stated in its national action plan on SDGs (under the National Development Planning Ministerial Regulation 7/2018).

[1]Target 2.1 means the first target of SDG2

Earlier in 2017, the Government of Indonesia (GOI) released the National Energy General Plan (locally known as RUEN). RUEN is the extension of the national energy policy, which has targets as shown in Table 1.

Table 1. Indonesian national energy policy targets [20]

Targets	**2015**	**2020**	**2025**	**2050**
Primary energy (MTOE)			400	1000
Primary energy (TOE/capita)			1.4	3.2
Power generation (GW)			115	430
Electricity consumption (kWh/capita)			2500	7000
Energy elasticity (%)			< 1	
Reduction of final energy intensity (% per year)	1	1	1	1
National energy mix:				
Renewable energy (%)			>23	>31
Oil (%)			<25	<20
Coal (%)			>30	>25
Natural gas (%)			>22	>24
Electrification ratio (%)	85	100		

Additionally, Indonesia’s national energy outlook is annually released by the Agency for the Assessment and Application of Technology (locally known as the BPPT). However, the outlook omits the impact of the SDGs implementation on energy demand. The latest outlook, for instance, exercises only demographic and economic variables under the RUEN implementation scenarios [21]. These scenarios do not necessarily reflect the SDGs.

The above discussions suggest that there is a need to estimate energy demand to meet the SDGs in Indonesia by 2030 and compare the results with the demand under the current energy policy (CP) scenario. In the absence of an integrated plan that accounts for this additional energy demand, Indonesia’s ambition to achieve all SDGs by 2030 is likely to fail. In this context, this study aims at estimating the additional energy requirement under the context of full implementation of the SDGs in Indonesia and compares the result with those under BAU and CP scenarios. This study aims to answer the following research questions:

a. What would be the national energy demand, in different sectors and by fuel, in 2030 if Indonesia achieves all of the SDGs?
b. What is the gap in energy demand between the SDGs scenario, BAU scenario, and current energy policy scenario?
c. How adequate is the current energy policy environment for meeting energy demand under the SDGs implementation?

This study also provides examples of how country-level energy demand is estimated under the SDGs regime and ensures that the procedure is applicable to other countries.

2. Methods

This study compared a complete implementation of SDGs scenario against business as usual (BAU) and current energy policy (CP) scenarios. The BAU scenario assumes no new policy will be implemented in the national development plan by 2030. In this case, the historical growth of sectoral fuel consumption was assumed to continue into the future. In contrast, the CP scenario considers all demand-side targets imposed by the RUEN. The availability of useful data directed the choice of 2015 as a baseline year and 2016 as the first year of the SDGs implementation. Figure 1 shows the data collection and analysis steps taken in this research.

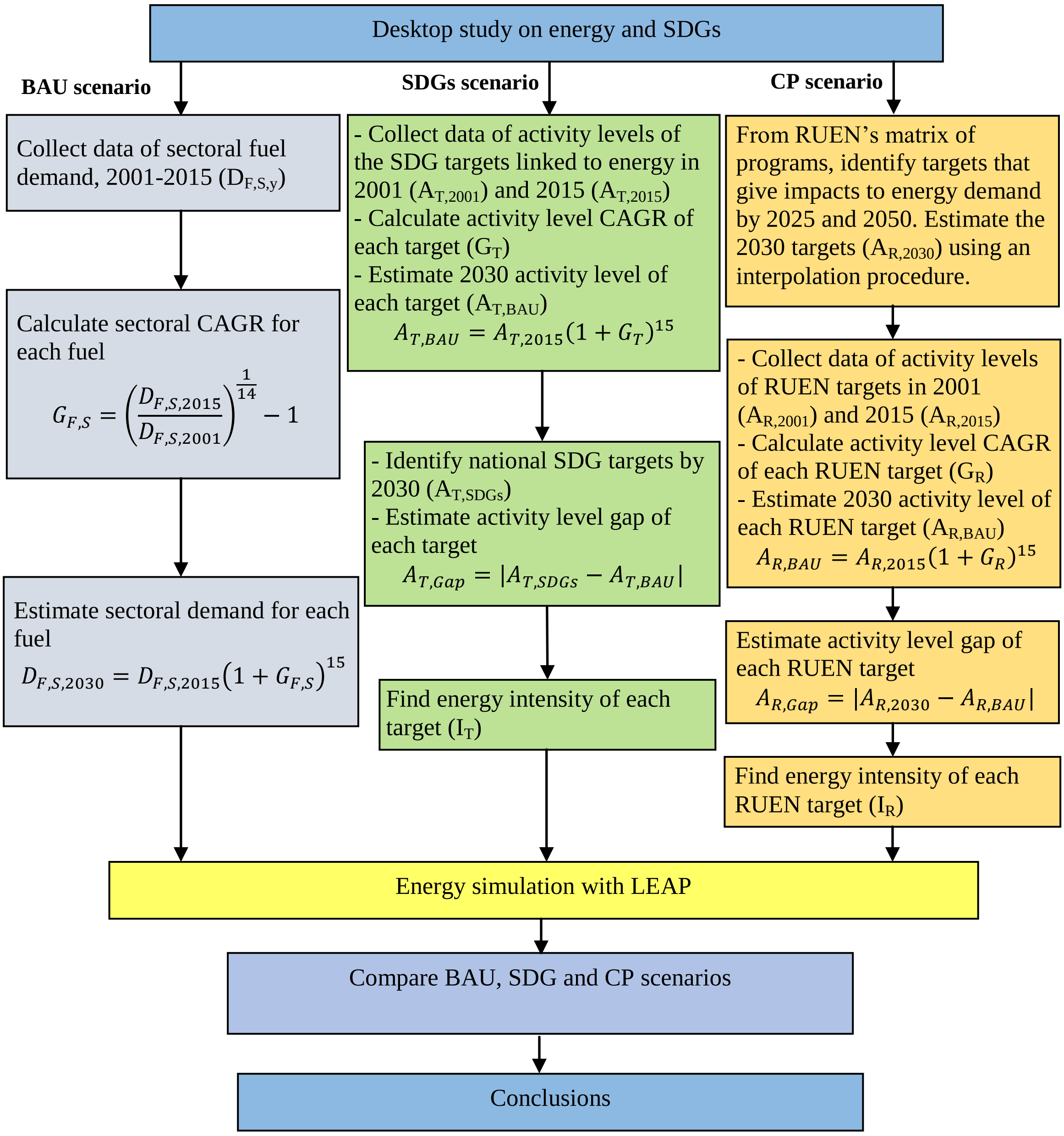

Figure 1. Flowchart of the methodology for estimating energy demand under BAU, SDGs, and CP scenarios

(2-collumn fitting image, print in colour)

The desktop study provided comprehensive information on links between SDGs and energy demand. Under the BAU scenario, data of sectoral energy demand from 2001 to 2015 was collected from the Indonesian Ministry of Energy and Mineral Resources (MEMR) reports. Next, the compound annual growth rate (CAGR) of sectoral energy consumption of each fuel was calculated [18],

$$G_{F,S} = \left(\frac{D_{F,S,2015}}{D_{F,S,2001}}\right)^{\frac{1}{n}} - 1 \qquad \text{(Eq. 1)}$$

$G_{F,S}$ represented the CAGR of the energy demand of fuel F in sector S, n indicated the total years between 2001 and 2015, while $D_{F,S,2001}$ and $D_{F,S,2015}$ represented energy demand for fuel F in sector S in 2001 and 2015, respectively.

The future energy consumption growth rates were assumed to equal $G_{F,S}$, and demand of fuel F of sector S by 2030 was estimated as

$$D_{F,S,2030} = D_{F,S,2015}\left(1 + G_{F,S}\right)^{m} \qquad \text{(Eq. 2)}$$

where m is the total years between 2015 and 2030.

An exception was made for the household and transport sectors, as the energy demand in these sectors is strongly linked to the population size. For these sectors, the energy use intensity (EI) of each fuel in 2001 and 2015 (in MJ/household for the household sector, and MJ/person for the transportation sector) was determined. Next, the CAGR of energy use intensity of each fuel ($G_{F,S}$) was calculated. Based on the $G_{F,S}$, the EI of each fuel in 2030 was estimated and the future energy demand of these sectors was projected based on the 2030 EIs.

Under the SDGs scenario, secondary data from the body of literature was obtained of the activity levels of the SDG targets linked to energy in 2001 and 2015. The activity levels include population, GDP, and other economic and socio-demographic activities that consume energy [22]. $A_{T,2001}$ and $A_{T,2015}$ represented the activity level of target T in 2001 and 2015, respectively. Next, the activity level CAGR of target T (G_T) was calculated as

$$G_{T} = \left(\frac{A_{T,2015}}{A_{T,2001}}\right)^{\frac{1}{n}} - 1 \qquad \text{(Eq. 3)}$$

The following step was to estimate the activity level of target T by 2030 ($A_{T,BAU}$), assuming the activity level CAGR of target T in the coming years will equal G_T. Therefore,

$$A_{T,BAU} = A_{T,2015}(1 + G_T)^{15} \quad \text{(Eq. 4)}$$

$A_{T,BAU}$ is the 2030 activity level of target T before the implementation of the SDGs. The next step was to identify the 2030 national SDG targets ($A_{T,SDGs}$). For example, some countries may consider 100% electrification ratio (Target 7.1) as too ambitious and difficult to achieve and set a target of 95% electricity access instead. In this case, we assumed Indonesia fully implements all of the SDG targets in its development plan.

After that, the activity level gap of target *T* by 2030 ($A_{T,Gap}$) was estimated

$$A_{T,Gap} = |A_{T,SDGs} - A_{T,BAU}| \quad \text{(Eq. 5)}$$

In order to calculate the energy demand of target T (D_T), the energy intensity of target *T* (I_T) was estimated using a similar procedure to that offered by Santika *et al*. [15]. For example, the energy intensity of providing a mobile phone for everyone ($I_{T5.b}$) was calculated as

$$I_{T5.b} = \frac{E_P}{t_{op}} \quad \text{(Eq. 6)}$$

where E_P and t_{op} are energy use per phone and phone operating time, respectively. Eq. 6 was solved using an energy use of 16 kJ/phone for an operating time of 27 hours [23], which gave energy intensity of 5.19 MJ·phone^{-1}·year^{-1}.

Once I_T was identified, D_T could be determined by

$$D_T = I_T . A_{T,Gap} \quad \text{(Eq. 7)}$$

D_T estimates, however, were automatically computed using the Long-range Energy Alternative Planning System (LEAP) once data such as activity levels, energy intensities, growth rates, the total energy of the base year and end year were entered into the modelling software. LEAP is an energy modelling software developed at the Stockholm Environment Institute to analyse energy policy and climate change [22]. It has been used especially in developing countries for integrated resource planning and emission assessment [24-28]. The Government of Indonesia also utilizes LEAP for the national energy projection and GHG emission assessment [29]. Other Indonesia's energy assessments using the LEAP model in their analyses include studies on Java-Bali power capacity expansion [30], long-term electricity planning [31], and renewable electricity for energy security and emission reduction [32].

Note that D_T might be made up of different fuels and different fuel consumption patterns across sectors. For instance, ensuring adequate food for everyone to end hunger (Target 2.1) required energy for farming (the agriculture sector), food distribution (the transportation sector) and retailing (the commercial sector). These sectors use various fuels (energy sources), including electricity, gasoline, diesel fuel, and natural gas. The approach used by this study was to consult the literature for the sectoral share of D_T and the fuel share of sectoral D_T. Otherwise, it was assumed that the shares were directly proportional to the baseline year's sectoral share and fuel share of national demand.

Next, the procedure for estimating energy demand under the CP scenario RUEN targets provided a large matrix of (planned) national energy programs with targets set for 2025 and 2050. Under the current energy policy scenario, RUEN targets having an impact on energy demand were identified, and their 2030 activity level of RUEN's target R ($A_{R,2030}$) was estimated based on the 2025 and 2050 RUEN targets. The next steps were similar to those under the SDGs scenario.

In the following section, yearly energy demand for the three different scenarios are presented, along with an analysis of energy demand by sector and fuel. Finally, these results are discussed and followed by a conclusion.

3. Results

The Ministry of Energy and Mineral Resources of Indonesia (MEMR) divides energy consumers into six sectors:

- industrial,
- household,
- commercial,
- transportation,
- other, and
- non-energy sectors.

The other sector includes mining, fishery, and construction sub-sectors. The non-energy sector is the sector that consumes fuels without releasing their energy content, which includes lubricant oil, gas, and petrochemicals used to produce substances such as ammonia and methanol [33]. Sources of energy (referred to as fuels in the texts) vary across sectors including biomass, coal, natural gas, briquette, oil, LPG, and electricity. The present study omitted the traditional use of biomass in the household sector.

3.1. BAU Scenario

Table 2 provides examples of estimates in industrial sector energy demand, by fuel, under the BAU scenario. The 2001-2015 consumption data were used to calculate future growth (CAGR), which, in turn, was used to estimate future consumption. The industrial sector total energy consumption is estimated to be 3,428.20 million GJ by 2030.

Table 2. Industrial sector energy demand by 2030 under the BAU scenario. Data sources: [34, 35].

Year	Industrial Sector (million GJ)									
	Biomass	Coal	Briquette	Gas	Kerosene	Diesel Oil	Fuel Oil	Other Petroleum Product	LPG	Electricity
2001	320.91	215.28	0.45	476.02	24.19	274.43	155.14	149.52	5.65	126.88
2015	260.67	408.38	0.29	709.89	1.52	301.70	56.50	276.29	4.58	228.42
CAGR	-0.015	0.047	-0.031	0.029	-0.179	0.007	-0.070	0.045	-0.015	0.043
2030	208.62	810.93	0.18	1,089.31	0.08	333.93	19.15	533.46	3.66	428.86
Total consumption projection in 2030: 3,428.20 million GJ										

The projection of the transportation sector's energy demand by 2030 under the BAU scenario using the energy intensity (EI) approach is shown in Table 3. Once the 2030 EIs were obtained, the energy consumption was determined by multiplying each EI with the 2030 projected population of 296.4051 million [36].

Table 3. Transportation sector energy demand by 2030 under the BAU scenario. Data sources: [34, 35].

Transportation sector								
	Gas	Avgas	Avtur	Gasoline	Kerosene	Fuel Oil	Diesel	Electricity
EI 2001 (MJ/cap)	3.90	0.52	241.90	2,063.57	0.76	14.48	1,806.02	0.81
EI 2015 (MJ/cap)	5.58	0.41	581.50	4,071.02	0.06	4.30	2,555.98	2.85
EI CAGR	0.02667	-0.02215	0.06465	0.04973	-0.18369	-0.08297	0.02512	0.09204
EI 2030 (MJ/cap)	8.31	0.28	1,488.13	8,430.74	0.0023	1.17	3,708.23	10.75
2030 Energy use (million GJ)	2.46	0.08	441.09	2,498.92	0.0006	0.35	1,099.14	3.18
Total consumption projection in 2030: 4,045.22 million GJ								

Sectoral energy demand estimations for 2030 under the BAU scenario are shown in Table 4. The transportation sector will consume the most energy, followed by the industry and household sectors. Overall, about 10,291.7 million GJ energy demand should be anticipated under the BAU scenario by 2030.

Table 4. Estimates of sectoral energy consumption by 2030 under the BAU scenario.

	Industry	Household	Commercial	Transportation	Other	Non-	Total

						Energy	
Million GJ	3,428.20	989.89	705.95	4,045.22	259.09	863.35	10,291.70

3.2. SDGs Scenario

An example of how to estimate additional energy demand under the implementation of the SDGs at the national level is provided below. Target 2.1 of the SDGs calls for zero hunger by 2030. The prevalence of undernourishment is an indicator of Target 2.1. The activity levels of Target 2.1 in 2001 and 2015 ($A_{T,2001}$ and $A_{T,2015}$) were 37,973,754 and 18,648,726 undernourished persons, respectively (see Table 5). Next, the CAGR of the undernourishment (G_T) and the number of undernourished people by 2030 ($A_{T,BAU}$) were calculated using the Eq. 3 and Eq. 4, which gave an estimate of 8,704,728 undernourished persons by 2030 under the BAU.

Table 5. Prevalence of undernourishment in Indonesia. Data source: [37]

Year	Total population	Prevalence of undernourishment	
		%	Persons ($\boldsymbol{A_T}$)
2001	208,647,000	18.2	37,973,754
2015	255,462,000	7.3	18,648,726
CAGR ($\boldsymbol{G_T}$)			-0.04953
2030	296,405,100	2.94%	8,704,728

The target ($A_{T,SDGs}$) is to reach zero undernourished people by 2030, and the undernourishment gap between the SDG target and the BAU estimate ($A_{T,Gap}$) becomes |8,704,728| undernourished persons (absolute value). Consequently, addressing the gap with SDGs implementation requires energy, and according to Santika, *et al*. [15], the energy required to provide food for the undernourished people in Indonesia (I_T) is 599.33 MJ·person^{-1}·year^{-1}. Therefore, the additional energy demand (D_T) as a consequence of Target 2.1 implementation in Indonesia by 2030 is approximately 5,217,004.64 GJ.

Due to a lack of data for some targets, calculations based on relevant associated information were made. For instance, Target 6.3 is to improve water quality by halving the proportion of untreated wastewater by 2030. According to the 2014-2019 Indonesian Medium-term development plan (locally known as RPJMN), wastewater treatment facilities should reach 34 million urban people by 2019. By 2030, the facilities were assumed to reach 50 million urban people. BAPPENAS *et al*. [36] estimated that Indonesia's urban population would be 187,920,833 persons (63.4%) by 2030, so about 137,920,833 urban people will remain without wastewater treatment facilities by 2030. Wastewater generation in urban Indonesia was about 0.12 $m^3 \cdot person^{-1} \cdot day^{-1}$ [38]. Therefore, untreated urban wastewater will be approximately 6,040,932,503 m^3/year by 2030. Halving this figure means treating 3,020,466,251.46 m^3/year more wastewater by 2030, which will consume more energy. Table 6 shows a summary of the procedure used to calculate the amount of extra wastewater that needs to be treated per annum by 2030.

Table 6. An example of the improvised procedure applied to Target 6.3

Variables	**Amount**	**Units**
Total population, 2030	296,405,100	Persons
Urban population 2030	63.4	%
Urban population, 2030	187,920,833	Persons
RPJMN target 2014-2019	34,000,000	Persons
Assumed 2030 access	50,000,000	Persons
Urban people without access	137,920,833	Persons
Wastewater generation	0.12	m^3□person^{-1}□day^{-1}
Wastewater untreated	6,040,932,503	m^3/year
Halving the untreated wastewater ($A_{T,Gap}$)	3,020,466,251	m^3/year

Once $A_{T,Gap}$ is determined, the additional energy demand as a consequence of Target 6.3 implementation can be estimated. The energy intensity of wastewater treatment in Indonesia was assumed to be 0.5 kWh/m^3 considering that the intensity ranged from 0.05 to 0.15 and from 0.95 to 1.25 kWh/m^3 in India and China, respectively [39, 40]. The extra energy consumption will, therefore, be 1,510,233,126 kWh or 5,436,839 GJ by 2030.

Table 7 summarises the results of the calculations of Indonesia's additional energy requirement under the SDGs regime by 2030. Twenty-four out of 25 SDG targets linked to energy as proposed by Santika *et al.* [15] were assessed (Target 1.4 about access to basic services was excluded as the achievement of other targets would contribute to it). The results reveal that 18 targets will require additional energy by 2030. Target 2.4 was omitted due to a lack of national data on land areas under sustainable agriculture, and the target also lacked a precise number making it difficult to assume a national target (Indonesia has not set one). Targets 4.3 and 17.8 were considered to be achievable under the BAU scenario; hence, no additional energy will be needed. Target 7.2, concerning the substantial increase in the renewable energy share, was assumed to transform energy sources from fossil fuel to renewables and thus affect energy supply only. The target will not change energy demand. Finally, Targets 7.3 and 8.1 should be calculated together, and the figure reflects the maximum allowable energy demand by 2030. This issue has been further elaborated in the discussion section.

Overall, SDGs implementation will require approximately 464.27 million GJ more energy on top of the BAU scenario by 2030. Figure 2 shows that Target 9.1 (access to quality infrastructure) will consume the most energy (about 169.41 million GJ) by 2030, followed by Target 11.2 (access to safe urban transport systems for all; 87.44 million GJ), Target 7.1 (access to clean fuels and technology for cooking; 83.23 million GJ), and Target 12.3 (food losses and waste; 76.03 million GJ). The energy demand for the other targets will be about 10 million GJ or less. Targets 5.b (equal access to mobile phones) and 13.1 (resilience to disasters) will consume the least energy (about 0.22 and 0.55 million GJ), respectively. The negative value of Target 12.5 (waste reduction) indicates a potential saving of energy.

Table 7. Summary of the additional energy requirement for SDGs implementation in Indonesia

SDG Targets	**Description**	**Activity levels (A_T)**	**SDGs Gap**	**Energy Intensity, annually**		**Additional Energy demand**	**Data and reference**	**Remarks**
			($A_{T,Gap}$)	**(I_T)**	**Unit**	**(GJ)**		
2.1	Zero hunger	Undernourish people	8,704,728 persons	599.33	MJ/person	5,217,005	[15, 37, 41]	
2.3	Double small farmer productivity	Small farmer households	8,722,526 households	1,611.99	MJ/household	14,060,598	[41-43]	2003-2013 Data
2.4	Sustainable agriculture	Land area under sustainable agriculture	NA	-	-	-		Data and target are not available
3.8	Universal healthcare access	Persons with unmet needs for healthcare	4,674,884 persons	475.63	MJ/person	2,223,495	[15, 44]	2011-2015 Data
4.1	Access to primary and secondary education	Elementary school students	1,512,505 students	798.34	MJ/student	1,207,487	[15, 45-48]	2014-2016 Data
		Junior high school students	2,224,973 students	991.87	MJ/student	2,206,888	[45-48]	2014-2016 Data
		Senior high school students	2,605,210 students	1,330.56	MJ/student	3,466,388	[45-48]	2014-2016 Data
4.2	Access to early childhood education	Kindergarten students	2,161,635 pupils	598.75	MJ/student	1,294,283	[15, 45-48]	2014-2016 Data
4.3	Access to tertiary education	Students of tertiary education	0	-	-	0	[49, 50]	The trend shows that the 40% target of gross enrolment rate will be achieved by 2030 under the BAU
5.b	Equal access to enabling technology	Persons with a mobile phone	42,328,459 persons	5.19	MJ/person	219,685	[15, 23, 51]	2015-2016 Data
6.1	Access to safe drinking water	Persons with drinking water access	56,148,718 persons	92.16	MJ/person	5,174,666	[39, 52-54]	2015-2017 Data
6.3	Halving the proportion of untreated Wastewater	Cubic meters untreated wastewater	3,020,466,251 m^3	1.8	MJ/m^3	5,436,839	[36, 38-40]	Improvised procedure
7.1	Access to electricity and clean cooking fuels	Households with electricity	0	1,314	MJ/household	-	[18, 34, 35, 55, 56]	100% of electricity access will be achieved by 2020
		Households cooking with LPG	12,095,286 households	7,087.26	MJ/household	85,722,464	[18, 34, 35, 57, 58]	Biomass and kerosene were replaced by LPG

SDG Targets	Description	Activity levels (A_T)	SDGs Gap	Energy Intensity, annually		Additional Energy demand	Data and reference	Remarks
		Households cooking with kerosene	304,519 households	-8,200.314	MJ/household	-2,497,151	[18, 34, 35, 57, 58]	Avoided kerosene use after conversion to LPG. Traditional biomass use was never included in the calculation since only commercial energy was considered.
7.2	Renewable energy share	Renewable energy does not change energy demand						
7.3	Energy efficiency	Targets 7.3 and 8.1 should be calculated together using national data, and the result should be regarded as a benchmark for maximum national energy consumption. See the discussion section and Santika, et al. [15].						
8.1	Sustainable economic growth							
9.1	Access to road infrastructure	Toll road length	3,261.04 km	10	TJ/km	32,610,400	[59-61]	Improvised procedure
		National road length	6,000 km	7.5	TJ/km	45,000,000		
		Provincial road length	6,000 km	5.4	TJ/km	32,400,000		
		Sub-provincial road length	18,000 km	3.3	TJ/km	59,400,000		
9.c	Access to information and communication technology	Persons in areas without mobile network cover	6,372,602 persons	1,702.94	MJ/user	10,852,184	[15, 62, 63]	2011-2014 Data
11.1	Access to adequate housing	Persons in urban slums	5,970,911 persons	864.00	MJ/person	5,158,867	[15, 64, 65]	2015-2016 Data
11.2	Access to convenient public transport	Persons with convenient public transport	29,640,510 persons	2,950.00	MJ/person	87,439,505	[66, 67]	Improvised procedure
11.6	Urban solid waste	Urban solid waste not collected	2,732,669.80 tonnes	588.07	MJ/t (diesel)	1,607,014	[68, 69]	2015-2016 Data
				432	MJ/t (electricity)	1,180,513		
12.3	Food losses and waste	Total population	296,405,100 persons	256.5	MJ/cap	76,027,908	[70-72]	Improvised procedure
12.5	Waste reduction	Waste recycled	5,188,000 tonnes	-1,640	MJ/t	-8,508,320	[69, 72-74]	Improvised procedure
13.1	Resilience to disasters	Relocated persons	403,441 persons	1,353.07	MJ/person	545,882	[65, 75]	Improvised procedure
17.6	Access to science	Fixed broadband subscriptions	23,074,583 subscriptions	315.36	MJ/subscription	7,276,800	[76, 77]	Improvised procedure
17.8	Access to the internet	Persons using internet	0	113.7	MJ/user	-	[78-80]	All Indonesian will have access to

SDG Targets	Description	Activity levels (A_T)	SDGs Gap	Energy Intensity, annually		Additional Energy demand	Data and reference	Remarks
								the internet by 2030
Total additional energy demand (MJ)						**464,268,084,283**		

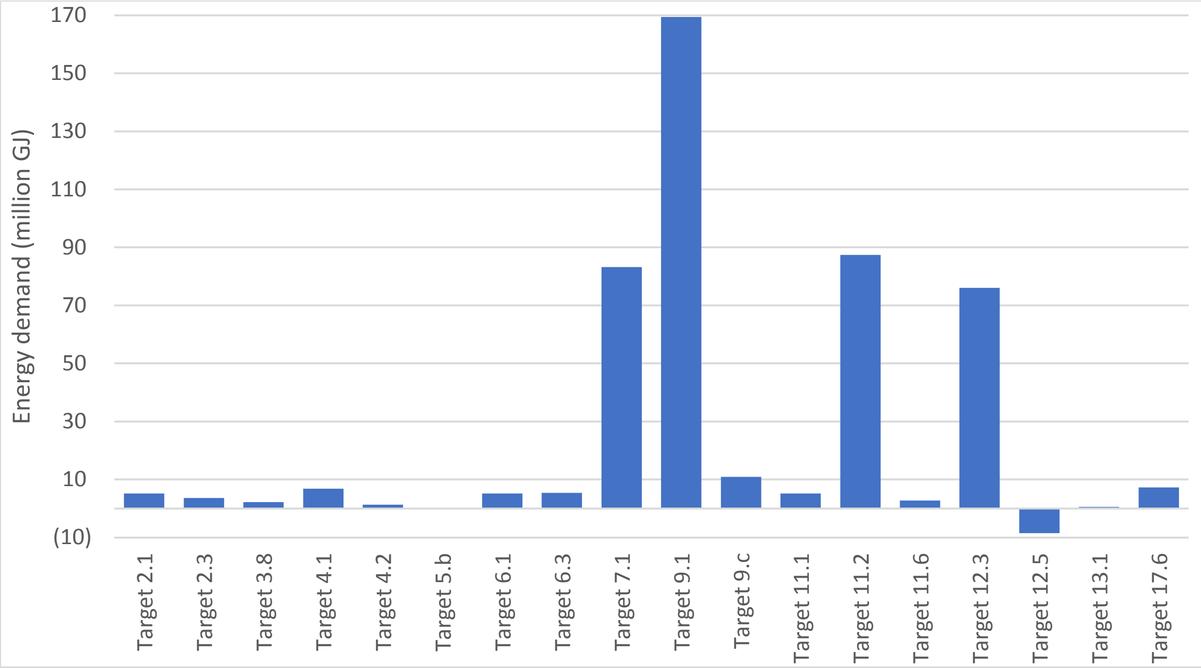

Figure 2. Additional energy demand as a consequence of SDGs implementation

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3.3. Current Policy Scenario

Nine RUEN targets related to energy demand were identified, as shown in the second column of Table 8. Since the targets need to be achieved by 2025 and 2050, RUEN targets for 2030 were also estimated (the third column of the table). It was assumed that only targets R1 and R3 would require more energy compared to the BAU scenario. Both targets anticipate about 2.05 billion GJ more energy in 2030. The other targets would not add or reduce energy demand as they replace one energy source with another. This analysis did not consider the potential to reduce energy demand as a result of added efficiencies of the substituting energy sources. LEAP results show that the total energy demand in 2030 will be about 12.29 billion GJ, which is approximately 2.00 billion GJ higher than the BAU. The discrepancy between this figure with the total demand calculated in Table 8 is accounted for by the assumption relating to target R8. The assumption in R8 will offset the transport demand under the BAU and CP scenarios at 3.11 billion GJ by 2025. The same assumption, however, will create less demand under the CP scenario by 2030 (see Table 9).

Table 8. Summary of RUEN targets and additional energy requirement under the current policy scenario in Indonesia

No	RUEN Targets	RUEN Targets	Additional	Remarks

		adjusted for 2030	Energy demand	
R1	Electricity consumption: 2,500 and 7,000 kWh/cap by 2025 and 2050	3,400 kWh/cap	2,036.07 million GJ	Assumption: this target is proportionally shared across sectors; the share is equal to the baseline year share
R2	Pipeline natural gas for cooking: 4.7 million households by 2025	10% of total households	It would not add or reduce energy demand	It was assumed to replace LPG
R3	Biogas for cooking: 1.7 million households by 2025	3.4% of total households	17.03 million GJ	It was assumed to replace solid biomass, which was omitted in the household sector
R4	Dimethyl ether (DME) production: 1 million ton by 2025 (about 10% of the estimated total LPG consumption in 2025)	It replaces 15% of total LPG consumption	It would not add or reduce energy demand	Assumption: mixed with LPG; 60% produced from coal, 40% from biomass
R5	Electrification ratio: 100% by 2020	-	-	Achieved under the BAU
R6	Natural gas use in the transport sector: 282.1 mmscfd by 2025 (about 372.77 MJ/cap)	552.4 MJ/cap	It would not add or reduce energy demand	This target supports the achievement of Target R8
R7	Electric vehicle energy use: 2.3 TWh by 2025 (about 26.55 MJ/cap)	37.8 MJ/cap	It would not add or reduce energy demand	This target supports the achievement of Target R8
R8	Petroleum-based fuels for transport: 75.3 million kilolitres or less by 2025 (about 2.55 billion GJ). Our estimate shows that it will be about 3.01 billion GJ by 2025 under the BAU	2.55 billion GJ or less by 2025	It would not add or reduce energy demand	The gasoline and diesel energy intensity growths were assumed to decrease to 4.45% and 2.3135% to achieve this target. 30% biodiesel and 15% bioethanol blends by 2025 were also assumed.
R9	Biodiesel for transport: 13.9 million kL by 2025 (524.3 million GJ)	319.67 million GJ	It would not add or reduce energy demand	This RUEN target was constrained by the B30 biodiesel blend target. This target supports the achievement of Target R8.
		Sum of R1 and R3 energy demand	2,053.1 million GJ	

Table 9. LEAP estimates of transport sector energy demand under the BAU and CP scenarios (in million GJ). Target R8, which is to be achieved by 2025, combined with Targets R6, R7, and R9, requires equal demand under the BAU and CP scenarios by 2025. Those targets create a demand discrepancy between the BAU and CP scenarios in 2020 and 2030.

Scenarios	2015	2020	2025	2030
BAU	1,844.78	2,392.82	3,108.55	4,045.08
Current Policy	1,844.78	2,402.82	3,108.56	4,002.50

3.4. Scenario comparison

Figure 3 shows the LEAP result of energy demand under the BAU, CP, and SDGs scenarios. Under the BAU scenario, energy demand will rise from 5.66 to 10.29 billion GJ between 2015 and 2030. Under the SDGs scenario, the demand will increase further from the same baseline point in 2015 to 10.76 billion GJ in 2030. The demand will increase even further to 12.30 billion GJ in 2030 under the CP scenario. These results indicate that mainstreaming the SDGs in the national development plan of Indonesia will increase national energy demand. However, the full realisation of its national energy plan (RUEN) will be more than enough to anticipate the rise of energy demand under the SDGs scenario.

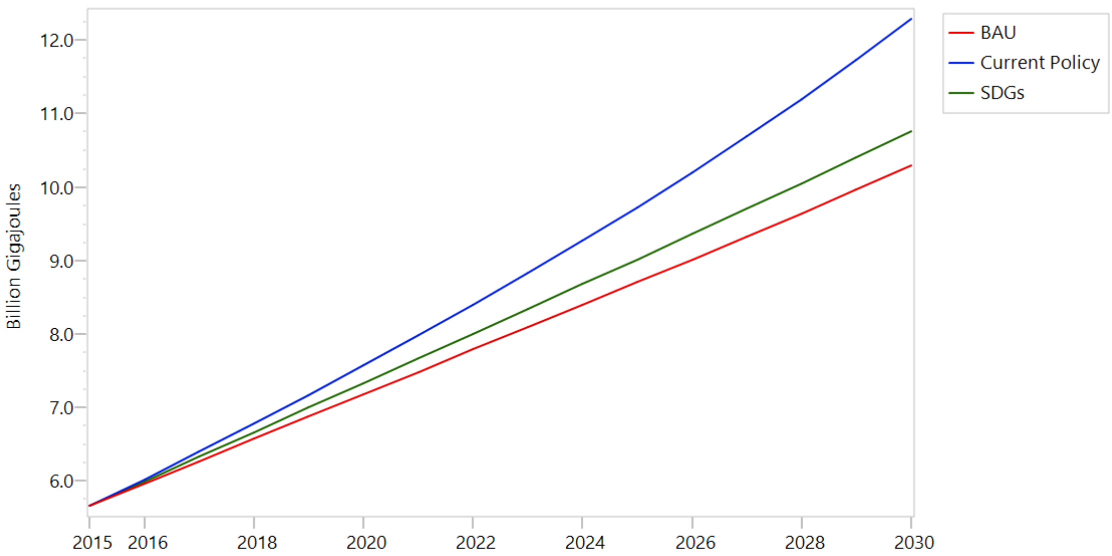

Figure 3. LEAP results of energy demand under three different scenarios

(2-column fitting image, print in colour)

The scenarios are also compared based on their sectoral energy demand, as shown in Figure 4. The 2030 BAU energy demand will almost be double the base year demand. Under this scenario, the transport sector will consume the most energy by 2030, followed by industrial and household sectors. Transport sector energy demand will grow about 5.37% annually from 1.84 billion to 4.04 billion GJ between 2015 and 2030 (see also Table 4). The other sectors' energy demand will also increase significantly, contributing to the overall energy demand of 10.29 billion GJ.

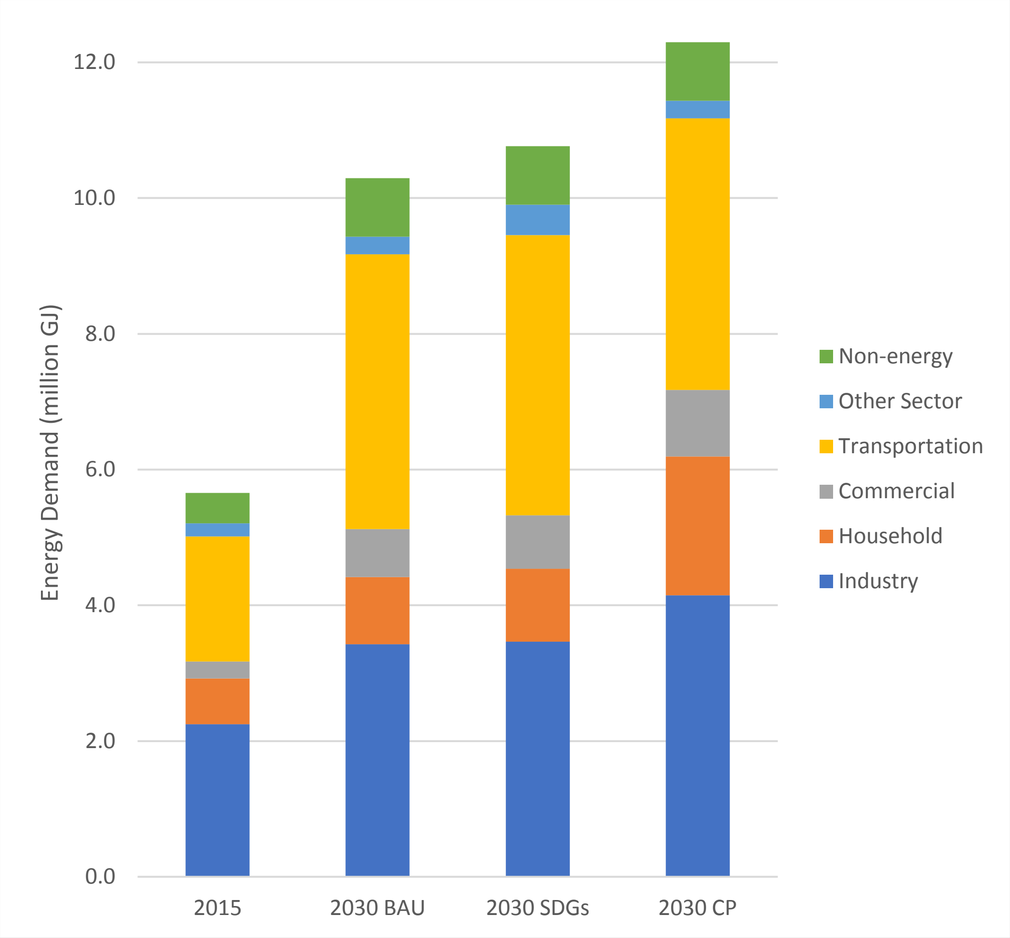

Figure 4. Comparison of Indonesian sectoral energy demand in 2030 under the BAU, SDGs, and CP scenarios

(2-column fitting image, print in colour)

Under the SDGs scenario, total energy demand will rise 4.51% above the BAU total demand to 10.76 billion GJ by 2030. This rise is a result of slight increases in energy demand of all sectors except the non-energy sector. Mainstreaming the SDGs in the developmental agenda of Indonesia will produce a small increase in sectoral energy demand.

The current policy scenario calls for 2 billion GJ more electricity by 2030 in order to reach 2.5 and 7.0 MWh/cap electricity by 2025 and 2050, respectively. The target is assumed to be distributed across sectors in proportion to the sectoral shares of electricity consumption in 2015, which is calculated from the MEMR data [33]. As a result, the energy demand of the industrial, household, and commercial sectors will increase significantly compared to BAU demand. This result suggests that the current energy policy in Indonesia anticipates higher energy demand from these sectors.

Figure 5 shows the scenario comparison of Indonesian energy demand in 2030 by fuel. Under the BAU scenario, gasoline, electricity, and diesel oil will contribute most of the rise in energy demand followed by natural gas, non-energy use, and coal. Incorporating the SDGs into the national development agendas will slightly increase the consumption of electricity, natural gas, gasoline, diesel oil, biodiesel, and LPG. The sharp increase in the 2030 electricity consumption under the CP scenario is much more significant. Electricity will, therefore, be the major contributor to increased energy demand in 2030 when following the Indonesian energy plan (RUEN, see Target R1 of Table 8). The rise of electricity use under the CP scenario will be more than double that under the BAU. The rise of natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use was also notable in the CP scenario; however, it will compensate the planned decline in gasoline, diesel, and LPG use in transport and household sectors (see also Table 10) .

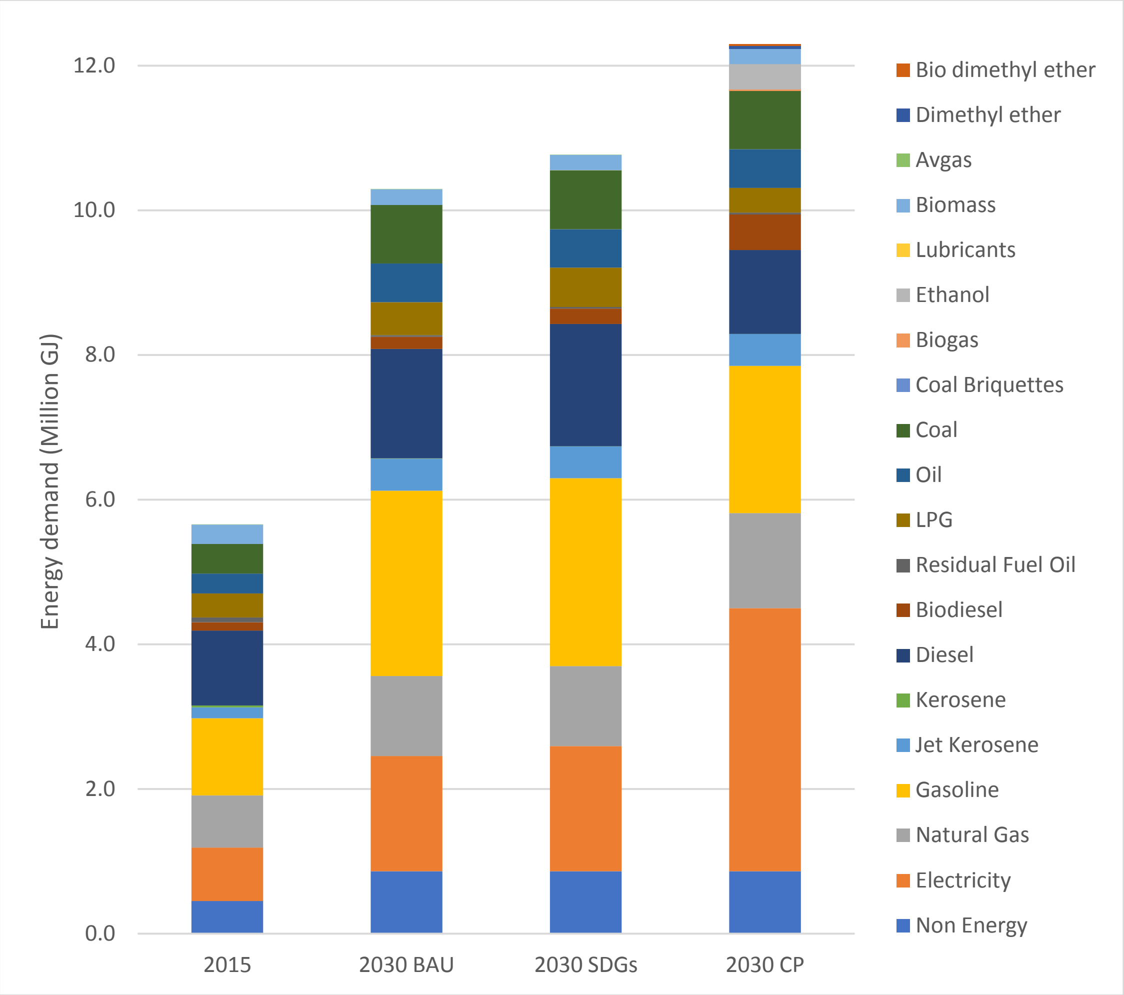

Figure 5. Comparison of Indonesian energy demand in 2030 under the BAU, SDGs, and CP scenarios, by fuel

(2-column fitting image, print in colour)

Table 10. Comparison of energy demand under the BAU and current policy scenarios

Fuel Type (Million GJ)	**2030 BAU**	**2030 CP**
Non Energy	863.35	863.35
Electricity	1,591.93	3,635.41
Natural Gas	1,105.83	1,315.51
Gasoline	2,563.12	2,034.98
Jet Kerosene	441.07	441.07
Kerosene	2.69	2.68
Diesel	1,513.64	1,155.23
Biodiesel	168.18	495.10
Residual Fuel Oil	22.58	22.58
LPG	458.53	343.66
Oil	533.44	533.44
Coal	810.89	810.89
Hard Coal Briquettes	0.18	0.18
Biogas	-	17.03
Ethanol	-	347.77
Biomass	215.88	215.88
Avgas	0.08	0.08
Dimethyl ether	-	36.39
Bio dimethyl ether	-	24.26
Total	10,291.38	12,295.91

3.5. Key modifying variables

Energy demand estimates under the BAU scenario assume that future energy demand growth (CAGR) equals past growth (see Eq. 1 and 2). Based on the equations, the CAGR is the key variable that will modify the energy demand estimate under the BAU. Variables that are positively associated with energy demand and its growth include population and GDP [81, 82]. Since GDP and its growth fluctuates, energy demand and its growth are also likely to vary. Therefore, the accuracy of demand estimates also depends on how good the CAGR is predicted. For instance, the 2030 BAU energy demand will increase by 33% to 13,687.22 million GJ if sectoral energy demand CAGRs increase by 2% (see Appendices, Table A.1).

Under the SDGs scenario, the key parameters for energy demand are SDGs activity level gaps and activity level energy intensities (see Figure 1 and Eq. 3-7). If we assume zero growth of the activity level CAGR of target T, or $G_T = 0$ (see Eq. 3), then

$$A_{T,BAU} = A_{T,2015} \qquad \text{(see Eq. 4)}$$

and

$$A_{T,Gap} = |A_{T,SDGs} - A_{T,2015}| \quad \text{(see Eq. 5)}$$

Solving Eq. 7 for each SDG target *T*, we found that the energy demand estimate under the SDGs scenario will be 943.85 million GJ in 2030, more than twice the previous estimate, or about 9.17% higher than that under the BAU (see Appendices, Table A.2).

On the other hand, energy demand under the current policy scenario depends largely on the national energy policy and plan. Different countries will have different objectives and priorities; therefore, different demands for energy.

4. Discussion

The results of this investigation reveal an expected energy demand of 10,291 million GJ by 2030 under the BAU scenario. This value is very close to that estimate by Indonesia's Agency for the Assessment and Application of Technology (locally known as BPPT). According to BPPT, 10,350.2 million GJ (1780 million BOE) energy will be needed by 2030 under the BAU scenario [21]. Results also show that 464.27 million GJ more energy should be added by 2030 if Indonesia is to mainstream the SDGs in its national development programs. The final energy demand under the SDGs scenario will be about 4.51% higher than the 2030 energy demand under the BAU scenario. For comparison, final energy demand in Indonesia grew about 3.05% annually between 2007 and 2017 [33].

Furthermore, if the current policy scenario can be realised, the anticipated demand will cover the demand needed under the SDGs scenario. Published in 2017, the RUEN, on which the Indonesian current policy environment is based, is well-developed and would easily satisfy the extra energy demand under the SDGs scenario. The additional energy demand of 464.27 million GJ under the SDGs scenario might appear modest compared to Indonesia's total energy demand (TFEC), but it is comparable to Nepal's TFEC in 2014, which was about 482.91 million GJ [83]. It will be interesting to see the impact of the SDGs implementation on energy demand in the least developed countries as the gaps between the current situation and the SDG targets are more likely to be wider. As the TFEC of these countries is relatively low, a substantial increase in energy demand (relative to the TFEC) will be necessary for them to fully implement all SDGs.

Under the SDGs scenario, some estimates were negative, which indicate that the implementation of targets in the national development plan will save energy. For instance, replacing kerosene with LPG to ensure access to clean cooking fuels (Target 7.1) will save energy because cooking with LPG is more efficient than cooking with kerosene. Similarly, waste recycling programs have a net energy saving potential, which will reduce overall energy demand [69, 72].

Target 7.3 was to double the global rate of improvement in energy efficiency. The target was translated as a 2.6% reduction in the global primary energy intensity of GDP (World EI) between 2010 and 2030 [84]. Since the World EI was 5.796 MJ/2011 PPP $ in 2010 [85], applying a 2.6% annual reduction gave a World EI of 3.422 MJ/2011 PPP $ by 2030. Therefore, Target 7.3 will be achieved if global energy intensity is less than or equal to 3.422 MJ/2011 PPP $ by 2030.

The 2030 world GDP was estimated using 2001 and 2015 per capita GDP data provided by the World Bank [86], which had a GDP CAGR of 2.48 % between 2001 and 2015. If this per capita global GDP growth is sustained by 2030 (i.e., Target 8.1 is achieved), the global primary energy consumption will be 73,083 MJ/cap by 2030. Table 11 provides the quantification summary of Targets 7.3 and 8.1.

Table 11. Global quantification of Targets 7.3 and 8.1

Variables	Amounts	Units
2010 World EI	5.796	MJ/2011 PPP$
Target 7.3 (CAGR)	-0.026	
2030 World EI	3.4222	MJ/2011 PPP$
2001 World GDP	10,504	$ 2011 PPP/cap
2015 World GDP	14,795	$ 2011 PPP/cap
World GDP CAGR	0.02477	
2030 World GDP (assuming the CAGR is maintained)	21,355	$ 2011 PPP/cap
2030 Primary energy use	73,083	MJ/cap

This annual primary energy use of 73,083 MJ/cap should be considered a new target designated especially for high-income countries in order to reduce energy inequality and CO_2 emissions. For comparison, the average primary energy use in high-income countries was 4,605.54 tonnes of oil equivalent per capita (or 192,825 MJ/cap) in 2015 [87]. In contrast, energy use was only 27,059 MJ/cap in the lower-middle-income countries in 2014. Primary energy consumption of as low as 60,000 MJ/cap has been associated with a very high human development index [88].

In the Indonesian energy context, the primary energy intensity of GDP was 3.525 MJ/2011 PPP $ in 2015 [85], and reaching the global target of 3.422 MJ/2011 PPP $ by 2030 will not be difficult, especially when the energy intensity annual growth of -2.79% between 2001 and 2015 is to be maintained by 2030 (calculation based on the World Bank data). Table 12 provides the key variables required to quantify energy demand in Indonesia by 2030 under the SDG Targets 7.3 and 8.1. The GDP data of the World Bank [86] were used to calculate the CAGR of the GDP between 2001 and 2015. If the same economic growth is sustained by 2030 (Target 8.1), the 2030 GDP will be about 18,850 2011 PPP $/cap. Multiplying this value by the 2030 primary energy intensity (2030 EI) gave a total primary energy supply (2030 TPES) of 64,505 MJ/cap which is less than the 73,083 MJ/cap benchmark previously discussed. If the population reaches 296.4 million by 2030 [36], the TPES will be 19,120 million GJ by 2030. Assuming 72% TPES to total final energy consumption (TFEC) conversion efficiency by 2030 [18], it was found that the energy demand by 2030 (2030 TFEC) will be about 13,766 million GJ. In other words, if Targets 7.3 and 8.1 are achieved by 2030, the TPES will be no more than 19,120 million GJ, and the TFEC will be about 13,766 million GJ or less, given that the TPES to TFEC ratio of 72% is also achieved.

Table 12. Quantification of Targets 7.3 and 8.1 in Indonesia

Variables	Amount	Units
2001 GDP	5,934	2011 PPP $/cap
2015 GDP	10,367	2011 PPP $/cap
CAGR of GDP	4.066	%
2030 GDP (assuming the CAGR is maintained)	18,850	2011 PPP $/cap
2030 EI (Target 7.3)	3.422	MJ/2011 PPP $
2030 TPES	64,505	MJ/cap
2030 TPES	19,120	Million GJ
Assumed TPES to TFEC conversion ratio	72	%
2030 TFEC	13,766	Million GJ

For comparison, total energy demand under the current policy scenario will be 12.30 billion GJ in 2030, which is equivalent to the primary energy supply of 57,616 MJ/cap or 3.057 MJ/2011 PPP $ of GDP. Under the current policy scenario (RUEN), Indonesia will consume less energy per capita compared to the world average in 2030. Indonesian production systems will also use less energy per dollar it produces compared to the global economy. The ambitious RUEN target to boost electricity consumption to 2,500 and 7,000 kWh/cap by 2025 and 2050, respectively, will increase primary energy consumption in 2030 from 48,225

MJ/cap (under the BAU) to 57,616 MJ/cap. Table 13 summaries the estimated energy demand under different scenarios and benchmarks.

Table 13. Summary of primary and final energy demand under different scenarios and benchmarks

Scenarios and benchmarks	**Primary energy demand in 2030 (MJ/cap)**	**Energy demand in 2030 (billion GJ)**
BAU	48,225	10.29
SDGs	50,449	10.76
Current policy	57,616	12.30
Minimum energy associated with a high human development index	60,000	12.80
National energy use if Targets 7.3 and 8.1 achieved nationally	64,505	13.77
Global energy use as suggested under Targets 7.3 and 8.1	73,083	-

Finally, RUEN targets related to energy demand (identified in Table 8) reflect Indonesia's commitment to provide access to electricity and clean cooking fuel for everyone (SDG Target 7.1) and to improve energy efficiency (Target 7.3). The renewable energy target (Target 7.2) is beyond the scope of the present study as renewable energy is related to the supply side of energy and does not change energy demand. It is anticipated that electricity access will reach everyone by 2020 under the BAU. The 100% clean cooking access, however, is more likely to be missed by 2030 under the RUEN. The calculations done in this study using World Bank data [89] suggests that more than 50 million people (17% of the population) will still be without access to clean cooking fuels and technology by 2030 (those mostly cooking with solid biomass). Providing urban households with pipeline natural gas will mostly replace LPG use, which is also a clean fuel. Biogas for cooking might be a solution, but the target is only 3.4% of the population, and the program cannot reach non-farming communities. Programs that directly address solid biomass use should also be introduced. For instance, programs to replace traditional stoves with improved cookstoves (ICS) could be implemented [90].

Energy efficiency measures under RUEN are represented mostly by fuel conversion programs which have more efficient fuels than the replaced ones (see targets R2, R3, R6, and R7 of Table 8). Target R8 shows Indonesia's commitment to reduce the use of petroleum-based fuels with either renewable energy or natural gas. RUEN offers many more programs and activities related to energy efficiency, but they lack precise numbers (difficult to quantify the targets to energy demand). For example, programs enforcing mandatory energy management for buildings and industries consuming 6,000 tonnes of oil equivalent or more, implementation of ISO 50001 on energy management, and promoting the use of efficient power plant technology. If these programs are fully implemented, a further reduction in energy demand is possible.

Research limitations and further study

The scope of SDGs is very broad, from ending poverty and hunger, providing universal access to healthcare, education, water, and energy to delivering equality, good infrastructure, healthy environment, peace, justice, and partnerships. The SDGs are also, directly and indirectly, interlinked as a network of goals and targets [14]. These complex interactions of targets make the corresponding energy demand more difficult to quantify [15]. In the present study, only the direct first-degree interactions of the SDGs and energy demand are calculated. It does not take into consideration second-degree interactions.

It should be noted that energy demand also interacts with the energy goal (SDG 7), but energy demand, per se, is not SDG 7. Some of the SDG targets may overlap, and, in some cases, there are second and third-degree interactions between the target and energy demand all of which add complexity to the calculation. For example, halving food losses (Target 12.3) in Indonesia requires energy for food processing and storing. Yet, it also will save enough food to feed the undernourished people (Target 2.1). Consequently, less food must be farmed, and less energy will be needed.

As is common in this kind of research, many assumptions have been made about such things as equal past and future growths of activity levels, proportionally distributed energy demand across different fuels, future population size, and GDP. Literature and historical data were consulted as the basis for these assumptions to ensure the values used were as close as possible to reality.

The CAGRs were used to estimate energy demand under the BAU and SDGs scenarios. The CAGRs assumed smooth exponential growth, and growth rates in the next 15 years would be similar to those in the last 14 years. Many studies, however, have found that energy demand and growth fluctuate. Even the International Energy Agency (IEA), with its vast amount of knowledge and data on the subject, admits that energy demand is very hard to predict, in part because there are large uncertainties in economic prospects, energy prices, and government policies [81, 91]. According to IEA, the purpose of developing energy scenarios is not to forecast future energy demand but to show how energy demand may evolve under certain circumstances.

For some SDG activity levels, however, data only covered a few years. For example, data on collected urban solid waste (Target 11.6) was available only for 2015 and 2016. Using the CAGR from a very short time span to estimate a long-term future might be problematic since a small change in the data might create a large variation in the final result. An interesting comparison could be made between the results of this paper and other methods of estimating future activity levels, such as regression and (excel-based) trendline methods. However, it is beyond the scope of this paper.

The above discussion indicates that this research framework can be extended to other countries to evaluate if their current energy policy environment will be sufficient to meet their energy demand under the SDGs regime. Another area of future investigation is energy supply, which should be evaluated for better policy responses related to energy access and security, sustainable energy technology applications, and emission reduction.

Future studies should also include a detailed analysis of emissions or environmental impacts. Approximate estimates of carbon emissions calculated using Indonesia's carbon intensity of 2.058 kg of CO2 per kg of oil equivalent primary energy use [92] shows that CO2 emissions may reach 863 million tonnes (or about 2.91 tonnes per capita) if low-carbon transitions are not undertaken, assuming 70% final to primary energy ratio (see Table 14). In comparison, the average CO2 emissions of Indonesia and the lower-middle-income countries were only 1.82 and 1.47 tonnes per capita in 2014, respectively [93]. While a summary of GHG emissions has been provided, a detailed emissions analysis is beyond the scope of this paper.

Table 14. Estimates of CO_2 emission in 2030

Scenarios in 2030	BAU	SDGs	CP
Energy use (billion GJ)	10.29	10.76	12.302
CO_2 emissions (million tonnes)	722.63	755.88	863.39

5. Conclusions and Policy Implications

Mainstreaming the SDGs in national development plans requires energy. Countries setting targets to ensure access to food, water, energy, health care, education, and other services to the public should anticipate an increase in their national energy demand. Activity levels and energy intensities of the SDG targets that require energy in their implementation can be identified and estimated to predict energy demand at the national level under the SDGs scenario. While the Indonesian final energy demand under the BAU scenario in 2030 will be almost double that in 2015, the demand under the SDGs scenario is expected to be 4.51%

higher relative to the demand under the BAU scenario in 2030. It implies that national energy planning in Indonesia should tolerate about 5% more energy demand than the routine estimates if the SDGs are to be accommodated in the national development programs. Fortunately, the full implementation of the current energy policy scenario will cover the additional demand as a result of the SDGs implementation.

The sectoral comparison shows that the transportation sector will consume more energy than the industrial sector under the BAU and SDGs scenarios by 2025. Under the current energy policy scenario, however, the industrial sector will still use more energy than the transportation sector by a small margin in 2030 due to the ambitious target of increasing electricity consumption. It will significantly increase energy use in the industrial, commercial and household sectors.

The energy demand analysis (by fuel) reveals that:

- Gasoline, electricity, and diesel oil use will increase the most under the BAU scenario.
- Natural gas, non-energy, and coal consumption will also increase significantly by 2030 under the BAU scenario.
- Under the SDGs scenario, the use of electricity, natural gas, gasoline, diesel oil, biodiesel, and LPG will only be slightly higher than that under the BAU scenario.
- The current energy policy scenario, on the other hand, calls for a dramatic increase in electricity use.
- A notable increase in natural gas, biodiesel, biogas, ethanol, and (bio) dimethyl ether use should also be expected under this scenario in order to reduce gasoline, diesel, and LPG imports.

Finally, this study translates Target 7.3 to a global energy intensity benchmark of 3.422 MJ/2011 PPP $ of GDP and combines Targets 7.3 and 8.1 to set a global primary energy use target of less than 73,083 MJ/cap by 2030. Under the current energy policy scenario, Indonesia's energy use may reach 3.057 MJ/2011 PPP $ or 57,616 MJ/cap, which will be less than the predicted global average consumption in 2030. The per capita energy consumption in 2030 will also be less than the minimum per capita energy use associated with a very high human development index.

The findings of this study have policy implications. First, Indonesia should continue the execution of its national energy plan (RUEN) to ensure that the additional energy demand under the SDGs regime will be met by 2030. The implementation of RUEN in the national development plan will satisfy Indonesia's final energy demand.

Next, Indonesia should increase efforts to improve energy efficiency and conservation in the transportation sector as the sector will show a remarkable increase in energy demand by 2030. The National Energy Board, through RUEN, has proposed fuel conversion programs from petroleum-based fuels to electricity, natural gas, biodiesel, and ethanol. It also suggests the acceleration of efficient public transport and services. A coherent transportation policy is needed to ensure effective inter-ministerial coordination and non-conflicting strategies [94]. Active transportation (walking and bicycling) policies should also be promoted as they will reduce energy use and emissions, improve health and well-being, and may create safer and more sustainable cities and human settlements.

In addition, to achieve the ambitious RUEN target of increasing per capita electricity consumption, Indonesia should maintain high economic growth, improve people's living standard, and accelerate the adoption of electric vehicle and cooking stove technologies. These are some factors associated positively with electricity consumption [81]. Furthermore, as fossil-based electricity consumption is a source of emissions, policy on electricity generation should ensure the adoption of low carbon technology.

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Appendices

Table A. 1. Effect of increasing CAGRs on energy demand

Branches	Energy demand		
	2015 BAU	2030 BAU	2030 BAU if CAGRs increase by 2%
Industry	2,248.131546	3,428.020466	4,576.173567
Household	675.665543	989.889779	1,322.444984
Commercial	246.816560	705.951851	931.384862
Transportation	1,844.783269	4,045.076831	5,363.053725
Other Sector	190.931481	259.091478	346.642612
Non Energy	450.308081	863.346029	1,147.522200
Total	5,656.636479	10,291.376434	13,687.221951

Table A. 2. Energy demand of SDGs assuming $A_{T,Gap} = |A_{T,SDGs} - A_{T,2015}|$

SDG Targets	Description	Activity levels (A_T)	SDGs Gap	Energy Intensity (yearly)		Energy demand
			($A_{T.Gap}$)	(I_T)	Unit	(MJ)
2.1	Zero hunger	Undernourish people	18,648,726	599.33	MJ/person	11,176,740,954
2.3	Double small farmer productivity	Small farmer households	13,450,417	413.33	MJ/household	5,559,460,859
2.4	Sustainable agriculture	Land area under sustainable agriculture				-
3.8	Universal healthcare access	Persons with unmet needs for healthcare	11,831,544	475.63	MJ/person	5,627,387,467
4.1	Access to primary and secondary education	Elementary school students	1,746,281	798.34	MJ/student	1,394,118,988
		Junior high school students	2,553,643	991.87	MJ/student	2,532,886,494
		Senior high school students	5,414,805	1330.56	MJ/student	7,204,722,276
4.2	Access to early childhood education	Kindergarten students	5,680,761	598.75	MJ/student	3,401,366,711
4.3	Access to tertiary education	Students of tertiary education	8,521,145	8208	MJ/student	69,941,554,635
5.b	Equal access to enabling technology	Persons with a mobile phone	150,977,192	5.19	MJ/person	783,571,628
6.1	Access to safe drinking water	Persons with drinking water access	115,485,091	92.16	MJ/person	10,643,106,006

SDG Targets	Description	Activity levels (A_T)	SDGs Gap ($A_{T,Gap}$)	Energy Intensity (yearly) (I_T)	Unit	Energy demand (MJ)
6.3	Halving the proportion of untreated Wastewater	Cubic meters untreated wastewater	4,113,426,251	1.8	MJ/m^3	7,404,167,253
7.1	Access to electricity and clean cooking fuels	Households with electricity	7,598,952	726.75	MJ/person	21,537,899,627
		Households cooking with LPG	20,054,976	7087.26	MJ/household	142,134,874,800
		Households cooking with kerosene	2,911,841	-8200.31		(23,878,007,580)
7.2	Renewable energy share	Renewable energy does not change energy demand				
7.3	Energy efficiency	Targets 7.3 and 8.1 should be calculated together using national data and the result should be regarded as a benchmark for maximum national energy consumption. See also Santika, et al. (2019)				
8.1	Sustainable economic growth					
9.1	Access to road infrastructure	Toll road length, in km	3,261.04	10	TJ/km	32,610,400,000
		National road length, in km	6,000	7.5	TJ/km	45,000,000,000
		Povincial road length, in km	6,000	5.4	TJ/km	32,400,000,000
		Sub-provincial road length, in km	18,000	3.3	TJ/km	59,400,000,000
9.c	Access to information and communication technology	Persons in areas without mobile network cover	7,625,227	1,702.94	MJ/user	12,985,334,302
11.1	Access to adequate housing	Persons in urban slums	23,528,050	864.00	MJ/person	20,328,235,373
11.2	Access to convenient public transport	Persons with convenient public transport	29,640,510	2,950.00	MJ/person	87,439,504,500
11.6	Urban solid waste	Urban solid waste not collected, tonnes	7,193,485.08	588.07	MJ/t (diesel)	4,230,307,014
				432	MJ/t (electricity)	3,107,585,556
12.3	Food losses and waste	Total population, cap	296,405,100	256.5	MJ/cap	76,027,908,150
12.5	Waste reduction	Waste recycled, tonnes	1,760,000	(1,640)	MJ/t	(2,886,400,000)
13.1	Resilience to disasters	Relocated persons	403,441	1,353.07	MJ/person	545,881,807
17.6	Access to science	Fixed broadband subscriptions	99,800,006	315.36	MJ/subscription	31,472,929,999
17.8	Access to internet	Persons using internet	240,254,552	1147.63	MJ/user	275,723,331,970
				Total additional commercial energy demand (MJ)		**943,848,868,788**

***Declaration of Interest Statement**

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

CRediT Author Statement

Wayan G. Santika: Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization. **M. Anisuzzaman:** Conceptualization, Methodology, Writing – Review & Editing. **Yeliz Simsek:** Data Curation, Writing – Original Draft. **Parisa A. Bahri:** Conceptualization, Writing – Review & Editing, Supervision. **GM Shafiullah**: Writing – Review & Editing, Supervision. **Tania Urmee:** Conceptualization, Methodology, Writing – Review & Editing, Supervision.