Manuscript Details

Manuscript number	ERSS_2018_532_R2
Title	From Goals to Joules: A quantitative approach of interlinkages between energy and the Sustainable Development Goals
Article type	Research Paper

Abstract

Energy isa key enabler in achieving the Sustainable Development Goals (SDGs) as energy plays the pivotal role in attaining the key targets of ending poverty and hunger, providing healthcare, education, and water, as well as sustaining economic growth and protecting the environment. Consequently, since the SDGs are executable only at local and national levels, mainstreaming the SDGs into local/national development planning will put pressure on the country's energy sector. Considering the broad scope of the SDGs, countries will prioritize different SDG targets based on their urgencies, resources, and capabilities. However, energy linkages with the SDGs and their targets are complex, with direct and indirect connections, synergies, and trade-offs. More importantly, there is a lack of capacity among policymakers to be able to develop an SDGs-responsive energy plan, as there is no guidance on how the impact of linkages can be translated into local/national energy planning. This study aims to examine the complexity of the interconnections between energy and the SDGs, as well as give examples of how these linkages can be quantified. Twenty-five SDG targets with direct links to energy are identified in this study, and a map of the multidimensional interaction between them are presented. The study also provides examples of quantification of the targets/indicators into their energy requirements. The results of the study will help energy planners and policymakers forecast energy demand more accurately for energy planning and policies under the SDGs regime.

Keywords	Sustainable Development Goals; energy planning; SDGs interlinkages; energy demand.
Manuscript category	Energy, consumption, and behavior

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October 19, 2018

To
The Editor
Energy Research and Social Science

Subject: Resubmission of Manuscript

Dear Sir,

Please find the paper entitled, **'From Goals to Joules: A quantitative approach of interlinkages between energy and the Sustainable Development Goals'**, which we would like to submit for publication in the 'Energy Research and Social Science' journal.

This work is a part of a Ph.D research undertaken at Murdoch University, Western Australia.

I declare on behalf of all the authors that this paper 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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Comment Responses

Reviewer 2 comments:

The quality of the article has been significantly improved and Reviewer 2 suggested changes have been successfully taken into account.

As a minor comment, in the new Figure 2, should be included the axis X values. Could also be interesting to provide a short (two or three words) name for each SDG Target, instead of using just numbers. Such as:

17.6: Access to Science.

17.8: Enabling technology.

This could also facilitate the readability of Table 3. However, it is just a suggestion, not a compulsory change.

For the rest, the article could be published in the current format.

Congratulations for the research.

Responses:

Thank you for your constructive feedback and kind wishes.

We have included the X axis value and added names for the targets (see Figure 2, Page 20). The names have also been added to Table 3, Page 16-18 to facilitate readability.

From Goals to Joules: A quantitative approach of interlinkages between energy and the Sustainable Development Goals

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Acknowledgment:
The authors wish to thank the School of Engineering and Information Technology, Murdoch University, Australia for providing the research grant to pursue this research. The research is also supported by the Ministry of Research, Technology, and Higher Education and the Ministry of Finance of the Republic of Indonesia through the Indonesia Lecturer Scholarship (BUDI-LPDP) granted to the first author. Appreciation is also extended to Mr. Thiyagarajan Velumail for his guidance with this research.

Role of the funding sources:
The funding sources had no involvement in any stages of the study.

Declaration of interest: None.

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Abstract

Energy is a key enabler in achieving the Sustainable Development Goals (SDGs) as energy plays the pivotal role in ending poverty and hunger, providing healthcare, education, and water, as well as sustaining economic growth and protecting the environment. Consequently, since the SDGs are executable only at local and national levels, mainstreaming the SDGs into local/national development planning will put pressure on the country's energy sector. Considering the broad scope of the SDGs, countries will prioritize different SDG targets based on their urgencies, resources, and capabilities. However, energy linkages with the SDGs and their targets are complex, with direct and indirect connections, synergies, and trade-offs. More importantly, there is a lack of capacity among policymakers to be able to develop an SDGs-responsive energy plan, as there is no guidance on how the impact of linkages can be translated into local/national energy planning. This study aims to examine the complexity of the interconnections between energy and the SDGs, as well as give examples of how these linkages can be quantified. Twenty-five SDG targets with direct links to energy are identified in this study, and a map of the multidimensional interaction between them are presented. The study also provides examples of quantification of the targets/indicators into their energy requirements. The results of the study will help energy planners and policymakers forecast energy demand more accurately for energy planning and policies under the SDGs regime.

Keywords: Sustainable Development Goals; SDGs; energy planning; SDGs interlinkages; energy intensity; energy demand.

1. Introduction

As a key enabler for the Sustainable Development Goals (SDGs), energy increases productivity, transforms economies and societies, and improves human life in terms of economic growth, food production, well-being and healthy lifestyles, education, gender equality and empowerment, water supply and sanitation, as well as employment [1]. The SDGs are global goals yet executable only in local and national contexts, and the implementation of the SDGs into local and national development planning will affect the energy sector. More energy will be required if a country strives to end poverty; eradicate hunger; improve health and well-being, education, and gender equality; provide clean water and energy; and achieve the other SDGs.

Studies have shown a strong correlation between per capita energy consumption and the human development index (HDI) [2-4]. They have found high and moderate increases in human welfare relative to energy use in the least developed countries and the transitioning nations, respectively. In contrast, saturation is found in developed nations, as consuming vast amounts of energy has no significant impact on human development [2, 5]. However, it does not imply that the SDGs are relevant for developing countries only [6]. While the developing countries focus on access to basic needs, *e.g.*, ending extreme poverty, the rich nations will address issues related to responsible consumption and production, climate change, and biodiversity [7, 8].

The challenge lies in finding ways to accommodate this energy demand with modern and sustainable energy services and the global natural resources considering their impact on the environment to ensure that the SDGs are well addressed. It poses difficulty in developing an energy plan that can adequately respond to the context of the SDGs in the understanding of how the achievement of different SDG targets will impact the energy supply and demand scenarios. It is because, on the one hand, the achievement of most SDG targets will require energy as an input, which will give rise to the energy demand. On the other hand, changes in one SDG target may influence the energy demand of other targets, as well as on how the energy resources are being utilized to supply the required energy. The SDGs also imply that energy decision makers should consider the impacts of their choices on the environment [9].

To the authors' knowledge, no study discusses the quantification of SDG targets and indicators into energy demand. The global research community is still building up their knowledge on how the SDGs will work at the national level and how the additional energy requirement can be quantified to ensure that all SDGs are adequately achieved. It includes discussions on the interconnectedness and cross-impacts of the SDGs, and how the countries would need to plan to achieve them. Le Blanc [10], for example, provides interlinkages and mapping of the SDGs as a network of targets based solely on the targets' wording. Since it only assesses the relationships purely on the wording content of the targets, the method cannot be used to acknowledge other distinct interconnections adequately. As an example, based on its targets' wording, the energy goal (SDG 7) is linked only to 3 other goals, which are inequality (SDG 10), sustainable consumption and production (SDG 12), and poverty (SDG 1) [1]. The links between energy and health (SDG 3), education (SDG 4), climate change mitigation (SDG 13), food (SDG 2), and water (SDG 6), among others, were not distinct. Another study proposed a nexus approach to explain the complexity of the SDG network of food, energy, and water [11]. Exploring the nature of interconnections among targets, it provided possible nexus interactions between some SDG targets related to energy, water, food, health, and education. Compared to the previous approach, this method is more comprehensive in explaining the interactions. The nexus approach, however, increases the complexity of the analysis and makes it harder to quantify the corresponding energy requirements.

Additionally, the International Council for Science (ICSU) [12] and Nerini, *et al.* [13] have mapped the linkages between the energy goal and other SDGs and the studies are claimed to be based on scientific evidence. The ICSU's SDGs and energy linkages are based on the International Institute for Applied Systems Analysis (IIASA) working paper which concludes that SDG 7 (energy) is interconnected with all other SDGs [14, 15]. The mapping of Nerini *et al.* [13] identifies 143 targets and 65 targets as having synergies and trade-offs with SDG 7, respectively. However, those studies do not address the impacts of pursuing the targets on the energy demand dynamics, *e.g.*, what the additional energy requirement for ending hunger is by 2030. Moreover, some of the targets proposed as related to energy are either social, institutional, policy, or regulatory targets, which have no direct links to energy demand. Some other targets have been covered by others or are difficult to quantify.

Various energy demand models are available to assist national planners in quantifying energy demand and supply, such as the Long-range Energy Alternatives Planning (LEAP), OSeMOSYS (Open Source Energy Modeling System), NEMS (The National Energy Modeling System) and MARKAL, that would presumably be able to model energy demand associated with different targets. However, these models are unable to capture additional energy requirements arising from the interlinkages between energy and other SDGs due to the lack of a mechanism for estimating this additional energy demand. This lack of a coherent approach or methodology that can quantify the energy required to achieve each SDG target poses an enormous difficulty for policymakers, particularly to enable them to develop an energy plan that is sufficient and responsive to realizing the SDG goals by 2030. This gap is thus a strong barrier to the achievement of the SDGs globally. First, the SDG targets that have strong and direct impacts on the energy demand and supply will need to be identified. While some targets may have flow-on effects on energy demand, for simplicity, this paper will consider only the first-order linkages of SDG targets with energy. It is the authors' opinion that data and information availability to estimate energy demands for the second and subsequent orders of linkages is inadequate, and thus it will not be attempted in this paper. As mentioned above, various studies have endeavored to map the interlinkages between energy and SDG targets. A review of those studies will lead to an interlinkages map that is robust and widely acceptable. The energy requirement for each of those interlinkages will then need to be quantified in a way that determines the additional energy requirement for achieving SDG targets compared to the business-as-usual (BAU) scenario, *i.e.*, if the SDGs were not to be mainstreamed.

[1] The coding of targets and indicators in the remainder of the paper will follow the coding of the UN official revised list of global SDG indicators. Target 1.4 means the fourth target of SDG 1 (the first goal). Indicator 1.4.2 indicates the second indicator of Target 1.4.

2. Background

The United Nations defined the SDGs as "*a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity*" [16]. They include five P's essential to humanity, *i.e.*, the people, the planet, prosperity, peace, and partnership. The SDGs are a global commitment pledged by state members of the United Nations incorporating 17 goals, 169 targets, and 232 indicators. However, even though the SDGs and their targets are meant to be achieved globally, they can only be executed at national and local levels. For example, Target 2.1 aims to end hunger globally by 2030. The target can be measured using the prevalence of undernourishment (Indicator 2.1.1). According to the Food and Agriculture Organization (FAO) data, about 800 million people in the world were estimated to live in hunger between 2014 and 2016 [17]. The two most populous countries in the world, India and China, have 15.2% and 9.3% undernourishment respectively, which means that almost 330 million people in these two countries would not have enough food to eat regularly. Undernourishment in India and China corresponds to 109 kcal and 74 kcal food deficit per person per day respectively [18]. It equates to approximately 21,255 million kcal and 9,990 million kcal worth of food per day to end hunger in India and China, respectively, by 2030. In efforts to end hunger and to produce enough food for everyone in these two countries (Target 2.1), additional energy will be required at different stages of food production and value chain, *e.g.*, for cultivation, fertilizer, irrigation, harvesting, processing, storing and transporting.

Similarly, Target 6.1 requires access to safe drinking water for all. Its indicator is the proportion of the population using safely managed drinking water services (Indicator 6.1.1). The World Health Organization shows that about 71% of the global population consumed safe drinking water in 2015 [19]. However, almost half of the world rural population lacked access during the same period. For example, less than 7% of Ugandans were served with consumable water in 2015. Based on a water requirement of at least 50 liters/person/day [20], 1.88 million m^3 of additional water will be needed daily to provide safe drinking water for everyone in Uganda by 2030. In Cambodia and Pakistan, less than 50% of the population have access to safe drinking water in 2015 [19]. Both countries should also consider mainstreaming Target 6.1 into their national plans. We estimate that in the absence of the SDGs only about 85% of the global population will have safe, consumable water by 2030. Water production requires energy, *e.g.*, for abstraction, conveyance, treatment, and pumping. A significant amount of additional energy will be required at the national level to ensure universal access to safe drinking water.

2.1. Overview of SDG 7

Energy, a vital element in achieving the SDGs, is included as SDG 7: "*Ensure access to affordable, reliable, sustainable and modern energy for all*." Modern energy comprises electricity, clean fuels and technology for cooking, and mechanical power (i.e., converted energy to motion for pumping and pushing) [21]. There are three primary targets under SDG 7, which represent the three pillars of sustainable energy, *i.e.*, ensuring access to clean and modern energy, increasing the share of renewable energy, and doubling energy efficiency. The proportion of the population with access to electricity and the ratio of the population with clean fuels and technology are the indicators measuring clean and modern energy access. The indicators for the second and third targets are renewable energy share in the total final energy consumption and energy intensity measured in terms of primary energy supply per unit of Gross Domestic Product (GDP), respectively.

The SDG 7 targets have been primarily based on the Sustainable Energy for All (SEforALL) objectives for 2030, which was announced in 2012 [22]. SEforALL is a United Nations global initiative to promote actions based on commitments to providing universal access to sustainable energy in recognition of its importance to sustainable development. Table 1 summarises the SEforALL global objectives for 2030, its baseline conditions, and the International Energy Agency (IEA) estimates for 2030. It shows that access to electricity and clean energy for cooking are set to be universal (100%) by 2030, while the baseline situations are 85.3% and 57.4%, respectively.

However, the IEA estimates that access to electricity and clean energy for cooking will reach only about 91% and 72% of the population by 2030, respectively, even if the IEA's New Policies Scenario is fully applied [22]. The New Policies Scenario considers energy policies that are under implementation as well as targets, aims, and intentions that have been announced but are yet to be implemented, such as the Nationally Determined Contributions (NDC) [23].

Similarly, the IEA predicts that the global renewable energy share of total final energy consumption (TFEC) will only be 21% by 2030, far below the target. The annual growth rate of the primary energy intensity will be around -2.1%, slightly below the 2030 target. When the SEforAll was initiated, the growth rate was -1.3% (2010-baseline) [24].

Table 1. Sustainable Energy for All (SEforALL) global objectives, baselines, and IEA estimates

	Access to electricity	Access to clean cooking fuels and technologies	Renewable energy share in TFEC	Energy efficiency (measured as the annual growth rate of primary energy intensity)
2030-Objectives	100%	100%	36%	-2.6%
2014-Baseline	85.3%	57.4%	18.3%	-2.1%
2030-IEA estimates	91%	72%	21%	-2.1%

Source: IEA and the World Bank [22]

To ensure universal access to affordable, reliable and modern energy services, we should anticipate an increase in energy demand. For example, providing electricity globally for 1.2 billion people who lack access [23] means that around 109.5 TWh electricity should be added by 2030. It is based on a household electricity consumption of 365 kWh per year (Tier 3 of the World Bank's Multi-Tier Framework for measuring electricity access) [25]. Similarly, 59.4 million metric tons of LPG equivalence will be required by 2030 to provide clean energy for cooking for the 2.7 billion people who currently cook using traditional biomass (based on the IEA [26] estimate of 22 kg annual consumption of LPG per capita in developing countries).

2.2. Energy reduction potential

It is clear that some targets will potentially reduce energy consumption. For instance, Target 7.3 calls for doubling the rate of energy efficiency, and its potential reduction will not be small. Cullen et al. [27] found that 73% energy reduction is possible by changing the design of passive systems using the most efficient technology that practically achievable.

The saturation phenomena previously discussed indicate that energy reduction is possible while maintaining high human development [2, 5]. As high human development can be achieved with as low as 63 GJ of energy per capita, scholars have suggested that high income countries should reduce their energy consumption [4, 28], even though the decoupling of energy consumption from human development is highly overestimated [29].

However, the main driver of energy consumption is the economic growth and vice versa, and reducing consumption will have a negative impact on growth unless the reduction is achieved through energy efficiency [30]. Energy efficiency implies the delivery of the same level of services using less energy. The study also suggests that increasing energy prices to curtail consumption will negatively impact the economy [30]. Studies about the relationship between energy and economic growth also show conflicting results [31-34]. A literature survey reviewing 48 studies about the link indicates that about half of the studies found causal relationships from energy to growth, suggesting that energy reduction will give an adverse effect to the economic growth [34]. Half others demonstrate that consumption can be reduced without affecting growth. We will discuss this reduction potential further when we review Targets 7.3 and 8.1 in the quantification and discussion chapters.

3. Methods

The study has been conducted in five key steps. First, in the Google Scholar search engine, we used keywords related to the goals. For example, in relation to SDG 2 about ending hunger, we used keywords such as ‘energy and food,’ ‘energy consumption and agriculture,’ ‘electricity use and food’ and ‘energy access and hunger.’ We also used the Google search engine to include evidence from the ‘grey’ literature. The collection of evidence was sorted to come up with the most relevant sample of literature. The list is not intended to be exhaustive since other studies [12-14] have provided more comprehensive records. We consider this step important to gain more knowledge about the linkages, which is essential for the second step.

Second, a simple qualitative content analysis [35-37] was conducted to identify SDG targets with strong links to energy demand. The analysis was based on the explicit content of the written texts of each SDG targets and indicators. Three conditions are set to identify if a target is linked to energy demand. They are (1) implementation of the target requires energy or reduce energy consumption, (2) the target is quantifiable in term of energy, and (3) the target has not been covered by other targets. A target should comply with all conditions to be identified as linked to energy demand. Authors meetings and expert consultations were held to interpret the content of each target and to review results until consensus is reached. Authors of this paper discussed to arrive at a correct interpretation of the content of all SDG targets and indicators word-by-word to come up with the list of targets with strong links to energy demand.

Third, we illustrate the complexity of linkages between energy and SDG targets based on the list of identified linkages between energy and targets, and group the targets based on sectors. The mapping also recognizes the second layer of interaction between energy and targets/indicators (the indirect link between energy and SDG targets). Next, independent energy experts with comprehensive experience in energy, sustainable development planning and policy, and climate change were consulted to comment on the revised list and the linkage map. The consultation was conducted through email correspondence and finalized with a teleconference.

Finally, it presents an in-depth quantitative analysis based on empirical evidence to quantify additional energy demand for each of the targets included in the synthesized interlinkages map. As mentioned earlier, this analysis addresses only first-order interactions between energy and SDG targets. The approach mainly uses algebraic manipulations to translate the SDG targets to their energy demand equivalence (in MJ/capita or MJ per unit of SDG indicators). Targets were translated into mathematical equations, which then were solved by using data for relevant targets. As this analysis aimed at developing a general framework to quantify additional energy requirement per unit of SDG activity using global data, a small margin of error could be possible if the model is directly applied at a national level. This margin of error could be eliminated/improved by using country-specific data, where available, into the equations that have been presented in this paper.

This quantification of energy demand for each of the energy-linked SDG targets is the core and original work presented in this paper and is believed to introduce a new paradigm of SDG-responsive energy planning at national levels. The total additional energy demand at a national level can be determined by summing up the extra energy required for all targets, and a set of recommendations can be presented for policymakers.

4. Interlinkages between energy and SDGs

Our collection of evidence sorts 88 samples of scientific and grey literature that support linkages between energy and the SDGs (see Appendix A for the list of evidence). There are samples of literature supporting every linkage between energy and the SDGs [13-15]. However, a closer look at the target level shows that targets of SDG 10, 14, 15, and 16 do not have strong or direct links with energy demand and can be omitted in this study, but they may have some implications on other aspects of energy.

The qualitative content analysis identifies only 25 targets with significant links to energy demand (Appendix B). The authors note that there are more targets with direct links to energy. However, these have been excluded for the reasons previously mentioned: they have been covered by other targets, the link with energy demand is difficult to quantify, or there is only a weak relationship. For instance, Targets 1.1, 1.2, and 1.3 are related to poverty eradication in all its dimensions. These targets are excluded considering that most other targets will contribute to them. Similarly, Target 10.1, which refers to the acceleration of the income growth of the bottom 40% of the population, is omitted because it has been addressed by Target 8.1. The analysis excludes the targets of SDG 10, 14, 15, and 16 for similar reasons.

The results were compared with those of Nerini *et al.* [13] and McCollum *et al.* [14] and found that Target 5.b, which is about information and communication technology (ICT) to empower women, is not in the list of Nerini *et al.* We argue that achieving Target 5.b will require energy. We also found that targets related to the means of implementation (Targets 5.b, 9.c, 17.6, and 17.8) that we consider related to energy demand are not in the list of McCollum *et al.* [14]. They omit the means of implementation targets entirely from the analysis while we assert that those four targets (about ICT and access to internet) are linked to and will increase energy demand.

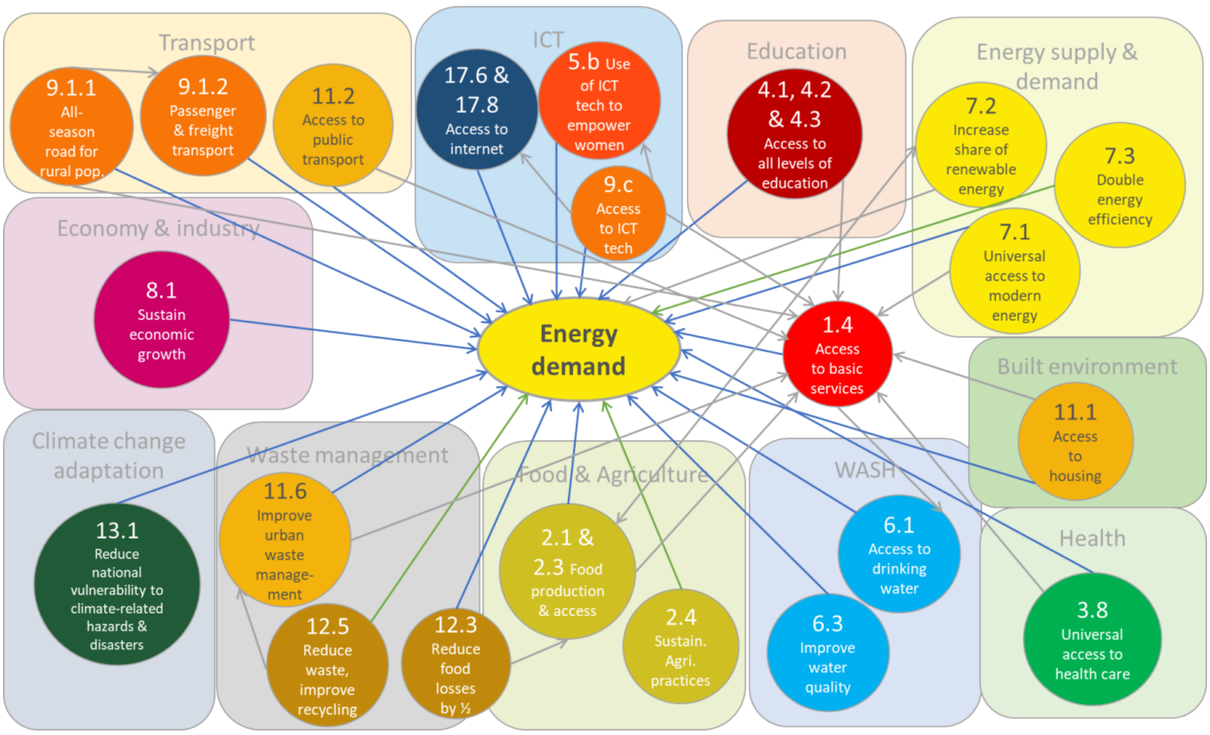

Figure 1. Multi-dimensional interactions between energy demand and SDG targets and indicators

Source: Authors' illustration
Print preference: color
2-column fitting image

Figure 1 illustrates the complexity of the interconnections between energy demand and SDG targets and indicators. The circles represent either targets or indicators, and those of the same color belong to the same goal. The direction of the arrows indicates the orientation of the effects. For instance, ensuring access to housing (Target 11.1) will influence energy demand and contribute to access to basic services (Target 1.4). Blue arrows mean that the targes will increase energy demand while the green and grey ones reduce energy demand and neutral, respectively. For example, increasing the share of renewable energy (Target 7.2) will change the composition of energy sources (fuels), but it will not increase or decrease energy demand. The energy-related targets and indicators are grouped into 11 sectors: transport; information and communications technology (ICT); education; energy demand and supply; built environment; health; water sanitation and hygiene (WASH); food and agriculture; waste management; climate change adaptation; and economy and industry.

As an illustration, providing access to basic services for everyone (Target 1.4) requires energy. Basic services include access to transportation, telecommunication, education, energy, healthcare, safe drinking water, sanitation, waste management, social welfare, public safety, and open space management [38]. Therefore, achieving Targets 3.8, 4.1, 4.2, 4.3, 6.1, 7.1, 9.1, 9.c, 11.1, 11.2, and 11.6 will contribute to the achievement of Target 1.4.

The interaction of Targets 2.1 and 2.3 (food production and access) with Target 7.2 (increasing renewable energy share), has to be carefully considered. In many cases, energy and food compete for land and water resources. Growing plants for biofuels, for example, requires land and water that otherwise can be used for agriculture [39, 40]. Another study shows that replacing a significant amount of petroleum with ethanol production from corn and biodiesel production from soybean in the US cannot be done without affecting food supplies [41].

Another subtle linkage, which can be easily overlooked, is in relation to Indicator 9.1.1 (access to rural road infrastructure). The construction of road networks requires energy. Once built, an improved road network will attract more vehicles [42], which will further increase energy demand in the transport sector. Similarly, success in doubling the energy efficiency may stimulate further consumption. Experts are cautious about the effectiveness of energy efficiency in reducing consumption due to the phenomenon called rebound effect [43-45]. The rebound effect indicates that any saving as a result of efficiency measures may encourage more consumption [46]. For example, efficient cars reduce energy consumption per travel, which in turn, may motivate more trips and increase the overall energy consumption.

5. Quantification of energy demand at target levels

Once the interlinkages have been mapped, the targets or their indicators were translated into energy demand. In general, multi-dimensional linkages add complexity to the energy demand equation. To estimate the energy requirements for achieving these targets we calculated the first-order connection only. The details are explained below.

5.1. SDG 1 – No poverty

Target 1.4. The target requires universal access to basic services for all which is to be measured by Indicator 1.4.1 - *Proportion of population living in households with access to basic services*. As explained in Section 3, basic services include access to transportation, telecommunication, education, energy, healthcare, safe drinking water, sanitation, waste management, social welfare, public safety, and the open space management. This target is covered by other targets, including Targets 3.8, 4.1, 4.2, 4.3, 6.1, 7.1, 9.1, 9.c, 11.1, 11.2, and 11.6, and so has not been included in energy quantification.

5.2. SDG 2 – Zero hunger

Target 2.1. The target is to end hunger and provide sufficient food for everyone, and measurable using Indicator 2.1.1 - *Prevalence of undernourishment*. Undernourishment is represented by the country's depth of food deficit (D_F). According to the data provided by the World Bank [18], D_F is estimated to be 90.25 kcal/person/day, globally. The energy intensity ($EI_{2.1}$) can be determined using the following equation:

$$EI_{2.1} = \frac{D_F}{EC_F} \cdot (E_{on-farm} + E_{off-farm})$$

The food energy content (EC_F) of cooked corn, for example, is 960 kcal/kg [47] and the on-farm agriculture energy use ($E_{on-farm}$) for corn is 2 to 5 MJ/kg (calculated from [48]). The range represents a more traditional farming method at one end and more energy intensive, modern farming at the other end. For simplicity, we have considered corn only. The off-farm agriculture energy use ($E_{off-farm}$) for value chain including processing, storing and transportation, is about twice the $E_{on-farm}$ [48] or approximately 4 to 10 MJ/kg. Using corn as an approach, the energy intensity to end global undernourishment is about 564 to 1410 kJ·cap^{-1}·day^{-1} or approximately 205.86 to 514.65 MJ·cap^{-1}·year^{-1}. The energy requirement for food preparation and cooking is not included as it will be covered by the household and industrial energy sectors.

Target 2.3. The target is to double the productivity and incomes of small farmers and measured with Indicator 2.3.1 - *Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size*. The small farmer land possession (LP_{SF}) can be estimated as

$$LP_{SF} = \frac{A_T \cdot S_{SF}}{SF_T}$$

The estimation of the world total agricultural area (A_T) is 4862.6 million ha in 2015 [49]. The share of the total land cultivated by small farmers (S_{SF}) is 12%, which consist of about 2.5 billion full and part-time farmers (SF_T) [50]. It gives us an LP_{SF} estimate of 0.23 ha/farmer.
The small farmer energy intensity ($EI_{2.3}$), therefore, is

$$EI_{2.3} = LP_{SF} \cdot E_F$$

The average annual agriculture energy consumption (E_F) ranges from 0 to 10 GJ/ha in most developing countries [51]. The $EI_{2.3}$, therefore, will range from 0 to 2.33 GJ·farmer^{-1}·year^{-1} in 2015. It is safe to assume that the additional energy required to double the small farmers' productivity will also be in the same range. It should be noted that doubling small farmers' productivity will feed the undernourished people in a country (Target 2.1). Therefore, Targets 2.1 and 2.3 will overlap to a certain degree.

Target 2.4 is to ensure a sustainable food production system. It can be measured with Indicator 2.4.1 - *Proportion of agricultural area under productive and sustainable agriculture*. The productive and sustainable agriculture with low-input integrated farming consumes on average 26.85% less energy per hectare than the conventional one (based on wheat, maize, and soybean crops cultivated in Italy) [52]. In mathematical equation it gives:

$$\frac{EI_{SA}}{EI_{CF}} = (100 - 26.85)\%$$

With the global, conventional farming energy intensity (EI_{CF}) of about 8.4 GJ·ha^{-1}·year^{-1} [48], the equation above gives us the productive and sustainable agriculture energy intensity (EI_{SA}) of about 6.1 GJ/ha. The energy saving (ES) potential of farming method conversion from conventional to productive and sustainable agriculture is

$$ES = EI_{CF} - EI_{SA} = 2.3 \text{ GJ·ha}^{-1}\text{·year}^{-1}$$

With the world population of 7.4 billion people [53] and the estimated global agricultural area of 4862.6 million ha in 2015 [49], the per capita agricultural area will be 0.66 ha/cap, and the energy saving potential will be 1.52 GJ·cap^{-1}·year^{-1}.

5.3. SDG 3 – Good health and well-being

Target 3.8. It is to provide universal health access, and its energy-related indicator is Indicator 3.8.1 - *Coverage of essential health services*. We assume that delivering essential health services means more people will visit health facilities. The energy intensity ($EI_{3.8}$) can be calculated as

$$EI_{3.8} = \frac{E_{HC}}{V_D}$$

The electrical energy consumption of health clinics (E_{HC}) ranges from 5 to 30 kWh/day [54]. For non-electricity energy consumption, an estimation is provided by the African Solar Designs [55], in which LPG use is about 6 kg/month. Assuming 83 persons average daily visits per health clinic (V_D) in Indonesian [56], the electricity energy intensities range from 22 to 132 kWh·cap^{-1}·year^{-1}. The thermal energy intensity is only around 3 g LPG per person, annually.

5.4. SDG 4 – Quality education

Target 4.1. By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes. We lack data to estimate the global average figures, but similar studies in the national context are available. For example, the study by Wang [57] shows that Taiwan elementary, middle, and high schools operational energy intensities are about 289, 310, and 734 kWh·student^{-1}·year^{-1}, respectively. The embodied energy of public school buildings (with three classrooms and an office) in Sri Lanka ranges from 224.97 to 483.47 GJ [58]. Assuming 20 students per classroom and 50 years of lifetime service, we found that the embodied energy intensities are 75 to 161.2 MJ·student^{-1}·year^{-1}.

Target 4.2. By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education. Total operational energy (OE) intensities of pre-primary schools in Italy and Hong Kong are 86 and 119 kWh/m^2, respectively [59]. However, due to the lack of data to convert them to per student unit, we assume that the operational and embodied energy intensities equal those of the primary school, which are 289 kWh·student^{-1}·year^{-1} and 75 to 161.2 MJ·student^{-1}·year^{-1}, respectively [57, 58].

Target 4.3. By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university. The average operational energy intensities in universities: Korea = 210 kWh/m^2 [60]; Griffith University Australia = 170 kWh/m^2 [61]; and Taiwan = 1,855 kWh·cap^{-1}·year^{-1}, ranging from 800 to 3,000 kWh·student^{-1}·year^{-1} [57]. The embodied energy intensity of a university building is assumed to be 20% of the operational energy.

5.5. SDG 5 – Gender ·equality

Target 5.b. The target is to provide access to enabling technology for women. The energy relevant indicator is Indicator 5.b.1 - *Proportion of individuals who own a mobile telephone, by sex*. For regular uses, a smartphone with the battery energy (E_B) of 1.2 Ah (about 16 kJ) per phone will last (t_h) for about 27 hours [62]. The estimated energy requirement for owning a mobile phone is

$$EI_{5.b} = \frac{E_B}{t_h} = \frac{16\frac{\text{kJ}}{\text{phone}}}{27\ \text{h}} \cdot \frac{24\ \text{h}}{\text{day}} \cdot \frac{1\ \text{phone}}{\text{person}}$$

Therefore, the $EI_{5.b}$ is estimated to be 14.22 kJ·cap^{-1}·day^{-1} or 5.19 MJ·cap^{-1}·year^{-1}. For different workloads, the battery life may range from 21 to 49 hours [62]. The estimates, therefore, will range from 2.86 to 6.67 MJ·cap^{-1}·year^{-1}.

5.6. SDG 6 – Clean water and sanitation

Target 6.1 is related to achieving universal access to safe and affordable drinking water and measured by Indicator 6.1.1 - *Proportion of population using safely managed drinking water* *services*. A study of the urban water supply energy use in China shows that the (electricity) energy intensity for drinking water processing is 0.29 kWh/m^3, which is equivalent to 33.2 kWh·cap^{-1}·year^{-1} [63]. A similar study in India reveals that the energy intensity is 0.3 kWh/m^3 or 18 kWh·cap^{-1}·year^{-1} [64].

Target 6.3 is to improve water quality, which is measured by Indicator 6.3.1 - *Proportion of wastewater safely treated*. The electricity energy intensities of urban wastewater treatment plants in China range from 0.95 to 1.25 kWh/m^3 [65] for plants' capacities between 10,000 m^3/day to 80,000 m^3/day. India's municipal wastewater (electrical) energy intensity ranges from 0.05 kWh/m^3 to 0.15 kWh/m^3 or about 0.6 to 3.8 kWh·cap^{-1}·year^{-1} [64].

5.7. SDG 7 – Affordable and clean energy

Target 7.1 is to achieve universal access to sustainable energy. Energy access includes electricity access and clean cooking fuel access, and the target is represented by two indicators: Indicator 7.1.1 - *Proportion of population with access to electricity* and Indicator 7.1.2 - *Proportion of population with primary reliance on clean fuels and technology*. The energy intensity for the former indicator ($EI_{7.1.1}$) can be estimated using the World Bank's multi-tier framework for energy access [66]. The framework divides household electricity uses into five tiers, as shown in Table 2. The higher the tier, the better the service (regarding capacity, services, duration of availability, reliability, and quality). At least Tier 3 electricity access should be provided to satisfy basic human needs for lighting, phone charging, radio, fan, television, food processing, and washing machine [66]. On the other hand, the energy intensity for cooking ($EI_{7.1.2}$) in the developing countries is about 22 kg·cap^{-1}·year^{-1} of LPG [26] or about 996 MJ·cap^{-1}·year^{-1}. Another study suggests that $EI_{7.1.2}$ is approximately 40 kg of oil equivalent or 1,674.72 MJ·cap^{-1}·year^{-1} [67].

Table 2. The multi-tier framework of electricity access [66]

Tier	Energy intensity (kWh·household^{-1}·day^{-1})	Energy intensity (kWh·household^{-1}·year^{-1})	*Services*
1	Min. 0.012	4.5	*Task lighting, phone charging, radio*
2	Min. 0.2	73	*Tier 1 + general lighting, fan, tv*
3	Min. 1	365	*Tier 2 + food processing and washing machine*
4	Min. 3.425	1,250	*Tier 3 + Refrigerator and iron*
5	Min. 8.219	3,000	*Tier 4 + Air conditioning*

Target 7.2 is to increase the renewable energy share. The indicator is *the renewable energy share in the total final energy consumption* (Indicator 7.2.1). The global renewable energy consumption in 2015 was 18.05% of the total final energy consumption [68]. The target is to increase it substantially, which lacks a precise number. A country would, therefore, need to select a share that could be considered as a substantial increase.

Target 7.3 is to double the global energy efficiency, measured by the Indicator 7.3.1 - *Energy intensity measured in terms of primary energy and GDP*. The global energy intensity in 2015 (EI_{2015}) was 5.13 MJ/$2011 PPP GDP [68]. According to the IEA and World Bank, the SDG target ($EI_{7.3}$) is to achieve the energy intensity growth of -2.6% by 2030 [22], which is equivalent to a global energy intensity of 3.58 MJ/$2011 PPP GDP by 2030. Our calculation using the World Bank data [68] shows that the annual energy intensity growth during the 2001-2015 period was about -1.58%.

Assuming the same annual growth for the next 15 years under the BAU, the energy intensity ($EI_{BAU2030}$) will be about 4.04 MJ/$2011 PPP.

5.8. SDG 8 – Decent work and economic growth

Target 8.1 is to maintain the per capita economic growth. GDP increases are usually associated with increases in energy consumption. However, sustaining the same per capita economic growth for the next 15 years means doing business as usual. Furthermore, the energy intensities of GDP (EI_{2015} and $EI_{7.3}$), in the MJ/GDP unit, have been determined under Target 7.3. It means that calculating the total energy consumption in year x (E_x) is as simple as

$$E_x = EI_x \cdot GDP_x$$

Target 8.1 is related to Target 7.3, and the energy equivalence of those targets should be combined. A simplified calculation of the energy correspondence of those targets is explained below. The 2030 total energy equivalence of the implementation of Target 8.1 without considering the efficiency measure (Target 7.3) will be

$$E_{8.1} = EI_{BAU2030} \cdot GDP_{8.1}$$

$GDP_{8.1}$ is the GDP of Target 8.1, which equals $GDP_{BAU2030}$. Since $GDP_{8.1}$ equals $GDP_{BAU2030}$, *therefore* $E_{8.1}$ equals $E_{BAU2030}$. Target 7.3 requires that the energy intensity is reduced to $EI_{7.3}$ by 2030. Therefore, the energy equivalence of the implementation of Targets 8.3 and 7.3 ($E_{8.1+7.3}$) will be

$$E_{8.1\,+\,7.3} = EI_{7.3} \cdot GDP_{8.1}$$

The 2030 energy reduction potential ($E_{7.3}$) will be

$$E_{7.3} = \left(EI_{BAU2030} - EI_{7.3}\right) \cdot GDP_{8.1}$$

or

$$E_{7.3} = E_{8.1} - E_{8.1\,+\,7.3}$$

Based on the World Bank data [69], the world GDPs in 2001 and 2015 are 10,453 and 14,778 $ (2011 PPP) per capita, respectively, giving an annual GDP growth rate of 2.5 %. Sustaining the same growth rate (Target 8.1, which is also the BAU) gives $GDP_{8.1}$ of 21,416 $ (2011 PPP) per capita by 2030. Solving for $E_{8.1}$ and $E_{8.1+7.3}$ gives 86,529 and 76,719 MJ per capita of global primary energy supply under the BAU and SDGs scenarios, respectively. Therefore, successful implementations of Target 7.3 will potentially save the world almost 9,810 MJ per capita by 2030.

Note that the energy calculated above is the primary energy supply. Its final energy consumption equivalence will depend on the national context of energy conversion technologies. The global conversion efficiency is roughly 68.76% in 2015, which is based on the global total primary energy supply (TPES) and TFEC of 13,647 and 9,384 million tons of oil equivalent (MTOE), respectively [70]. Assuming 70% efficiency by 2030, the TFEC equivalences of $E_{8.1}$ and $E_{8.1+7.3}$ will be around 60,570 and 53,704 MJ/capita, respectively. The final energy reduction potential will be about 6.867 MJ/capita by 2030. Caution should be exercised while using equations for this target as the use of GDP growth rate in the BAU scenario would mean that the impact of GDP on energy demand has already been included under the BAU scenario. Therefore, the modality of estimating effects of Target 8.1 will depend on how GDP growth rate is considered in the national energy planning.

5.9. SDG 9 – Industry, innovation, and infrastructure

Target 9.1. The target is to provide access to quality infrastructure. Its energy-related indicators are Indicator 9.1.1 - *Proportion of the rural population who live within 2 km of an all-season road* and Indicator 9.1.2 - *Passenger and freight volumes, by mode of transport*.

Calculating the energy required to ensure people live within 2 km of a reliable road is complicated. We need to estimate the proportion of the rural population with road access, widely known as the rural access index (RAI), by understanding the population distribution (where people live), road networks (the location of the roads), and the road quality [71]. Moreover, the Inter-agency and Expert Group on SDG Indicators of the United Nations classifies Indicator 9.1.1 a Tier 3 indicator [72]. Tier 3 is the lowest level of the classification indicating that the methodology and standards of the indicator are under development or testing.

The literature shows that the energy requirement of constructing a single carriageway road ($EI_{9.1.1}$) is 3.3 to 11.7 TJ/km, which is based on studies in European countries [73]. Another study shows that the average energy requirement for asphalt road construction, maintenance, and operation is about 580 $GJ \cdot km^{-1} \cdot year^{-1}$ (hot method, 13 m wide) [74]. To convert it to a per-capita unit, the RAI needs to be determined. The index will also give us the number of the population without the access. There is no easy way to translate this number to a road requirement in km per capita. In the meantime, the world is still waiting for the new methods of measuring rural access.

An example of the energy quantification data for the Indicator 9.1.2 is provided by the Deutsche Bahn [75]: Rail passenger EI = 0.38 to 0.98 MJ/pass-km; road passenger EI (bus) = 1.19 to 1.3 MJ/pass-km; rail freight EI = 0.35 MJ/ton-km; road freight EI = 1.38 MJ/ton-km; air freight EI = 10.25 MJ/ton-km. We lack data of global energy intensities of different modes of transport and methods of converting them to per capita energy consumption. However, calculating Indicator 9.1.2 based energy demand in the national context will be possible as long as the national target is set in the standard pass-km and ton-km units and the EIs are known.

Target 9.c is to provide access to communications and information technology, which can be assessed with Indicator 9.c.1 - *Proportion of population covered by a mobile network, by technology*. Assuming 300 users/km^2, the wireless network power intensities (P_W) are approximately 18, 27, and 68 W/user for the LTE (4G), WiMAX, and HSPA (3G) technologies, respectively [76]. The energy intensity is

$$EI_{9.c.1} = P_W \cdot t$$

For the networks with non-stop operating hours (t) of 8760 hours a year, the energy intensity for the LTE, WiMAX, and HSPA technologies are 157.68, 236.52, and 595.68 $kWh \cdot user^{-1} \cdot year^{-1}$, respectively, which are equivalent to 567.65, 851.47, and 2,144.45 $MJ \cdot user^{-1} \cdot year^{-1}$.

5.10. SDG 11 – Sustainable cities and communities

Target 11.1 is to ensure access to adequate housing. The amount of energy required to provide adequate housing varies from country to country. The embodied energy intensities of multi-story, two-story, and single-story houses in India are estimated to be 4.32, 4.81, and 5.23 GJ/m^2, respectively [77]. Assuming a floor surface area of 10 m^2/person for adequate housing [78] and 50 years of lifetime services, the energy intensities ($EI_{11.1}$) are 864, 962, and 1,046 $MJ \cdot cap^{-1} \cdot year^{-1}$. The housing operational energy requirement for lighting, appliances, and cooking is omitted as it has been covered by Target 7.1.

Target 11.2 is to provide access to a sustainable urban transport system and can be measured by Indicator 11.2.1 - *Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities*. Convenient access to public transport (PT) can be defined as a waiting time of less than 15 minutes at a bus stop less than 500 m away from home [79]. It can also mean a station with a convenient park and ride facility and a travel time of less than 30 minutes to destination. Increasing the proportion of the population with convenient access to PT means providing more bus stops and stations and increasing the frequency of the arrival and departure of buses and other PT, therefore increasing the energy use. We choose buses to represent public transport. The average energy intensity of traveling by bus ($EI_{Average}$) in low income cities is 0.59 MJ/passenger-km [80]. For simplicity, the additional energy requirement to upgrade the services to the convenient level ($EI_{11.2}$) can be assumed to range from zero to 0.59 MJ/passenger-km. Once the public transport is convenient, a shift from private car to public transport is expected, which presumably will reduce energy demand in the transport sector. It is the second-order interaction between energy and Target 11.2. This study only focusses on the first-order interaction.

Target 11.6. The target is to reduce cities environmental impact, which is to be measured with Indicator 11.6.1 - *Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities*. A study in Austria shows that the energy intensity of Target 11.6 ($EI_{11.6}$) is 529.75 to 537.88 MJ·cap^{-1}·year^{-1} or 1,657 to 1,682 MJ/t of municipal solid waste (MSW), which is consumed during waste collection and treatment processes including transportation, collection containers, and treatment of bio-waste, bulky waste and residual waste [81].

5.11. SDG 12 – Responsible consumption and production

Target 12.3 - By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses. Since food losses and waste in developed countries mostly related to consumer behaviors and preferences, which are not associated with energy, we focus on the food loss in the developing world because of their poor harvesting methods, inadequate storage facilities and transportation infrastructure, and limited processing and packaging (retailing) technologies [82]. The energy intensity for achieving Target 12.3 ($EI_{12.3}$) can be estimated as

$$EI_{12.3} = (EC_{Storage} + EC_{Retailing}) \cdot L_{Half}$$

The energy requirement for the transportation infrastructure is not considered here as it has been covered by Target 9.1. Food losses are about 114 and 159 kg·cap^{-1}·year^{-1} in South/Southeast Asia and Sub-Saharan Africa, respectively (calculated from [83]). The target of halving the losses (L_{Half}) means 57 and 79.5 kg·cap^{-1}·year^{-1}. Modernizing post harvesting food processes in developing countries includes the energy consumption for storage ($EC_{Storage}$) and energy consumption for retailing ($EC_{Retailing}$) of about 2 MJ/kg and 2.5 MJ/kg, respectively [48]. Using the equation, the energy intensity will approximately be 256.5 and 357.75 MJ·cap^{-1}·year^{-1} in South/Southeast Asia and Sub-Saharan Africa, respectively.

Target 12.5 is to reduce waste generation, which is to be measured with Indicator 12.5.1 - *National recycling rate, tons of material recycled*. The energy requirement for waste collection and treatment at waste management facilities is between 529.75 and 537.88 MJ·cap^{-1}·year^{-1} (1,657 to 1,682 MJ/t of MSW) [81], as described in Target 11.6. However, since recycling reduces indirectly raw materials to be extracted, processed, and transported, there is a net energy saving potential ($ES_{12.5.1}$) of 461.50 to 523.25 MJ·cap^{-1}·year^{-1} (1.64 GJ/t of MSW) [81, 84]. Industrial waste is not considered, assuming that it has less waste reduction opportunity. Note that if the energy requirement for waste collection and treatment has been included in Target 11.6, the energy intensity of this target ($EI_{12.5}$) is -1,001 to -1,053 MJ·cap^{-1}·year^{-1} (-3.13 to -3.29 GJ/t).

5.12. SDG 13 – Climate action

Target 13.1 - Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. The embodied primary energy required to build a temporary, post-disaster container house of 4 occupants is approximately 82.6 to 226.7 GJ [85]. The primary energy intensity, therefore, ranges 20.65 to 56.675 GJ/cap. Assuming 70% primary to final energy conversion factor and 20 years of lifetime services, the final energy intensity ($EI_{13.1}$) is 722.5 to 1,983.63 MJ·cap^{-1}·year^{-1}. The operational energy requirement (for lighting, comfort, and appliance uses) is omitted, as it has been included under the normal condition (before the disaster).

5.13. SDG 17 – Partnerships for the goals

Target 17.6 is to enhance access to science, technology, and innovation. Its energy-related indicator is Indicator 17.6.2 - *Fixed Internet broadband subscriptions per 100 inhabitants, by speed*. The power requirement of an internet infrastructure with a shared passive optical network (PON) connection serving an access rate of 25 Mbps (P_{PON}) is 9 to 11 watt/customer [86]. Assuming 8760 hours of continuous service a year, the annual energy intensity of the target is

$$EI_{17.6} = P_{PON} \cdot 8760$$

It gives 78.84 to 96.36 kWh/customer (or 283.82 to 346.9 MJ/customer), annually.

Target 17.8 is to enhance the use of enabling technology, which is to be measured by Indicator 17.8.1 - *Proportion of individuals using the Internet*. The energy intensity for the target can be estimated as

$$EI_{17.8} = P_{PC} \cdot t_{Net}$$

The time spent on the internet for medium users (t_{Net}) is 20 to 60 minutes/day [87]. The power requirement to access the internet (P_{PC}) using laptop and desktop computers ranges from 12 to 169 watts/user [88]. Therefore, the energy intensity ($EI_{17.8.1}$) ranges from 4 to 169 Wh·user^{-1}·day^{-1} or 5.3 to 222.1 MJ·user^{-1}·year^{-1}. Applying a wider time span of 1 to 620 minutes for light to heavy users [87], the energy intensity ranges from 0.26 to 2,295 MJ·user^{-1}·year^{-1}.

6. Results and discussion

Table 3 provides an overview of the energy required to fulfill each SDG target. Twenty-five targets previously identified are translated into energy demand. Target 1.4 is not included since most of the other targets will contribute to it. Targets 2.4, 7.3, and 12.5 have negative values, which indicate that those targets will reduce energy consumption. Target 7.2 may affect primary energy supply and the fuel shares, but it does not increase or decrease final energy uses. Energy equivalence of Target 8.1 is the overall average energy requirement per capita. It was calculated together with Target 7.3 to provide the energy reduction potential under the implementation of energy efficiency measures.

The quantification process applied simple algebraic methods, and the results at the country level may vary depending on the country data. A major implication of this procedure is that it relies on many assumptions, and the credibility of the estimates depend on the reliability of assumptions and the quality of data and references. Therefore, Table 3 also provides an assessment of our levels of confidence to the assumptions and references. Low, medium and high are the three levels of confidence we use to assess assumptions and references. The combination of assumptions and references levels of confidence determines the overall confidence level of the outcomes, which applies five levels of confidence: very low, low, medium, high, and very high.

Overall, two targets (3.8 and 11.2) have low confidence levels due to low confidence levels on the assumption side. For example, in estimating the global energy requirement to ensure health access (Target 3.8), we lack data of the global average energy demand per health clinic visit and total visits per unit of time. Our assumptions using estimates from Africa and Indonesia studies lack confidence in the accuracy of the assumptions. A similar reason applies to assumptions of Target 11.2. However, the confidence level of the assumptions in the national context can be improved by applying estimates taken from studies conducted locally.

On the other hand, we are highly confident with the estimates of Targets 5.b and 17.8. Assuming wide ranges of estimates taken from reputable sources increases the confidence level of the assumptions. On the references side, evidence from peer-reviewed studies convinces us that the data are highly credible. Our confidence level is very high when the confidence levels of both assumptions and references are high.

Table 3. Summary of total energy demand associated with the SDG targets

SDG targets	Descriptions	Energy demand	Units	Assumptions (confidence)	Data and references (confidence)	Overall Confidence
2.1	Undernourishment	205.86 to 514.65	$MJ \cdot cap^{-1} \cdot year^{-1}$	Corn to replace food; the off-farm energy use is twice the on-farm (Medium)	[18, 47, 48] (Medium)	Medium
2.3	Food production	0 to 2,334	$MJ \cdot farmer^{-1} \cdot year^{-1}$	Average energy consumption in developing countries is used; overlap between Targets 2.1 and 2.3 (Medium)	[49-51] (Medium)	Medium
2.4	Sustainable agriculture	-1,520 to 0	$MJ \cdot cap^{-1} \cdot year^{-1}$	Based on wheat, maize, and soybean crops cultivated in Italy (Medium)	[48, 49, 52, 53] (Medium)	Medium
3.8	Access to health care	79.2 to 475.2	$MJ \cdot cap^{-1} \cdot year^{-1}$ (electricity)	Based on energy estimate intended for Africa; using average visit data from Indonesia (Low)	[54-56] (Medium)	Low
		0.147	$MJ \cdot cap^{-1} \cdot year^{-1}$ (LPG)			
4.1	Primary & secondary education	587 to 1,404 (OE)	$MJ \cdot student^{-1} \cdot year^{-1}$ (elementary school)	Based on Taiwan's school energy intensity and study done in Sri Lanka; 20 students per class, 50 years lifetime service (Medium)	[57, 58] (High)	High
		990 to 2,938 (OE)	$MJ \cdot student^{-1} \cdot year^{-1}$ (junior high school)			
		1,890 to 3,987 (OE)	$MJ \cdot student^{-1} \cdot year^{-1}$ (senior high school)			
		75 to 161.2 (EE)	$MJ \cdot student^{-1} \cdot year^{-1}$			
4.2	Pre-primary education	587 to 1,404 (OE) 75 to 161.2 (EE)	$MJ \cdot student^{-1} \cdot year^{-1}$	Based on the elementary schools EI (Low)	[57-59] (High)	Medium
4.3	Tertiary education	2,880 to 10,800 (OE) 576 to 2,160 (EE)	$MJ \cdot student^{-1} \cdot year^{-1}$	Based on studies in Taiwan and the US (Medium)	[57, 60, 61] (High)	High
5.b	Access to mobile phone	2.86 to 6.67	$MJ \cdot cap^{-1} \cdot year^{-1}$	Mobile phone batteries are recharged every 21 to 49 hours on average (High)	[62] (High)	Very high
6.1	Access to drinking water	64.8 to 119.52	$MJ \cdot cap^{-1} \cdot year^{-1}$	Based on studies in China and India (Medium)	[63, 64] (High)	High
6.3	Water quality	2.16 to 13.68	$MJ \cdot cap^{-1} \cdot year^{-1}$	Based on studies in China and India (Medium)	[64, 65] (High)	High

SDG targets	Descriptions	Energy demand	Units	Assumptions (confidence)	Data and references (confidence)	Overall Confidence
7.1	Access to energy	Tier 3: 328.5 to 1,125	MJ·cap^{-1}·year^{-1} (electricity)	Based on the World Bank framework for energy access; Tier 3 is adopted; 4 persons per household (Medium)	[26, 66, 67] (High)	High
		996 to 1,674.72	MJ·cap^{-1}·year^{-1} (cooking)	Based on the IEA and World Bank recommendation (Medium)		
7.2	Renewable energy share	The target does not change the final energy consumption				
7.3	Energy efficiency	-6,867 to 0	MJ·cap^{-1} in 2030	The targets are calculated together; the annual EI and GDP growths under the BAU are the same as those of the past; the primary to final energy conversion factor is 70% by 2030. (Medium)	[22, 68-70] (High)	High
8.1	Sustainable economic growth	53,704 to 60,570	MJ·cap^{-1} in 2030 (this is the overall demand calculated together with Target 7.3. See the discussion section)			
9.1.1	Access to road	3.3 to 11.7	10^6 MJ·km^{-1}	This indicator is under development; the figures are based on studies in European countries. (Medium)	[71-74] (Medium)	Medium
9.1.2	Transportation infrastructure	Rail pass.: 0.38 to 0.98 Bus: 1.19 to 1.3	MJ·pass-km^{-1}	They are based on studies in Germany; calculating energy requirement is possible as long as the targets are set in MJ·pass-km^{-1} and MJ·ton-km^{-1} and the EIs are known. (Medium)	[75] (Medium)	Medium
		Rail freight: 0.35 Road freight: 1.38	MJ·ton-km^{-1}			
9.c	Access to ICT	LTE (4G): 567.65 WiMAX: 851.47 HSPA (3G): 2,144.45	MJ·user^{-1}·year^{-1}	300 mobile network users/km^2; nonstop operation of 8760 h/year. (Medium)	[76] (High)	High
11.1	Access to housing	864 to 1,046 (EE)	MJ·cap^{-1}·year^{-1}	Based on a test case study on Indian housing practices; floor area of 10 m^2/person; the OE is covered by Target 7.1. (Medium)	[77, 78] (High)	High

SDG targets	Descriptions	Energy demand	Units	Assumptions (confidence)	Data and references (confidence)	Overall Confidence
11.2	Access to public transport	0 to 0.59	$MJ \cdot pass\text{-}km^{-1}$	Busses are to represent public transport (PT); the average EI is based on studies in low-income cities; the EI to upgrade to the convenience level is twice the EI of the inconvenience PT (Low)	[79, 80] (Medium)	Low
11.6	Solid waste management	529.75 to 537.88	$MJ \cdot cap^{-1} \cdot year^{-1}$	Based on a study in Austria (Medium)	[81] (High)	High
12.3	Food waste & losses	256.5 to 357.75	$MJ \cdot cap^{-1} \cdot year^{-1}$	Consider only food losses; data of the developing countries. (Medium)	[48, 82, 83] (Medium)	Medium
12.5	Waste reduction	-1,001 to -1,053	$MJ \cdot cap^{-1} \cdot year^{-1}$	Industrial waste is not considered; based on a study in Austria (Medium)	[81, 84] (High)	High
13.1	Resilience to disasters	722.5 to 1,983.63	$MJ \cdot cap^{-1} \cdot year^{-1}$	Based on a study in Turkey; 70% primary to final energy conversion factor. (Medium)	[85] (High)	High
17.6	Access to science	283.82 to 346.9	$MJ \cdot customer^{-1} \cdot year^{-1}$	Nonstop operational hours of 8760 h/year; shared passive optical network (PON) connection serving an access rate of 25 Mbps (Medium)	[86] (High)	High
17.8	Access to internet	0.26 to 2,295	$MJ \cdot user^{-1} \cdot year^{-1}$	1-620 minutes/day internet use; internet access using laptop or desktop computers (High)	[87, 88] (High)	Very high

Twenty-two targets, sharing the same unit, are comparable. Targets 8.1, 9.1, and 11.2 are excluded for the reasons previously explained: calculated together with another target (Target 8.1), weak indicator and insufficient data (Targets 9.1 and 11.2). Figure 2 illustrates targets associated with high and low energy demand and reduction potential. Mainstreaming Target 4.3 (access to tertiary education) will consume energy the most per person. On the other hand, providing access to mobile phones (Target 5.b), clean water (Targets 6.1 and 6.3) and internet (Target 17.8, should be combined with Target 17.6, however) require relatively a minimal amount of energy. In contrast, successful implementation of Target 7.3 (energy efficiency) will reduce energy demand dramatically considering that its high energy reduction potential per capita will be multiplied by the whole population. Indeed, a study comparing the effects of Targets 7.1 (providing clean energy access) and 7.3 on the residential sector energy demand in Indonesia shows that energy efficiency measures may cancel out the additional energy required to ensure clean energy access for everyone [89].

Targets 2.1 (food access) seems to consume less energy per person than Target 2.3 (small farmers productivity). The upper limits of $E_{2.1}$ and $E_{2.3}$ are approximately 514.65 $MJ{\cdot}cap^{-1}{\cdot}year^{-1}$ and 2,334 $GJ{\cdot}farmer^{-1}{\cdot}year^{-1}$, respectively. However, $E_{2.3}$ is the energy demand per farmer to produce food. Considering land possession of only 0.23 ha per farmer (subsection 5.2) and a modest corn production of 1721 kg/ha [90], each farmer will produce around 396 kg of corn per year, which is enough to feed eleven undernourished people (Target 2.1) whose annual food deficit is equivalent to 34 kg of cooked corn per capita (calculated from subsection 5.2). In order to ensure more food for everyone, addressing Target 2.3 may require less energy per capita than Target 2.1.

Similarly, addressing Target 12.3 (halving food losses) will potentially consume less energy per capita than implementing Target 2.1 if the objective is to provide more food. Successful endeavors in halving the food losses in Sub-Saharan Africa, for instance, may save about 79.5 $kg{\cdot}cap^{-1}{\cdot}year^{-1}$ of food (sub-section 5.11). Meanwhile, addressing food deficit in the region (Target 2.1) may produce only about 49.9 $kg{\cdot}cap^{-1}{\cdot}year^{-1}$ of food. In other words, consuming a comparable amount of energy, Target 12.3 may save more food than Target 2.1 can produce.

In the energy perspective, (developing) countries can start with Targets 6.1 (clean water access), 6.3 (water quality improvement), 2.3 (small farmers production), 12.3 (food losses reduction), 2.4 (sustainable food production systems), 3.8 (health care access), 7.1, 72, and 7.3 (energy access, shares, and efficiency), 4.2 (preschool education), 4.1 (primary and secondary education), 5.b, 9.c, 17.6 and 17.8 (communication and internet infrastructure and access), 11.6 and 12.5 (solid waste management and recycling). Consuming relatively more energy per capita, the rest of the targets will be the next priority.

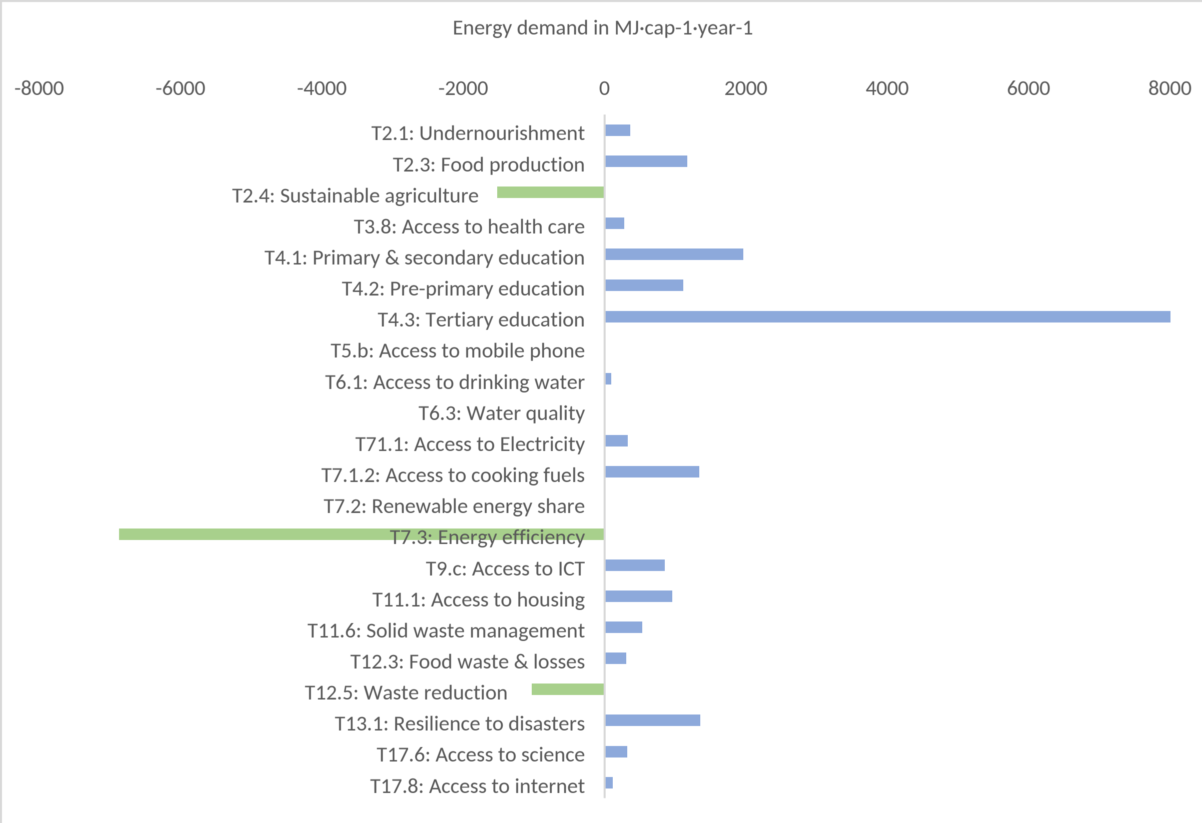

Figure 2. Additional energy requirement under the SDGs regime. Blue and green bars indicate energy demand and reduction potential, respectively.

Source: Authors' illustration
Print preference: color
2-column fitting image

Using the interlinkages map of SDGs targets with first-order connections to energy, this paper has developed a framework to quantify additional energy requirement (compared to business-as-usual) per unit of activities for the interlinked 25 targets. A set of examples have been proposed that can be used by national policymakers to estimate the energy requirement for a country using their country-specific data into these equations.

To illustrate how this process will work at a national level, we provide two examples below. Ending hunger in a developing country such as Indonesia means more energy demand to produce enough food for nearly 20 million people who were undernourished in 2015 [91]. We merely assume that the food supply at the time was not enough to satisfy demand, and the deficit will be produced domestically. With a depth of food deficit of 51 kcal·cap^{-1}·day^{-1} during the same year [18], the total food deficit in Indonesia was about 365,232 Gcal. According to the Ministry of Agriculture, Indonesian diets mostly lack meats, roots and tubers, and fruits and vegetables [92, 93]. The caloric requirements of meats for a balanced diet is twice as much as that of roots and tubers or fruits and vegetables [93]. For simplicity, meats, roots and tubers, and fruit and vegetables are converted to equivalent amounts of poultry, potatoes, and tomatoes, respectively. Using a similar procedure for Target 2.1, our calculation reveals that approximately 11.76 PJ of additional energy will be needed to produce enough food for everyone in Indonesia by 2030. It equates to an energy intensity of 599.5 MJ·cap^{-1}·year^{-1}, slightly higher than the global $EI_{2.1}$ of 514.65 MJ·cap^{-1}·year^{-1} estimated in section 5. The difference is related to the use of more detailed data specific to Indonesia including the depth of food deficit (51 vs. 90.25 kcal·cap^{-1}·day^{-1}) and the food assumed to cover the deficit.

Another example can be taken from Target 4.1 about universal education access for all girls and boys. The minimum elementary school's floor to student ratio in Indonesia, according to the Ministry of National Education Regulation No. 24/2007, is 3.3 m^2/student. The intensity of energy consumption of efficient government office buildings (without air conditioning) in Indonesia is expected to be 5.6 $kWh \cdot m^{-2} \cdot month^{-1}$ or less, which is based on the Ministry of Energy and Mineral Resources Regulation No 13/2012. Therefore, energy consumption should be approximately 221.76 $kWh \cdot student^{-1} \cdot year^{-1}$ or 798.33 $MJ \cdot student^{-1} \cdot year^{-1}$. It is lower than the average consumption of 1,040 $MJ \cdot student^{-1} \cdot year^{-1}$ shown in subsection 5.4. The difference is partly due to the assumption of building without air conditioning that we chose. Assuming energy consumption of 8.5 $kWh \cdot m^{-2} \cdot month^{-1}$ regulated for air-conditioned government buildings, we found that the energy consumption will be 1,212 $MJ \cdot student^{-1} \cdot year^{-1}$, which is now higher than the average figure. These two examples demonstrate that choosing the right assumption is a key to accurate estimation.

Some quantification figures are directly adopted from scientific studies, such as Target 5.b (access to mobile phones for women). Daily energy requirement to charge batteries for smartphones of normal uses can be assumed similar globally. For some other targets, we lack data, as in Target 6.1 (access to clean water). In this case, we select figures provided by studies conducted in India and China. The energy required to produce a cubic meter clean water is comparable: 0.29 kWh in China [63] and 0.3 kWh in India [64]. Interestingly, when they are converted to per capita consumption, the energy requirement differs significantly: 33.2 and 18 $kWh \cdot cap^{-1} \cdot year^{-1}$ in China and India, respectively [63, 64]. The difference is mainly due to the per capita water consumption contrast between China and India.

Some overlapping or double counting might be inevitable. For instance, providing Tier 2, or higher, electricity access to a house (Target 7.1) surely will include an assumption of electricity consumption of 200 $Wh \cdot day^{-1} \cdot household^{-1}$, or higher, for lighting, television, fan, and phone charging. Target 7.1 will cover Target 5.b (access to mobile phones for everyone) for households provided with electricity access during the 2015-2030 period. However, for houses electrified before the SDGs implementation, adding mobile phones to them will require additional energy. Similarly, doubling the productivity of small farmers (Target 2.3) and halving the food waste and losses (Target 12.3) will add and save more food to feed the undernourished people (Target 2.1). However, it will be true if undernourishment is related to the issue of food availability, but not affordability.

On the other hand, sustaining the global GDP growth (Target 8.1) only (without combining it with Target 7.3) should not be considered as an ambitious target. Maintaining something that has already been achieved is just doing business as usual. Therefore, the energy equivalence of Target 8.1 ($E_{8.1}$) is the total energy demand under the BAU. The total energy demand under the SDGs regime is the energy demand associated with the combination of Targets 8.1 and 7.3 ($E_{8.1+7.3}$), which will be lower than $E_{8.1}$.

Our suggestion is to consider the energy equivalence of Target 8.1, together with Target 7.3 (doubling the global energy efficiency), as a benchmark for local/national energy consumption. As stated in subsection 5.8, the energy consumption benchmark will be

$$\mathrm{E}_{8.1\,+\,7.3} = \mathrm{EI}_{7.3} \cdot \mathrm{GDP}_{8.1}$$

It means that the global average energy consumption in 2030 under the SDGs scenario should not be higher than 76,719 $MJ \cdot cap^{-1} \cdot year^{-1}$ of primary energy or 53,704 $MJ \cdot cap^{-1} \cdot year^{-1}$ of final energy (sub-section 5.8). Therefore, $\mathrm{E}_{8.1}$ and $\mathrm{E}_{8.1+7.3}$ should not be added with the energy demand of the other targets when estimating the additional energy requirement under the SDGs regime.

We also recommend that the primary energy consumption benchmark of 76,719 $MJ \cdot cap^{-1} \cdot year^{-1}$ will be one of the prioritized SDG targets for the developed nations in order to reduce emissions and inequality among countries. The average primary energy consumption in the high-income countries was 192,765 MJ/cap in 2015 [94], more than 2.5 times the proposed benchmark. Meanwhile, the average primary energy consumption in the low and middle-income countries was only 55,467 MJ/cap in 2014 [94]. It is consistent with Steinberger and Roberts' findings [4] suggesting that energy requirements associated with high human development decrease over time and, beyond 2010, high human development is attainable with primary energy consumption of less than 70,000 MJ/cap. The benchmark is higher than the 2000-watt society target [28]. The energy consumption target of the society is 2000 W/cap, in which 2000 W equals 2 kWh/h or 63,072 MJ/year.

7. Conclusions

The analysis of interlinkages between energy and SDG targets revealed a complex interaction involving synergies and trade-offs that would significantly impact future energy scenarios at national and local levels. This paper developed a process to estimate the additional energy demand to be anticipated and its consequences to the energy supply side in comparison to the baseline scenario, which is essential to forecast local/national energy demand under the SDGs scenario. Consequently, it bridged the gap between the wide recognition in the scientific community about the need to incorporating the impacts of SDG targets on energy due to interlinkages and the lack of a mechanism on how to practically estimate the changes in energy demand in response to the interlinkages. It has been done by quantifying energy demand for each of the identified direct links and developing a universal computation method to allow estimation at a national level. While three targets would contribute to the reduction in energy demand, the net demand has been found to be positive.

This study suggests that policymakers can no longer work in silos and develop energy plans based on assumptions from the energy sector only and try to achieve SDG 7, but they also need to incorporate the additional energy demand that would be necessary to accomplish other SDGs. Each country has different starting points and priorities that make the implementation of the SDGs in local and national development planning unique for that country. Therefore, different goals, targets, and priorities need to be set to match national resources and capabilities. We suggest that policymakers first work with representatives from all sectors and identify target levels of these 25 SDG targets and then use the methods to estimate additional energy demand required to achieve those targets. The results then can be added to the baseline energy demand to obtain an SDG-responsive energy scenario.

The breadth of interconnection found in this paper as well as in other literature is highly complex and has multi-dimensional linkages. As the first research of its kind and due to the lack of sufficient data, this paper has considered only the first-order connections. We recommend that further research is carried out to extend this framework to enable incorporation of subsequent orders of linkages. We also recommend further research to incorporate the Nationally Determined Contributions (NDCs) under the Paris Agreement into this framework to capture the emission reduction targets and appropriately cover the supply side of the energy planning.

8. References

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Appendix A

Energy links with other SDGs and evidence	**Remarks**
SDG 1. End poverty in all its forms everywhere **Evidence:** [1-4]	Economic growth, which is vital in ending poverty, is enabled by energy because energy along with labor and capital are essential for production [1]. Energy together with water and food are essential for human welfare and poverty reduction [2]. The Oxford Poverty and Human Development Initiative proposes three dimensions of poverty, which are health, education, and standard of living [3, 4]. Ten indicators are used to measure them: Child mortality and nutrition (measures health); years of schooling and child school attendance (education); and electricity, drinking water, sanitation, flooring, cooking fuel, and asset (standard of living). Electricity and cooking fuel are two indicators, among others, used to measure poverty. Electricity also enables the supply of drinking water and improves sanitation, health, and education.
SDG 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture **Evidence:** [2, 5-8]	Energy is used in every aspect of food production, from cropping, livestock and fisheries production, processing, distribution, retail, preparation to cooking. The United Nation Food and Agriculture Organization [5] estimated that the food sector share in global final energy demand was about 32% in 2011. The more food is produced, the more energy is required. For example, Smil [6] compared US corn production in 1945 and 2007 and found that the fourfold increase in corn yield in 2007 needed three times more energy. This situation makes food production susceptible to energy price fluctuation [2].
SDG 3. Ensure healthy lives and promote well-being for all at all ages **Evidence:** [9-14]	In the health sector, electricity provides significant improvement to public health and well-being in general. It provides heat and light and controls room temperature for comfort, cools refrigerators for a better quality food and vaccine storage, powers pumps to deliver clean water, and supplies power to operate health devices. On the other hand, for the 1.2 billion people without electricity and the 2.7 billion people still cooking with solid biomass [9], the health risks are high, especially those caused by prolonged exposure to indoor air pollution [10]. The pollution generated by the burning of solid fuels usually affect women and children the most and is comparable to smoking two packs of cigarettes a day [11]. Ensuring access to clean cooking energy will significantly reduce indoor air pollution, thereby decreasing deaths in children due to respiratory infections, as well as provide cooked food and boiled water for healthier families [12].
SDG 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all **Evidence:** [15-23]	Energy is vital for equitable education and boosting opportunities for lifetime learning. For example, there is a high correlation between the electrification and literacy rates of children above six years old in India, as reported by Kanagawa and Nakata [15]. A study in north-western Madagascar confirms that electricity access allows children to study more hours in the evening, and provides free time for girls to study, replacing time otherwise spent helping mothers with house chores [16]. The UNESCO Institute for Statistics estimates that, globally, more than 61 million children of primary school age were out of school in 2015 [17]. Therefore, providing equitable quality education for all, from pre-primary to secondary education means more than a million new classrooms will still be needed globally, and more energy should be generated to build, operate and maintain them.
SDG 5. Achieve gender equality and empower all women and girls	Energy can provide meaningful gender benefits [24]. Lack of energy access affects women severely more than men [25]. It has negative consequences on health due to indoor air pollution [11], as previously described in the discussion about the relationship between energy and health. Studies in India and

Evidence: [11, 16, 24-27]	Madagascar have shown that school girls spend more time collecting solid fuels and less time studying, or fewer opportunities of receiving study help from mothers [16, 26]
SDG 6. Ensure availability and sustainable management of water and sanitation for all **Evidence:** [9, 28-33]	Energy and water nexus studies suggest that energy and water depend on each other. Energy needs water in each stage of its production: for power generation, irrigation of agriculture for biofuels, and fossil fuel production and distribution [28]. Conversely, the water sector needs energy, e.g., for water distribution, desalination, and wastewater processing [9]. The role of energy in ensuring availability and sustainable management of water and sanitation for all is quite straightforward. Universal access to safe drinking water (Target 6.1) will not be achieved without energy access. In fact, with 1.8 billion people globally using contaminated drinking-water sources [29], a tremendous amount of energy will be needed to achieve the target.
SDG 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all **Evidence:** [34-44]	The relationship between energy and economic growth has been studied since the 1970's [34-37], yet results are mixed and conflicting [38-41]. Some studies show a bi-directional causal relationship between energy consumption and economic growth (known as feedback hypothesis), other studies show unidirectional causality from energy consumption to economic growth (growth hypothesis) or otherwise from economic growth to energy use (conservation hypothesis), the rest show no causality between them (neutrality hypothesis). For example, an international literature survey on the nexus examining 48 studies indicates that growth, feedback, conservation, and neutrality hypotheses are supported by 29%, 27%, 23%, and 21% of the studies, respectively [41]. Another meta-analysis study assessing the causal relationship between renewable energy consumption and economic growth shows similar results [35]. The study reveals that 18 studies published in 2013 alone offer 24, 21, 16, and 14 observations supporting feedback, growth, neutrality, and conservation hypotheses, respectively. Mixed results are also observed in the study by Bhattacharya, et al. [42], which examines the top 38 renewable energy consuming countries. Inconclusive and conflicting results imply that policies should be designed carefully, case by case. Bidirectional/feedback and growth causalities indicate that reduction in energy consumption (energy conservation) may limit economic growth. On the contrary, conservation and neutrality hypotheses suggest that energy conservation can be implemented without significant impact on economic growth. Some authors recommend the development of a new and more robust methodology to avoid these mixed results [35, 41, 43]. In our analysis, we intuitively assume that sustaining economic growth requires more energy unless it is explicitly stated that the country being assessed has successfully decoupled energy use from economic growth.
SDG 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation **Evidence:** [45-58]	In energy economics, energy demand is usually expressed as a function of income, urbanization, and industrialization [45-48]. Others employ the STIRPAT model of Dietz and Rosa [49], which is a reformulation of the IPAT model of Ehrlich and Holdren [50]. They suggest that energy demand correlates with population size, GDP (affluence), industrialization, urbanization, energy intensity, and specific effects of countries and time [51, 52]. In both models, industrialization and urbanization are significant predictors of energy consumption. Industrialization and urbanization are considered as human relocation from farming to manufacturing jobs and from villages to cities [51]. They require extensive infrastructure development for housing, transportation, communication, etc., which in turn demand a massive amount of energy.

SDG 10. Reduce inequality within and among countries **Evidence:** [59]	The role of energy in decreasing inequality within and among countries is not a popular topic for analysis in the scientific literature. Pitt [59] examined the effect of kerosene subsidy on social equity (as kerosene was considered a basic need and thereby should be made affordable to the poor) and found that the benefit was unevenly distributed. Urban households, which were only 18.5% of the total households in 1978, enjoyed 36.8% of the subsidy or about 250% higher than the subsidy for rural families. Examination of the goal in its target level shows that most targets are policy/regulatory targets that have no direct links to energy. Others have been covered by targets in other goals. Therefore, we disregard the link between energy and SDG 10.
SDG 11. Make cities and human settlements inclusive, safe, resilient and sustainable **Evidence:** [44, 60-72]	Energy is fundamental to cities and urban development. Indeed, urban areas consumed about 64% of global primary energy in 2013, mostly for power generation, industries, buildings, and transportation [60]. Furthermore, in a country like China, urban areas account for 84% of total energy consumption [61]. There is increasing concern about urban energy demand as it intensifies, along with the expanding trend of urbanization globally [62]. According to IEA [60], some components shape urban energy systems: affluence, population density, building stock and infrastructure age, land availability, economic structure, and climate. Furthermore, most household energy consumption is related to dwellings and transport energy [63]. Therefore, energy is required to provide adequate housing, basic services, and safe transport systems.
SDG 12. Ensure sustainable consumption and production patterns **Evidence:** [5, 6, 65, 73, 74]	Sustainable consumption and production (SCP) are effective ways to consume and create products and services to reduce resource use and environmental impacts. It implies that the link between energy and SPC is direct through increased efficiency in their production and indirect through reduced products and services consumption as energy is embedded in the production processes of goods and services.
SDG 13. Take urgent action to combat climate change and its impacts **Evidence:** [75-77]	There is a strong relationship between energy and climate change. The energy sector contributes around two-thirds of total GHG emissions, which are associated with climate change [75]. Additionally, on reviewing the literature on UK policies, Lovell, et al. [76] observe that climate change is viewed as energy supply, energy demand, (carbon) market-efficiency, and international problems by policy actors.
SDG 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development **Evidence:** [78, 79]	The ocean helps to reduce the impact of climate change by absorbing CO_2 from the atmosphere. However, this makes the ocean more acid in the process [78]. The situation may, in turn, disturb the calcification of corals and plankton. However, research on the impact of ocean acidification on marine life is only at the beginning of gaining a full understanding of the phenomenon [79]. It is difficult to quantify the relationship between energy demand and the targets of SDG 14 or to find justification on how energy planning should be designed in response to actions taken to achieve them. Therefore, we have omitted the link between them.
SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	The link between energy and terrestrial ecosystems is notable in the relationship between wood fuels and deforestation in developing countries, especially in energy poverty regions. In Brazil, for example, fuelwood contributes to deforestation together with other factors such as land clearing for agriculture [80]. Much earlier in Malawi, to meet the demand for fuelwood in 1990, deforestation was predicted as unavoidable [81]. However, Leach [82] refutes this widespread perception. He argues that the notion is based on a supply-demand projection which applies a wrong logic. Usually, the fuelwood demand of a country is compared with its forests' tree stock, mostly ignoring

Evidence: [80-83]	the fact that most rural solid fuel demand comes from animal wastes, crop residues, dead trees and branches, and farm trees. The gap between the projection of supply and demand creates an apparent wood fuel crisis, which is perceived to accelerate deforestation [83]. The global energy goal of ensuring access to affordable, reliable, sustainable and modern energy for all (SDG 7) hopefully will substitute fuelwood with other clean fuels and settle the dispute. An assessment of the targets of SDG 15 shows that they are mostly about land management and regulatory targets with no strong links to energy demand.
SDG 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels **Evidence:** [84, 85]	The link between energy and SDG 16 manifests itself in energy justice. With 2.7 billion people still cooking with traditional biofuels and 1.2 billion people left in the dark without electricity [84], the world energy distribution is vastly unjust [85]. However, a close review of the targets of SDG 16 shows that there are no direct links between energy demand and the targets, since most targets belong to social, institutional, and regulatory targets.
SDG 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development **Evidence:** [86-88]	The link comes from two indicators of SDG 17 that measure internet broadband subscriptions and the proportion of individuals using the internet. Providing internet services requires energy.

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