Elsevier Editorial System(tm) for Journal of Cleaner Production
Manuscript Draft

Manuscript Number: JCLEPRO-D-19-12281R2

Title: An analysis of additional energy requirement to meet the Sustainable Development Goals

Article Type: Original article

Keywords: Sustainability Development Goals; Climate Change; Energy Demand Analysis; Energy Policy; Chile

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Abstract: United Nations' members came together in 2015 and agreed on seventeen sustainable development goals which include hundred and sixty-nine targets related to sustainable development into the overall economic, environmental and social contexts of countries to be achieved by 2030. In order to achieve these goals, more effort may be required than the current policies and strategies. This is particularly true for the energy sector as energy is the key enabler for all development activities. Therefore, there is a need to analyse the required effort and energy to implement these goals based on countries´ specific context. The objective of this paper is to assess the indicators of energy-related sustainable development goals and calculate the additional energy requirement to achieve each goal by 2030 for Chile. The key findings of the research indicate that Chile will meet fourteen energy-related sustainable development targets by 2030 under the business as usual scenario. However, Target 2.1, Target 5.b, Target 12.3, Target 13.1, and Target 17.6 require extra energy to meet sustainable development goals in Chile by 2030. Approximately 16 million GJ additional energy is required in order to meet energy-related sustainable development goals in Chile than the business as usual scenario by 2030. This research output can provide insights to researchers trying to assess the achievement of sustainable development goals in other developing countries.

Detailed responses to reviewers

Paper “An analysis of additional energy requirement to meet the Sustainable Development Goals”

Journal: Journal of Cleaner Production

By: Yeliz Simsek, Wayan G. Santika, M. Anisuzzaman, Tania Urmee, Parisa A. Bahri, Rodrigo Escobar

Date: April 2020

Dear Editor and Reviewer,

Thanks for all your valuable comments and suggestions to help us to improve the quality of our paper. We have considered all your comments and carried out the according to changes in the paper. With the help of all suggestions and comments, a new version of manuscript was prepared carefully. The main changes and improvements are mentioned in detail in the following section.

We thank the editor and reviewers for helping us advancing and updating this study.
In the following parts of this report, comment of reviewer and our detailed answer for each comment can be found.
Best regards,
Dr Yeliz Simsek

Goal and structure of this report

This report includes the comments of editor and two reviewers of *Journal of Cleaner Production* regarding the manuscript *"An analysis of additional energy requirement to meet the Sustainable Development Goals"* and answer of authors for each comment/suggestion. Thanks for all appreciated suggestions to help us to improve the quality of our paper. We considered all comments and reorganized our work. With the help of all suggestions and comments, the new version of manuscript was formulated carefully. The main changes and improvements are as follows:

Reviewer #: (2nd revision)	**Response to Reviewer:**
The discussion is still very weak. This section should explore and discuss the main findings with other international similar works (used in section 1) Please ensure that all relevant statements within this section (and in the entire paper) contain supporting references to build on the existing literature.	**In order to make discussion section stronger, the following changes are realized:** **1) More information is added to Introduction (Section 1) to make better connection between findings and current literature.** **2) The results and discussion sections are separated from each other to make the main findings and discussion section more comprehensive in the manuscript.** **3) The results and discussion section are formed to explore the main findings with other similar studies. And the statements are supported with relevant references.**
	Revision in Introduction - Section 1. **The following information is added to introduction Section 1 to make comparison between calculated energy demand results and Chilean government's demand prediction.** *".....Additionally, there are some recently published studies related to power generation and electricity expansion planning for Chile (O'Ryan et al., 2020; Quiroga et al., 2019; Ramirez Camargo et al., 2019;*

	Rodríguez-Monroy et al., 2018; Verastegui et al., 2019). However, there are no published researches about Chile on demand forecasting and the energy demand analysis of sustainable development goals. Energy demand projection for Chile is only available at Chilean government´s reports. Depending on the low, medium and high demand projection, the report indicated that energy demand in Chile would vary between 1,440-1,675 million GJ by 2030 (Ministerio de Energía, 2017).” **Additionally, the following information is added to introduction Section 1 to make comparison between similar researches and the results of our study.** *"…In the literature, energy is mostly emphasized with SDG 7 as mentioned above, and studies analyzing energy-related goals or calculating energy demand due to achieving these targets for developing countries are limited. For instance, Santika et al. studied extra demand for sustainable development goals and compared the results with the energy demand of the current policy scenario for Indonesia. According to the main results, current policy scenario requires more energy than SDG scenario in Indonesia (Santika et al., 2020)..”*
	Revision in Results - Section 3. **In the results section, (Section 3), the calculated energy demand of BAU and benchmarking are compared to Chilean governments demand forecasting values mentioned in the introduction (Section 1).** *"…Based on the available national energy balance reports for Chile between 2008 and 2015 (Comision Nacional de Energia, 2019), the growth rate of energy demand is calculated as 1.394% per year and it is used to estimate energy demand for 2020, 2025 and 2030 business as usual (BAU) scenarios. Total energy demand for BAU 2030 is calculated as 1,447.03 million GJ which is obtained as a close value to low*

	energy demand projection of Chilean government for 2030 (mentioned in Section 1) (Ministerio de Energía, 2017). Also, due to approximately 16 million GJ additional energy requirement, energy demand for 2030 SDGs was obtained as 1,463.08 million GJ. *In addition to BAU and SDGs scenarios, Target 7.3 and 8.1. are taken into account for benchmarking. When the global energy intensity target (3.422 MJ/2011 PPP GDP) is considered, the total energy demand for Chile is calculated as 1,618.87 million GJ by 2030, which is within the demand values estimated by the Chilean government (mentioned in Section 1) (Ministerio de Energía, 2017)….”*
	Revision in Discussion Section 4. **The first paragraph of the discussion section, targets which required high energy demand are discussed, these goals are associated with some studies in the literature and some suggestions are mentioned to reduce energy demand of these targets.** *“….The main findings showed that Target 12.3, which is about halving per capita global food waste by 2030, requires much more energy than other targets in Chile. In the analysis, the prevention of food losses calculation is assumed as a function of energy consumption for storing and retailing which are assumed 2 MJ/kg and 2.5 MJ/kg, respectively (Smil, 2008). Energy efficient technologies and the most appropriate renewable energy solutions for cold storage and refrigeration should be investigated to reduce the additional energy demand to meet this target for Chile as mentioned in the literature (Büyüközkan et al., 2018; Puig et al., 2018), which will also make contribution to meet SDG 7. Moreover, Target 13.1 needs a significant amount of energy to be met because Chile is one of the countries with the highest natural disaster potential in the world. In order to reduce the impact of disasters on national energy demand, countries under a highly vulnerable category like Chile must adopt disaster preventive actions besides post-disaster plans. The United Nations published Sendai framework to guide the multi-hazard*

	management of disaster risk by preventing new and reducing existing disaster risk (United Nations, 2015). The Chilean Government has also agreed on developing the National Platform for Disaster Risk Reduction under National Strategic Policy and Plan. Moreover, it was highlighted the importance of international cooperation to share good practices and disseminate learning and reiterated Chile's commitment to the Sendai Framework for Disaster Risk Reduction and its indissoluble link with sustainable development and climate change agendas (UNISDR, 2019)….." **In the second paragraph of discussion section, the benchmarking calculation is discussed. If the expected/calculated energy intensity value (3.058 MJ/2011 PPP GDP) is considered for Chile, instead of suggested global energy intensity target (3.422), the change of energy demand and supply is discussed.** *"…The benchmarking calculation mentioned in the result section is done by considering the suggested global energy intensity target (3.422) for 2030 (The World Bank, 2017). On the other hand, when energy intensity for 2030 is calculated based on the growth rate, it is obtained 3.058 MJ/2011 PPP GDP for Chile, which means that Chile will meet the global energy intensity target before 2030 (Figure 5). Table 2 compares the global and calculated energy intensity, total primary energy supply (TPES) and demand for Chile. When the calculated energy intensity value for Chile is considered, the total energy demand is obtained 1,446.67 million GJ, which is closer to BAU 2030 scenario. It means that if Chile achieves its calculated energy intensity target by 2030 instead of the global target, energy demand and supply will be less than the global target. Thus, Target 7.3 will be achieved by Chile due to having less or equal energy intensity to 3.422 MJ/2011 PPP $ by 2030.* ***Table 2.*** *The comparison of global and calculated energy intensity, TPES and demand for Chile..."*

	Also, again in discussion section, energy use per capita results for Chile SDG scenario and suggested global primary energy supply average value (73.08 GJ/cap) are compared. *"….Additionally, energy use per capita is calculated for Chile for 2015 and 2030 SDG scenario and presented in Table 3. Also, the results are compared to global primary energy supply average value (73.08 GJ/cap) which is assumed based on suggested global targets of 7.3 and 8.1 (Santika et al., 2020). The primary energy supply of Chile per capita showed 8.69 GJ/cap increase in fifteen years and reached 100.8 GJ/cap by 2030. It shows that by meeting SDG targets, Chile will consume much more energy than the expected global average of 73.08 GJ/cap. Chile needs to consider reducing per capita energy consumption by decoupling energy use from the economic growth, reducing the carbon intensity of energy, improving energy efficiency, and reducing energy demand by considering sectoral solutions such as having electric and more efficient vehicles in the transport sector, high efficiency in process technologies in industry and mining etc.* ***Table 3.*** *Comparisons of per capita energy use in Chile and suggested global targets…"* **Furthermore, a similar analysis which is realized for Indonesia is compared to Chile case study by presenting the additional energy requirement of Chile and Indonesia for each target.** *"…Moreover, in order to understand that Chile´s current situation to meet SDGs, a similar analysis which is realized for Indonesia (Santika et al., 2020) is compared to Chile case study. Table 4 shows the additional energy requirement of Chile and Indonesia for each target. The additional energy requirement to meet energy-related SDGs for Indonesia is calculated almost 474 million GJ when it is obtained approximately 16 million GJ for Chile. Both countries do not have a target to make agriculture more sustainable; therefore, Target 2.4 cannot be considered in both analyses. When Chile meets several targets as business as usual, Indonesia requires much more effort to meet energy-related sustainable*

	development goals by 2030. While Indonesia requires the highest extra energy (169 million GJ) to meet Target 9.1 which is about rural population access to roads, Chile achieves this target by business as usual in 2030. Also, the results showed that both countries must focus on halving food losses and require more energy to meet Target 12.3. It is interesting to obtain that only target which requires more energy for Chile than Indonesia is Target 13.1 which is about replacing affected people after the disaster. Due to having the highest natural disaster potential in the world, Chile requires three times more energy than Indonesia to achieve this target. *Table 4. The comparison of additional energy requirement/savings to meet energy-related SDGs for Chile and Indonesia…..”* **Finally, per capita energy use of Chile and Indonesia (SDG scenario) are compared to suggested global primary energy supply value (73.08 GJ/cap) (Santika et al., 2020).** *“……In order to make a more inclusive comparison, per capita energy use of Chile and Indonesia are compared for SDG scenario and presented in Table 5. Additional energy demand per capita to meet SDGs for Indonesia is obtained almost 1.8 times more than Chile because Indonesia requires much more effort to meet energy-related SDGs by 2030 (Santika et al., 2020). However, when the total demand and supply per capita by 2030 for SDG scenarios are considered, Chile is obtained approximately two times more than Indonesia. In 2030, Indonesia will have almost 31% less primary energy usage per capita than suggested global primary energy supply value (73.08 GJ/cap) when Chile will exceed global value with approximately 39%. Therefore, until 2030, when Chile needs to consider reducing per capita energy consumption, Indonesia should increase energy usage per capita.* ***Table 5.** Comparison of per capita energy usage in Chile and Indonesia for SDG scenario….”*

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An analysis of additional energy requirement to meet the Sustainable Development Goals

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Abstract

United Nations' members came together in 2015 and agreed on seventeen sustainable development goals which include hundred and sixty-nine targets related to sustainable development into the overall economic, environmental and social contexts of countries to be achieved by 2030. In order to achieve these goals, more effort may be required than the current policies and strategies. This is particularly true for the energy sector as energy is the key enabler for all development activities. Therefore, there is a need to analyse the required effort and energy to implement these goals based on countries´ specific context. The objective of this paper is to assess the indicators of energy-related sustainable development goals and calculate the additional energy requirement to achieve each goal by 2030 for Chile. The key findings of the research indicate that Chile will meet fourteen energy-related sustainable development targets by 2030 under the business as usual scenario. However, Target 2.1, Target 5.b, Target 12.3, Target 13.1, and Target 17.6 require extra energy to meet sustainable development goals in Chile by 2030. Approximately 16 million GJ additional energy is required in order to meet energy-related sustainable development goals in Chile than the business as usual scenario by 2030. This research output can provide insights to researchers trying to assess the achievement of sustainable development goals in other developing countries.

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Word count: 8348

An analysis of additional energy requirement to meet the Sustainable Development Goals

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1. Introduction

In 2015, 193 members of the United Nations (UN) agreed on the sustainable development goals (SDGs) by targeting to eliminate discrimination and inequality, end poverty, and overcome climate change by 2030 (United Nations, 2019a). The Sustainable Development Goals include 17 goals and 169 targets integrating matters related to sustainable development into the overall economic, environmental and social contexts of countries (Salvia et al., 2019). In order to reach sustainable development, these objectives must be measured and monitored. Therefore, the UN defined global indicators list to track the progress in each target (United Nations, 2019a). SDGs are universal targets; they are similarly applicable to all countries and must be assessed for both developing and developed countries. However, when an industrialized country focuses on SDGs related to climate change and renewable energy deployment in the energy sector, a developing country might give priority to different goals such as ending hunger, improve the health system and energy access. Thus, implementing SDGs requires different approaches for each country due to having distinct challenges (Gusmão Caiado et al., 2018).

Energy is a main empowering factor for the SDGs. Implementation of the SDGs into local and national development of long and medium-term planning is expected to affect the energy sectors, which means for some countries, much efforts and more energy will be required if a country attempts to achieve the SDGs (Santika et al., 2019). Thus, it is required to investigate the connection between the energy sector and implementation of SDGs.

Several studies were conducted based on SDGs since 2015 by developed and developing countries all around the world. Studies related to the energy sector and SDGs implementation in the literature are summarized as follows: Santika et al. studied the interconnections between energy and the SDGs. Twenty-four targets of SDGs which has direct links to energy were identified, and they are quantified to see their impact on national energy demand (Santika et al., 2019). Also, Mccollum et al. worked on energy-related interactions between SDGs by assessing the relation of SDG 7 and other SDGs to demonstrate how energy policy implementation can affect other sustainable development targets (Mccollum et al., 2018). The integrated multi-criteria decision-making analysis was realized to decide the most appropriate renewable energy source by addressing SDG 7. The most suitable renewable energy source was found as solar PV for Turkey to meet the SDG 7 (Büyüközkan et al., 2018). Srikanth worked on suggestions for the government of India to develop India's progress towards a low-carbon economy in parallel to the achieving SDG 7 target by recommending providing financial support to off-grid solar, wind and hybrid energy projects in the rural areas of India (Srikanth, 2018). The contribution of renewable energy deployment to achieve SDGs for African countries also exist in the literature. In the research, the link between renewable energy and 10 SDGs are studied, and it was discussed that renewable energy investments could have interaction impacts through many of the SDG (Schwerhoff and Sy, 2017). Furthermore, the renewable energy potential of Vietnam and its challenges were studied to achieve the nationally determined contribution and the Sustainable Development Goals by highlighting the importance of renewable energy promotion and the international collaboration in Vietnam (Chan and Sopian, 2018). In addition to renewable energy researches, studies including the contribution of SDGs to energy efficiency also exist in the literature. Alawneh et al. worked on the contribution of water and energy efficiency in buildings to achieve UN SDGs in Jordan by developing an integrated index for the assessment (Alawneh et al., 2018). Also, the contribution of energy-efficient buildings to meeting SDGs 11 and 13 is studied. By using empirical survey data, the drivers impacting the supply of and demand for energy efficiency measures were identified and categorized within four categories (Di Foggia, 2018). Finally, Puig et al. worked on the importance of energy efficiency improvements to meet the SDGs by analyzing six targets and discussing the reasons of energy efficiency relevance to achieve these targets (Puig et al., 2018).

In the literature, energy is mostly emphasized with SDG 7 as mentioned above, and studies analyzing energy-related goals or calculating energy demand due to achieving these targets for developing countries are limited. For instance, Santika et al. studied extra demand for sustainable development goals and compared the results with the energy demand of the current policy scenario for Indonesia. According to the main results, current policy scenario requires more energy than SDG scenario in Indonesia (Santika et al., 2020). Additionally, there are some recently published studies related to power generation and electricity expansion planning for Chile (O'Ryan et al., 2020; Quiroga et al., 2019; Ramirez Camargo et al., 2019; Rodríguez-Monroy et al., 2018; Verastegui et al., 2019). However, there are no published researches about Chile on demand forecasting and the energy demand analysis of sustainable development goals. Energy demand projection for Chile is only available at Chilean government´s reports. Depending on the low, medium and high demand projection, the report indicated that energy demand in Chile would vary between 1,440-1,675 million GJ by 2030 (Ministerio de Energía, 2017).

Therefore, there is a need to identify energy-related goals, analyze the indicators to see how far a country to achieve these goals and calculate the additional energy requirement or savings to implement these goals to national energy plans based on countries´ specific context. This study attempts to fill these gaps in the literature. The contributions of the study are 1) determining energy-related SDGs 2) realizing indicator-based assessment to understand the current situation of the targets in Chile, 3) calculating the additional energy requirement or savings for each target and 4) forecasting the total energy demand in case of meeting energy-related sustainable development goals. This paper aims to evaluate the indicators of energy-related SDGs, calculate the extra energy requirement or savings for each target and predict the total energy demand when an intervention is needed to meet the target for 2030 in Chile.

This paper is organized as follows. Section 1 contains the review of the energy and SDG related studies in the literature, the objective of the research, contribution to the literature, and content of the study. Section 2 presents the methodological approach followed in the research, including a literature review and database search, case study application, and analysis including indicator assessment and energy demand calculations for each target. Section 3 includes the main findings and results. Section 4 discusses case study Chile to achieve each target under relevant sustainable development goals and comparison to Indonesia. Finally, section 5 concludes the paper and includes suggestions for future research.

2. Methodology

The methodological approach of this research is presented in Figure 1. Four main steps are followed in the methodology as illustrated in the figure: 1) literature review and database search, 2) analysis, 3) case study application and 4) results comparison, discussion and conclusion. In the literature review and database search, energy-related SDGs and their indicators are obtained from the literature. Also, the method to quantify these goals and related data for Chile which is used to apply this approach in a case study are investigated from literature, international/national reports and databases. After that, analysis is conducted by realizing indicator assessment, energy intensity estimation and finally, additional energy requirement calculations for case study Chile. As a conclusion, energy demand calculation for business as usual, SDGs scenarios and benchmarking results are compared to conclude the research. The details of each step are explained in detail in the following sub-sections.

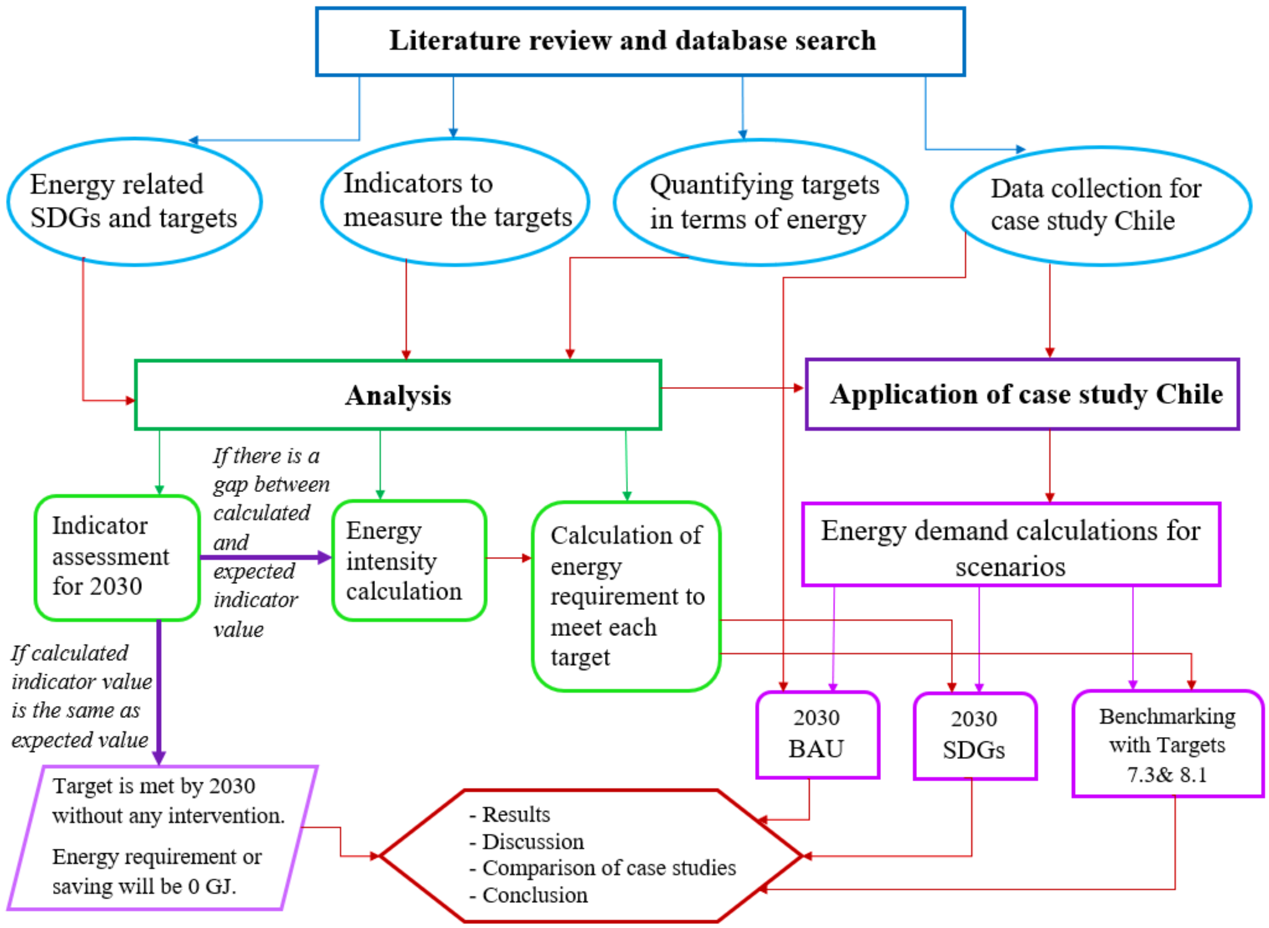

Figure 1. The methodological approach of the research

2.1. Literature review and database search

UN defined a list of the global indicators to measure the SDGs and their targets (United Nations, 2019b). By considering these indicators, "Measuring Distance to the SDG Targets" report was published by OECD to help member countries evaluate their current situation and to prioritise the areas where further effort is needed to achieve the SDGs. This measuring distance approach also provides a way for countries to comprehend their national implementation of SDG and challenges in a comparative framework (OECD, 2019).

The indicator-based assessment of SDGs may vary from developing country to a developed country. Therefore, the European Union defined a set of indicators to check member countries achievement on SDGs by considering new EU policy priorities, including EU longer-term visions beyond 2020 (EUROSTAT, 2019). Also, they developed a methodology to measure the indicator distance of current situation and future target, which takes into account the actual rate of change of the indicator based on the compound annual growth rate (CAGR) (European Commission, 2017). According to defined indicators and methodology, European Member States performance on SDGs are assessed into three categories: economic, environmental and social. In overall score, Sweden and Denmark had the best scores when Bulgaria and Romania resulted in the lowest scores between EU countries (Delli Paoli and Addeo, 2019). Besides the EU context, studies including indicator assessment for regions in the world (Moyer and Hedden, 2019) and Asian countries examples can be found in the literature (Huan et al., 2019).

The literature on the SDGs has been widely researched and several articles mentioned SDGs since 2015; however, studies about energy-related SDGs are still limited and only one specific study which worked on the targets with direct links to energy was found. Based on this reference, twelve sustainable development goals were found as having direct links to energy. Also, it mentioned how to quantify these energy-related goals for developing countries (Santika et al., 2019). Also, data availability and accuracy are of great importance for the assessment of these indicators, especially in developing countries (Shaaban and Scheffran, 2017). Global and local database searches are realized to collect information in order to apply this approach to a case study for Chile.

In this study, the indicators to measure energy-related goals and targets are determined from the literature review (OECD, 2019; Santika et al., 2019; The World Bank Group, 2017a; United Nations, 2019b). The indicators for all targets and related goals considered in this study are presented in Table 1. The chosen indicators are used to calculate the gap between the current situation and the targeted value for the year 2030, as suggested in EU SDG assessment methodology (European Commission, 2017). After determining energy-related goals and the indicator to measure the targets, quantification of targets to calculate the required energy to meet the goals by 2030 is obtained based on the studies in the literature. An approach with determining energy intensity for each indicator is taken into account to calculate the total required or saved energy to meet the target (Santika et al., 2019).

2.2. Application of case study

Figure 2 shows the 2019 Global SDG Index scores and ranking for the first 50 countries. Denmark has the best SDG scores with 85.2 in the world and followed by Sweden, Finland and France (Sachs et al., 2019). Although developed countries are seen at the top of the ranking list, it is interesting to see some developing countries are in the top fifty countries including Chile, Costa Rica, Moldova, and Ecuador. In this study, Chile, having a score of 75.6 and being 31st country in the SDG global ranking list (Sachs et al., 2019), is considered as a case study to show how to calculate the required energy to meet energy-related SDGs. Chile is chosen for being a developing country and having databases which are publicly available and easy to access. Global and country-wide databases were utilized to access and collect large data for the analysis.

Therefore, analysis including indicator-based assessment, energy intensity calculation and the total required energy or energy savings to meet each target is realized for Chile. Then, two scenarios and a benchmarking are considered to compare the results to see the impact of SDGs implementation on Chilean energy demand by 2030. Firstly, the energy demand of 2030 for business as usual scenario is calculated based on the available data from the national energy balance of Chile between 2008-2017. Then, energy demand for SDGs scenario is calculated by taking into account the additional energy requirement from each target. Finally, benchmarking which considers Targets 7.3. and 8.1. is mentioned to verify the total energy demand for 2030 and compared with two other scenarios. The detailed calculations are presented in the analysis the scenarios were compared in the result and discussion section.

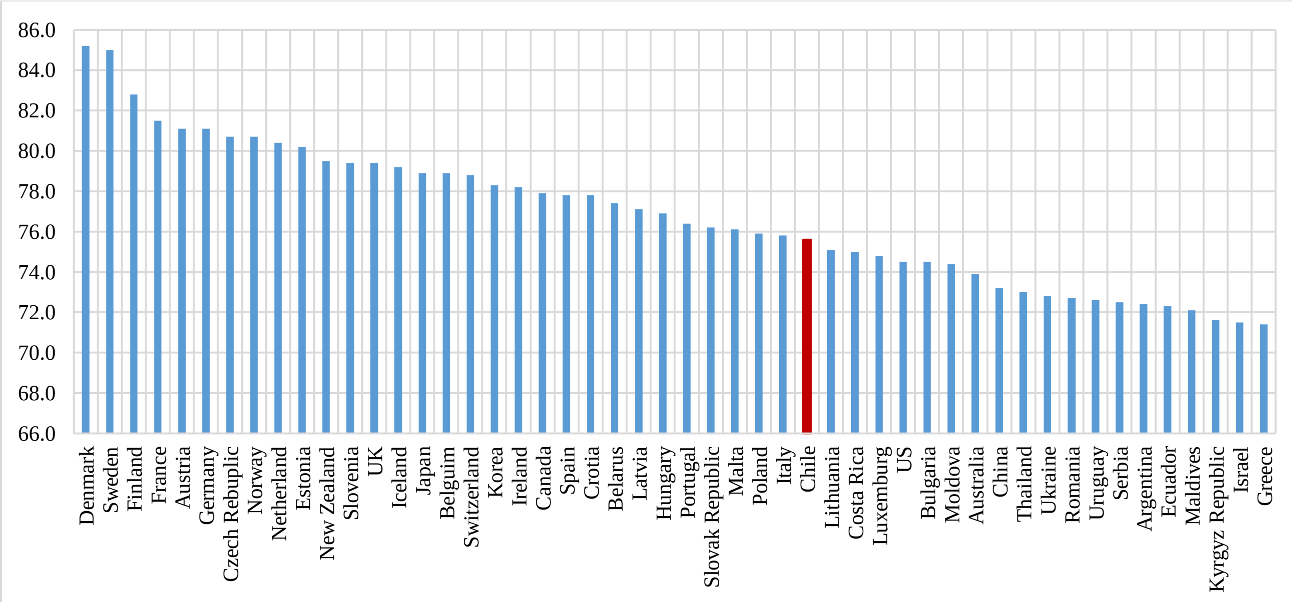

Figure 2. The Global SDG Index scores and ranking for the first 50 countries in 2018

Source: The figure was constructed based on reference (Sachs et al., 2019)

2.3. Analysis

The first step of the analysis is the assessment of the indicators for each target. The indicator-based assessment focuses on determining an expected evolution for each indicator, measuring the observed evolution of the indicator, and comparing the observed evolution versus the expected evolution (Allen et al., 2017). In order to measure this evolution, the compound annual growth rate (CAGR) is calculated as suggested in the literature. CAGR is a measure of the constant growth of a data series. The biggest advantage of the compound growth rate is that the metric takes into consideration the compounding effect. The metric smooths the historical data, omits the effect of volatility, and implies the steady growth of the data series (European Commission, 2017; Sachs et al., 2019).

Based on the available data for each indicator, CAGR is calculated from the equation (1) (European Commission, 2017; Sachs et al., 2019):

$$CAGR_{(calculated)} = \left(\frac{I\_value_{\_ending\ at\ T2}}{I\_value_{\_beginning\ at\ T1}}\right)^{\frac{1}{(T2-T1)}} - 1 \qquad (1)$$

$I\_value_{\_\text{beginning at T1}}$= The value for the indicator at year T1

$I\_value_{\_\text{ending at T2}}$= The value for the indicator at year T2

T1: the year for the beginning value

T2: the year for ending value

After obtaining the growth rate from equation (1), the indicator value for 2030 is calculated as presented in equation (2) (Teall and Hasan, 2002):

(BAU: Business as usual)

$$I\_value_{\_BAU} = I\_value_{\_ending\ at\ T2} * \left(1 + CAGR_{(calculated)}\right)^{2030-T2} \qquad (2)$$

$I\_value_{\_BAU}$= The calculated value for the indicator at 2030 based on the growth rate

Finally, the gap between the calculated indicator value (business as usual) and the expected value to meet the target is calculated from the equation (3) as follows (Allen et al., 2017):

$$I\_value_{\_Gap} = I\_value_{\_2030} - I\_value_{\_BAU} \qquad (3)$$

$I\_value_{\_Gap}$ = The gap between the calculated indicator value and expected value to meet the target

$I\_value_{\_2030}$ = The expected value for the indicator at 2030 to meet the target

If the calculated indicator value is the same as the expected value, it is assumed that the target is met by 2030 without any intervention. Thus, the additional energy requirement or saving will be 0 Gigajoule (GJ). On the other hand, if there is a gap between calculated and expected indicator value for 2030, energy calculation is realized for these targets. Therefore, energy intensity (EI) calculation for each target is obtained from the literature (Santika et al., 2019). EI for each target can be a global value or depends on the country context. Finally, the total required energy or energy savings to meet each target is calculated from the equation (4) by multiplying the energy intensity and indicator gap value as presented here (Santika et al., 2019):

$$E\_required\_total \text{ or } E\_total\_savings = EI * I\_value_{\_Gap} \qquad (4)$$

Additionally, in this section, indicator assessment by using equations (1), (2) and (3) and additional energy requirement calculation by using equation (4) are performed for each target. The assumptions and the approaches of the analyses were presented in Table 1. Moreover, due to the requirement of additional energy, the analysis of Target 2.1, Target 5.b, Target 12.3, Target 13.1, and Target 17.6 are explained in detail in this section. Finally, Target 7.3 and 8.1 are explained in this section to address benchmarking in the results and discussion section.

Goal 2_End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Target 2.1: By 2030, end hunger and ensure access by all people, in particular, the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round:

In order to assess Target 2.1, the indicator "*prevalence of undernourishment (% of the population)"* is considered (United Nations, 2019b). Based on the available data for Chile between 2000 and 2016, the prevalence of undernourishment is calculated by 2.41% of the population for 2030 as presented in Figure 3 which means 498,875.60 people will be undernourishment under the business as usual scenario (Instituto Nacional de Estadísticas, 2018).

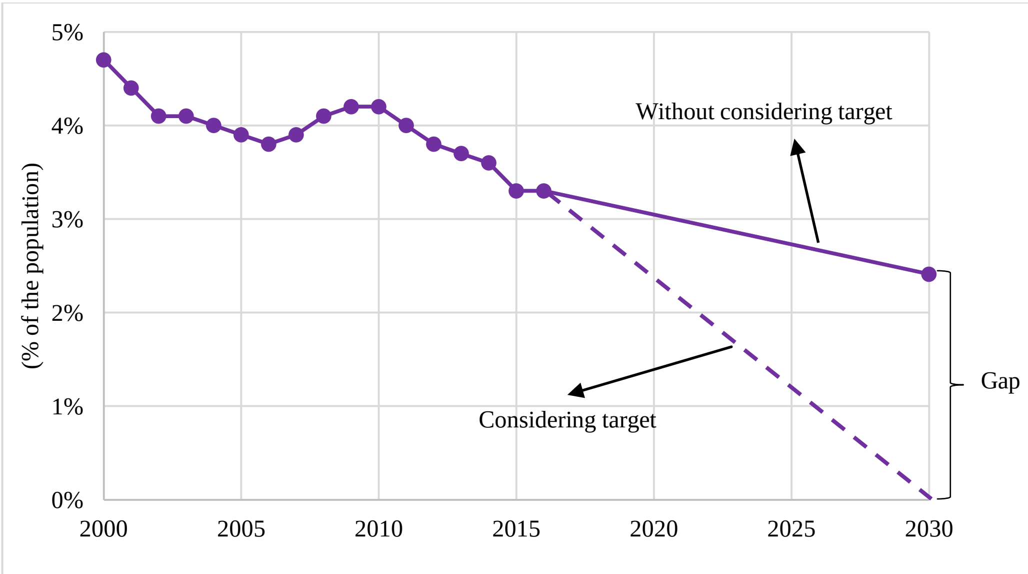

Figure 3. The projection of prevalence of undernourishment in Chile (% of the population) between 2000 and 2030

Source: The figure was constructed based on reference (The World Bank Group, 2017a)

In order to meet the target, which is ending hunger by 2030, all people must be nourished. Thus, the energy intensity is calculated based on equation (5) (Santika et al., 2019):

$$EI = D_f * EC_f/(Eon_{farm} + Eoff_{farm}) \quad (5)$$

D_f = Country´s depth of food deficit = 90.25kcal*person^{-1}*day^{-1} (Santika et al., 2019)

EC_f = The food energy content of cooked potato = 930.00 kcal/kg (USDA, 2018)

$Eon_{farm, max}$ = On-farm agriculture energy usage= 0.005 GJ/kg (Smil, 2008)

$Eoff_{farm, max}$ = Off-farm agriculture energy usage= 0.010 GJ/kg (Smil, 2008)

EI (max)= 0.531 GJ/cap/year (Cap: Capita)

Energy intensity can be calculated depending on different food content in countries nourishment plans. In this research, it is assumed based on the potato due to the high amount of potato consumption in Chile. EI is calculated as 0.531 GJ*cap^{-1}*year^{-1} (see Table 1). In conclusion, the extra energy requirement to meet the target (nourishing all people by 2030) is calculated by 265,057.83 GJ for Chile.

Goal 5_Achieve gender equality and empower all women and girls

Target 5.b: Enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women:

The indicator *"proportion of individuals who own a mobile telephone"* is proposed to measure the Target 5.b. which points achieving gender equality in technology usage (United Nations, 2019b). In 2016, 73.9% of the population had a mobile phone and also in 2020, 75.10% of the population is expected to have a mobile phone in Chile (Statista, 2016). In order to calculate 2030 value for this indicator, the growth rate is obtained as 1.18%, which resulted that 5,130,570.70 people (25% of the population) is estimated to be without a mobile phone in 2030 as presented in Figure 4.

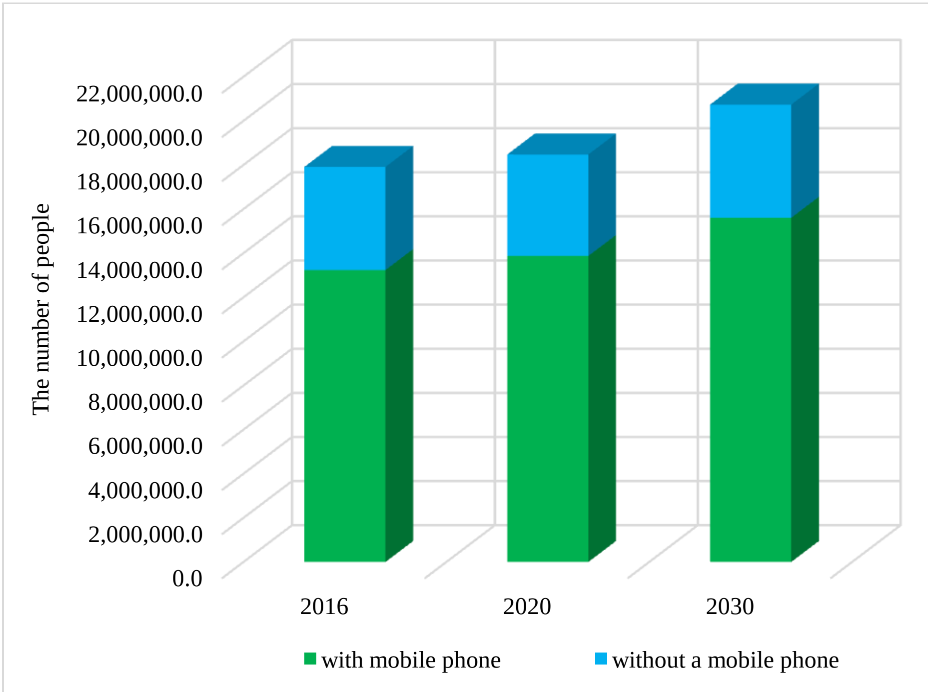

Figure 4. The number of people with and without a mobile phone in Chile in 2016, 2020 and 2030

Source: The figure was constructed based on reference (Statista, 2016)

The energy intensity requirement for a mobile phone is obtained 0.00519 GJ*cap^{-1}*year^{-1} (see Table 1) (Carroll and Heiser, 2010; Santika et al., 2019). Therefore, an additional energy requirement is calculated as 26,627.66 GJ to meet the target in Chile which is about enhancing the use of the mobile phone for all.

Goal 7_Ensure access to affordable, reliable, sustainable and modern energy for all

Target 7.3: By 2030, double the global rate of improvement in energy efficiency:

This target which is measured with indicator *"energy intensity measured in terms of primary energy and gross domestic product (GDP)"* aims to double the global rate of improvement in energy efficiency based on 2010 (United Nations, 2019b). The global rate of improvement in energy efficiency is expected at 2.6% by 2030 (The World Bank, 2017). By considering this rate of improvement, the global energy intensity is calculated as 3.422 Megajoule (MJ)/$2011 PPP GDP by 2030.

The energy intensity level of primary energy (MJ/2011 PPP GDP) for Chile is 3.777 (MJ/2011 PPP GDP) in 2015 based on accessible data (The World Bank Group, 2017a). When energy intensity for 2030 is calculated based on the growth rate, it is obtained 3.058 MJ/2011 PPP GDP for Chile, which is better than the global targeted value in 2030. Therefore, the target will be met before 2030 as presented in Figure 5.

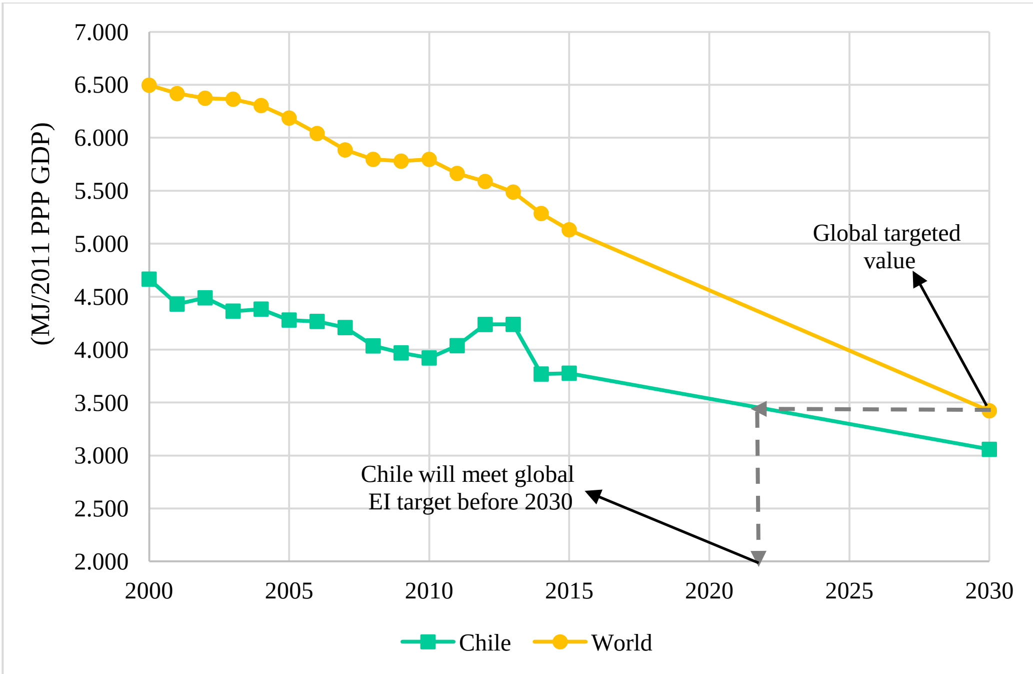

Figure 5. The comparison of primary energy intensity per gross domestic products for Chile and World

Source: The figure was constructed based on reference (The World Bank, 2017; The World Bank Group, 2017a)

Goal 8_Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Target 8.1: Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries:

Target 8.1. is assessed with the indicator *"annual growth rate of real GDP per capita"* (United Nations, 2019b). GDP PPP per capita between 2000 and 2017 is available in the database for Chile (The World Bank Group, 2018) and the growth rate is calculated as 2.80%. Thus, the calculated GDP per capita for 2030 is 32,592.96$ 2011 PPP/cap. The target aims that energy intensity in 2030 will be 3.422 MJ/2011 PPP GDP for Chile, which is also a global target (The World Bank Group, 2017a). Finally, the calculated total primary energy supply in 2030 for Chile has obtained 2,312,671,558.63 GJ. From Chilean National energy balances, the conversion ratio for energy supply to demand is obtained 70% (Comision Nacional de Energia, 2019). Therefore, based on Target 8.1, total energy demand is calculated as 1,618,870,091.04 GJ for 2030. This target is a reference point, which shows the expected energy demand in 2030 and it can be used as a benchmark to check all targets additional energy requirement. In this study, the energy value obtained from this target is compared to BAU and SDG 2030 scenarios in the discussion section.

Goal 12_Ensure sustainable consumption and production patterns

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:

Indicator *"global food loss index"* is utilized to assess the target which aims to halve global food waste per capita (United Nations, 2019b). Food losses in Latin America are obtained approximately 220 kg/cap/year based on the literature (FAO, 2011). The targeted food loss will be 110 kg/cap/year by 2030.

The energy intensity which is obtained from the literature as presented in equation (6) is a function of food losses (L_half), energy consumption for storing (EC_storing) and retailing (EC_retailing) (see Table 1) (Santika et al., 2019; Smil, 2008):

$$EI = \left(EC_{storing} + EC_{retailing}\right) * L\_half \qquad (6)$$

Therefore, the additional energy requirement from halving food waste in Chile is calculated as 10,263,968.06 GJ.

Goal 13_Take urgent action to combat climate change and its impacts

Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries:

In order to evaluate this target, *the number of deaths, missing persons and directly affected people attributed to disasters per 100,000 populations* is considered as an indicator.

This target is essential for Chile due to having active volcanos, biggest recorded earthquakes and potential tsunamis in history. The number of people displaced after the last three biggest earthquakes and tsunamis in Chile is obtained as follows: 1,500,000.00 people in 2010, 970,000.00 people in 2014, and 1,000,000.00 people in 2015 (Barrionuevo and Robbins, 2010; NRC and IDMC, 2015). By taking into account the latest disasters, the average number of people displaces is obtained approximately 1,156,666.67 people.

Also, the average embodied final energy intensity to build a temporary, post-disaster container house is approximately 1.35 $GJ*cap^{-1}*year^{-1}$ (see Table 1) (Santika et al., 2019). Thus, the total required energy to replace affected people after the disaster in Chile is calculated by 1,565,045.18 GJ.

Goal 17_Strengthen the means of implementation and revitalize the global partnership for sustainable development:

Target 17.6: Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism:

"Fixed Internet broadband subscriptions per 100 inhabitants" is the indicator to measure Target 17.6 (United Nations, 2019b). Data for fixed broadband subscriptions in Chile is obtained between 2010 and 2017 (The World Bank Group, 2019a). The growth rate is calculated by 7.96% between available years. Thus, 12,454,704.18 people are expected to be without subscription in 2030. The energy intensity to meet the target is obtained 0.284–0.347 GJ/customer from the literature (Santika et al., 2019). When the average energy intensity is considered, the additional energy requirement to meet this target for Chile is calculated as 3,927,715.51 GJ.

Table 1. Indicators assessment and additional energy requirement/savings calculation of energy-related SDGs to meet targets

ENERGY-RELATED SDGs: (Santika et al., 2019)		**Indicator assessment for Chile 2030:** (OECD, 2019; United Nations, 2018)	**Energy Intensity (EI):**	**Additional energy requirement/savings to meet the target for Chile:**
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture				
Target 2.1	Indicator 2.1.1: Prevalence of undernourishment	Data: 2000-2016 (The World Bank Group, 2017a) CAGR: -1.20% Prevalence of undernourishment in 2030: 498,875.60 people	$\mathrm{EI} = \mathrm{D_f} * \mathrm{EC_f}/(\mathrm{Eon_{farm}} + \mathrm{Eoff_{farm}})$ D_f = Country´s depth of food deficit = 90.25kcal*person^{-1}*day^{-1} (Santika et al., 2019) EC_f = The food energy content of cooked potato = 930.00 kcal/kg (USDA, 2018) $Eon_{farm,\ max}$ = On-farm agriculture energy usage= 0.005 GJ/kg (Smil, 2008) $Eoff_{farm,\ max}$ = Off-farm agriculture energy usage= 0.010 GJ/kg (Smil, 2008) EI (max)= 0.531 GJ/cap/year	*Assumptions: Total energy is calculated to nourish all people by 2030 and EI (max) is considered.* *E_required_total =* *265,057.83 GJ*
Target 2.3	Indicator: Cereal yield (Kg per hectare)	Data for cereal yield in Chile is accessed between 2009-2013 (The World Bank Group, 2017a). The growth rate is calculated as 6.07% based on available data. By considering the calculated growth rate, cereal yield in 2030 is calculated 14582 (kg/hectare), which is more than planned value to double the agricultural production.	The target aims to double the agricultural productivity compared to 2015, which means Chile should increase cereal yield from 7082 (kg per hectare) to 14164 (kg per hectare) by 2030.	*Calculated cereal yield for 2030 is obtained more than planned value to double the agricultural production.* *Therefore, it is assumed that the target will be met in 2030.*
Target 2.4	Indicator 2.4.1: Proportion of agricultural area under productive and sustainable agriculture	Data: 2000-2016 (The World Bank Group, 2017b) Based on the growth rate of 0.26% which is obtained between 2000 and 2016 for Chile, the total agricultural area for 2030 is calculated as 16,316,256.50 m^2.	A country which has sustainable agriculture targets will have 26.85% less energy per hectare than conventional agriculture (Alluvione et al., 2011). Based on the literature, the approximate energy saving= 2.225 GJ*hectare^{-1}*year^{-1} when sustainable agriculture is considered (Fischer-Kowalski, 2008; Santika et al., 2019).	*There is no target for Chile to make agriculture more sustainable. Therefore, E_total_saving=0 GJ*
Goal 3. Ensure healthy lives and promote well-being for all at all ages				
Target 3.8	Indicator 3.8.2: The number of people spending more than 10% of household consumption or income on out of pocket health care expenditure or income	Data: 1997-2006 (The World Bank Group, 2017a) CAGR: 15.69%		*Based on the CAGR 15.69% which is calculated from available data between 1997 and 2006 for Chile, 100% of the population will spend money on health in 2030 without any intervention, which means additional energy is not required to meet this target.* *E_required_total = 0 GJ*

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all				
Target 4.1	Indicator 4.1.1: Primary and secondary school enrollment ratios (% gross)	The first target in this goal is assessed by indicators of primary and secondary school gross enrolment ratios (The World Bank Group, 2017a). It is assumed that primary education is for children aged 7 to 12 and secondary education is for children aged 12 to 18 (Corsi-Bunker, 2011). Primary school enrolment (% gross) in Chile was informed at 99.8 % in 2016, according to the World Bank (The World Bank Group, 2017c). Moreover, secondary school enrolment in Chile (% gross) is 84.42% in 2000 and 99.66% in 2017 (The World Bank Group, 2017d). The growth rate calculated based on available data (CAGR= 0.98%) shows that the secondary school enrolment in Chile will reach 100% before 2030.		*Target "primary school education for all" is already achieved before 2030.* *With the calculated growth rate, secondary school enrollment ratios (% gross) will also reach 100% by 2030.* *E_required_total = 0 GJ*
Target 4.2	Indicator 4.2.1: Pre-primary school enrollment (% gross)	Pre-primary school enrolment (% gross) data is obtained between 2013 and 2017 for Chile (The World Bank Group, 2017a). The growth rate is calculated as 2.15% with available data, and it was obtained that the target for 100% pre-primary school enrolment will be met in 2030 in Chile.		*Preprimary school enrollment will reach 100% in 2030 without any intervention.* *There is no surplus energy requirement to meet the target.* *E_required_total = 0 GJ*
Target 4.3	Indicator 4.3.1: School enrollment in tertiary education (% gross)	In Chile, the values for this indicator are obtained 36.22% in 2000 and 91.47% in 2017 (The World Bank Group, 2017a). CAGR between 2000 and 2017 is calculated with equation (1) and found as 5.60%.		*This growth rate shows that the target (100% enrollment) will be met before 2030 for tertiary education.* *E_required_total = 0 GJ*
Goal 5. Achieve gender equality and empower all women and girls				
Target 5.b	Indicator 5.b.1: Proportion of individuals who own a mobile telephone	Data= 2016-2020 (Statista, 2016) CAGR= 1.18% Population without a mobile phone in 2030= 5,130,570.70 people	EI for owning a mobile phone (Carroll and Heiser, 2010; Santika et al., 2019): EI $=E_b/t_h$ = ((16 kj/phone) / (27 hours)) * (24 h/day) * (1 phone /person) E_b=1.2 Ah (about 16 kJ) per phone t_h= 27 hours The energy intensity requirement for a mobile phone is estimated at 0.00519 $GJ*cap^{-1}*year^{-1}$.	*The total additional energy requirement when all population own a mobile phone by 2030:* *E_required_total =26,627.66 GJ*
Goal 6. Ensure availability and sustainable management of water and sanitation for all				
Target 6.1	Indicator 6.1.1: Proportion of population using safely managed drinking water services	The improved water source mentioned in the target means being accessible on-premises, available when needed and free from faecal and priority chemical contamination including piped water, boreholes or tube wells, protected dug wells, protected spring and packaged or delivered water (The World Bank Group, 2017a). For Chile, proportions of the population using safely managed drinking water is available between the years 2000 and 2015, which are 91.57% and 98.15%, respectively (The World Bank Group, 2017a). The growth rate is calculated by 1.48% based on available data.		*Based on the calculated CAGR, 100% of the population will reach safe drinking water in 2030 without any intervention.* *E_required_total = 0 GJ*

Target 6.3	Indicator 6.3.1: Proportion of wastewater safely treated	Data= 2000-2015 (OECD data, 2019) The proportion of wastewater safely treated is increased significantly between these years as follows: 20.90% and 99.93%, accordingly (OECD data, 2019). The calculated growth rate (CAGR= 10.99%) shows that the target "100% wastewater treatment" is met before 2030 for this target in Chile. The additional energy requirement to meet this target is zero.		*The proportion of wastewater treatment is already reached 100% in 2017. Thus, the target is already met before 2030.* *E_required_total = 0 GJ*
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all				
Target 7.1	Indicator 7.1.1: Proportion of population with access to electricity	Data= 2000-2016 (The World Bank Group, 2017a) The first indicator for Target 7.1 "100 % electricity access" is already met in Chile by 2016 (The World Bank Group, 2017a).		*Target 7.1 "100 % electricity access" is already met in Chile by 2016.* *E_required_total = 0 GJ*
	Indicator 7.1.2: The proportion of the population which accesses clean technologies for cooking	Data for Chile is available between 2000 and 2013, which shows that the ratio increased from 86.10% 91.67% in thirteen years (The World Bank Group, 2017a). The calculated growth rate (0.48%) shows that 100% of the population will access clean cooking technologies in 2030 without any intervention.		*Based on the calculated CAGR, 100% of the population will access clean cooking technologies in 2030 without any intervention.* *E_required_total = 0 GJ*
Target 7.2	Indicator 7.2.1: Renewable energy share in the total final energy consumption	The renewable electricity production in Chile showed an increasing trend, which was increased from 15% to 19,92% from 2015 to 2018, respectively (IRENA et al., 2018; Renewable Energy Policy Network for the 21st Century (REN 21), 2018).	The share of renewable energy is related to energy. However, the target does not affect the final energy consumption.	*Additional energy requirement or saving is not considered to calculate for this target.* *E_required_total = 0 GJ*
Target 7.3	Indicator 7.3.1: Energy intensity measured in terms of primary energy and GDP	Data= 2000-2015 (The World Bank Group, 2017a) CAGR= -1.40% EI at 2030= 3.058 (MJ/2011 PPP GDP)	This target aims to double the global rate of improvement in energy efficiency based on 2010 (United Nations, 2019b). Until 2010, the global rate of improvement in energy efficiency was 1,3%. Therefore, CAGR was expected at 2.6% between 2010 and 2030 and global EI needs to be reduced to 3.422 MJ/$2011 PPP GDP by 2030.	*EI at 2030 for Chile= 3.058 (MJ/2011 PPP GDP) which is better than the global targeted value (3.422 MJ/$2011 PPP GDP) in 2030. Therefore, the target will be met before 2030.*
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all				
Target 8.1	Indicator 8.1.1: Annual growth rate of real GDP per capita	Data= 2000-2017 (The World Bank Group, 2018) CAGR= 2.80%. GDP per capita for 2030= 32,592.96 $ 2011 PPP/cap.	The target aims that energy intensity in 2030 will be 3.422 MJ/2011 PPP GDP for Chile in parallel to the global target (The World Bank Group, 2017a)	*TPES 2030= 2,312,671,558.63 GJ* *By considering 70% conversion to supply to demand in National Energy Balance in Chile* (Comision Nacional de Energia, 2019) *Total energy demand in 2030= 1,618,870,091.04 GJ*

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation			
Target 9.1	Indicator 9.1.1: "Rural Access Index (RAI)" which is the share of rural people who live within 2 kilometers (about 20 – 30 minutes walking time) of the nearest all-season road (Eqbali et al., 2017)	For Chile, RAI (% of rural population) was obtained for 2002 and 2004, which are 59% and 76%, respectively (Fay and Morrison, 2005; The World Bank, 2004). With these available data, the growth rate is calculated 12.63% and it shows the target "100% of the rural population access to roads" will be met by 2030.	*The target "100% of the rural population access to roads" will be met by 2030 by considering the calculated growth rate for Chile.* *E_required_total = 0 GJ*
Target 9.c	Indicator 9.c.1: The proportion of population covered by a mobile network, by technology	Mobile network coverage (% population) in Chile: 100% by 2012 (GSM Association, 2007).	*The target for 100 % of the population covered by a mobile network in Chile is already met before 2030.* *E_required_total = 0 GJ*
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable			
Target 11.1	Indicator 11.1.1: Proportion of urban population living in slums, informal settlements or inadequate housing	In 2005, 9% of the urban population and in 2007, 1% of the total population lives in slums in Chile (Brain et al., 2009; The World Bank Group, 2017e). The population living in slums during last years in Chile reduced significantly. Therefore, the target which is "none of the population lives in the slums by 2030" will be reached before 2030.	*The target which is "none of the population lives in the slums by 2030" will be reached before 2030.* *E_required_total = 0 GJ*
Target 11.2	Indicator 11.2.1: Proportion of population uses public transport	The proportion of the population uses public transport in Chile was announced at 29.10% in 2012 with a 0.5% annual decrease between 2001 and 2012 (El Ministro de Transportes y Telecomunicaciones, 2015). By considering this negative growth rate, only 20.10% of the population is expected to use public transportation in 2030. The expected proportion of population uses public transport in 2030= 20.10%	*In Chile, there is no target to encourage people to use public transportation in 2030.* *Therefore, energy contribution is not considered for this target.*
Target 11.6	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	When generation and collection of solid urban waste data are investigated for Chile, it is found that all generated solid waste is collected from cities in Chile based on the available databases (OECD data, 2018; OECD iLibrary, 2018; UN data, 2018). It is also assumed that all regularly collected wastes have adequate final discharged in Chile.	*The target "100% urban waste collection" will be met before 2030.* *E_required_total = 0 GJ*
Goal 12. Ensure sustainable consumption and production patterns			
Target 12.3	Indicator 12.3.1: Global food loss index	Food losses in Latin America is cited approximately 220 kg/cap/year (FAO, 2011). The targeted food loss (L_half) will be 110 kg/cap/year. The energy intensity (EI) (Santika et al., 2019): $\mathrm{EI} = \left(\mathrm{EC}_{\mathrm{storing}} + \mathrm{EC}_{\mathrm{retailing}}\right) * \mathrm{L\_half}$ EC_storing = Energy consumption for storing (MJ/kg) EC_retailing = Energy consumption for retailing (MJ/kg) L_half = Halving the losses based on target(kg/cap/year)	*E_required_total = 10,263,968.06 GJ*

Target 12.5	Indicator 12.5.1: National recycling rate, tons of material recycled	The recycling rate of total waste in Chile is obtained at 0.4% in 2009 and 1% in 2013 (OECD, 2015; United Nations, 2011). Based on available data, it is calculated that 56.95% of the total produced waste will be recycled in 2030. However, there is no target for the recycling ratio of produced wastes by 2030 in Chile. Therefore, energy-saving by meeting this target is not considered.	If this target is considered for a country, the net energy reduction potential of recycling can be assumed as 1.64 GJ/tonnes as mentioned in the literature (Beigl and Salhofer, 2004; Cleary, 2009; Santika et al., 2019).	*There is no target for recycling ratio of produced wastes by 2030 in Chile.* *Therefore, energy-saving by meeting this target is not considered.* *E_total_savings= 0 GJ*
Goal 13. Take urgent action to combat climate change and its impacts				
Target 13.1	Indicator 13.1.1: Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	The number of people displaced after the last three biggest earthquakes and tsunamis in Chile: 1,500,000.00 people in 2010, 970,000.00 people in 2014, and 1,000,000.00 people in 2015 (Barrionuevo and Robbins, 2010; NRC and IDMC, 2015). The average number of people displaces is obtained approximately 1,156,666.67 people.	The average embodied final energy intensity to build a temporary, post-disaster container house is approximately 1.35 $GJ*cap^{-1}*year^{-1}$ (Santika et al., 2019).	*Thus, the additional energy requirement to replace affected people after the disaster in Chile is calculated:* *E_required_total =1,565,045.18 GJ*
Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development				
Target 17.6	Indicator 17.6.2: Fixed Internet broadband subscriptions per 100 inhabitants, by speed	Data= 2010-2017 (The World Bank Group, 2019a). CAGR= 7.96% between available years. The number of people without subscription in 2030= 12,454,704.18	The energy intensity to meet the target: 0.284–0.347 GJ/customer (Santika et al., 2019).	*When the average energy intensity is considered, the additional energy requirement to meet this target (100% of population with broadband subscription) for Chile is:* *E_required_total=3,927,715.51 GJ*
Target 17.8	Indicator 17.8.1: Proportion of individuals using the Internet	Data= 2000-2017 (The World Bank Group, 2017a). CAGR= 10.97%		*Based on the calculated CAGR, the target "100% of population using internet" is expected to be met before 2030 without any intervention.* *E_required_total = 0 GJ*

3. Results

Results obtained from the analysis of different indicators suggest that Chile would achieve fourteen energy-interlinked SDGs by 2030 under the business as usual scenario. However, five targets: Target 2.1, Target 5.b, Target 12.3, Target 13.1, and Target 17.6 require extra energy to be achieved by 2030. On the other hand, Target 2.4, Target 11.2, and Target 12.5 are not taken into account due to not having specific targets for sustainable agriculture, use of public transportation and recycling in Chile.

Figure 6 presents the additional energy requirement to meet the five energy-related targets (Target 2.1, Target 5.b, Target 12.3, Target 13.1, and Target 17.6) in Chile. In order to meet Target 2.1, which is ending hunger by 2030, all people must be nourished by 2030. Results show that the prevalence of undernourishment was obtained as 498,875.60 people for Chile in 2030. Energy intensity can be calculated depending on different food content in countries nourishment plans. In this study, energy intensity is assumed based on growing potato due to the high amount of potato consumption in Chile. Finally, the additional energy requirement to meet this target is calculated as *265,057.83 GJ*.

Target 5.b. which aims to enhance the use of enabling technology which is measured with the indicator "proportion of individuals who own a mobile telephone". Chilean population without a mobile phone in 2030 is calculated to be 5,130,570.70 people. Therefore, additional energy is calculated as *26,627.66 GJ* to meet this target by 2030. It is the target with the lowest additional energy requirement by 2030.

Target 12.3, which is about halving food losses, requires maximum additional energy among all energy-interlinked targets. Food loss in Latin America is mentioned approximately 220 kg/cap/year in the literature (FAO, 2011). Within the scope of this target, it will be halved and reduced to 110 kg/cap/year. Also, the prevention of food losses calculation is assumed as a function of energy consumption for storing and retailing, which means the food losses will be prevented and decreased by having more storage capacity and retailing. Thus, the additional energy on demand for this target is calculated as *10,263,968.06 GJ*.

Chile is one of the countries with the highest earthquake potential in the world. In history, it can be found that Chile was affected by drought, floods, tsunamis, volcanic eruptions, forest fires, and earthquakes. Thus, Target 13.1 is a vital target for Chile. It is hard to estimate the number of people displaced after disasters. In the analysis, the average number of people affected by natural disasters is taken into account based on the recent disasters in Chile and the additional energy requirement to meet the target is calculated as *1,565,045.18 GJ*.

The results showed that Target 17.6, which is measured with the indicator "Fixed internet broadband subscriptions" requires additional energy to be met by 2030 in Chile. It is estimated that 12,454,704 people are expected to be without subscription in 2030. The energy intensity to meet the target is obtained 0.284–0.347 GJ/customer from the literature (Santika et al., 2019). Using the average energy intensity, and the additional energy requirement to meet this target for Chile is calculated as *3,927,715.51 GJ.*

Finally, the total additional energy requirement is calculated 16,048,414.24 GJ for Chile to meet considered energy-interlined SDGs. In some cases, there can be overlapping or double counting between targets. For instance, Target 2.1 which is about ending hunger and Target 12.3 halving per capita global food waste by 2030 are related targets. By halving the food loss for

Target 12.3, Target 2.1 ending hunger can be achieved as business as usual. However, these are second-order impacts which are difficult to analyse due to a high level of uncertainties and so, have not been studied in this paper. In this study, all targets´ contribution to energy demand is calculated individually because Target 12.3 requires much more energy than other targets.

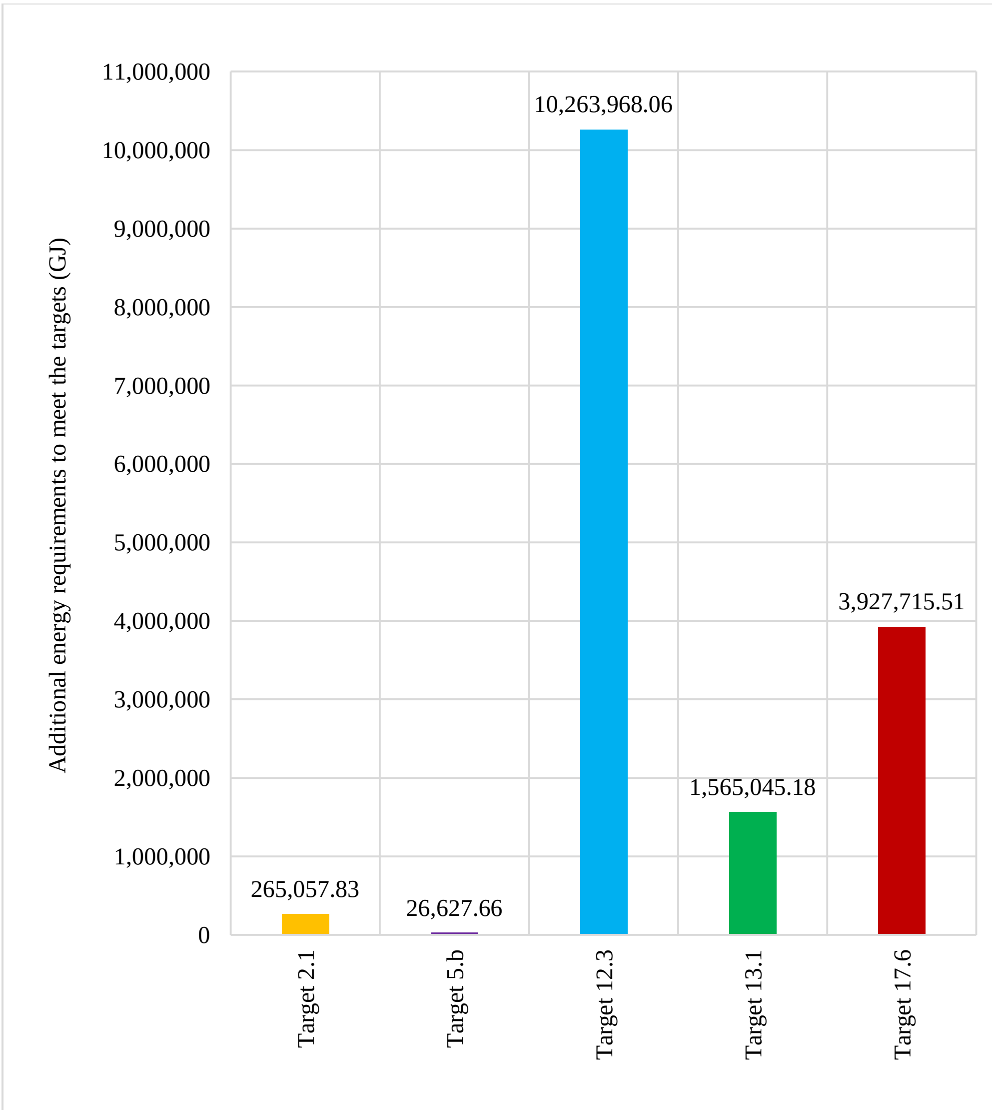

Figure 6. The additional energy requirement to meet the five energy-related targets in Chile

In order to understand the impact of this additional energy on total energy demand, future projections for different scenarios and benchmarking results are presented in Figure 7 for Chile. Based on the available national energy balance reports for Chile between 2008 and 2015 (Comision Nacional de Energia, 2019), the growth rate of energy demand is calculated as 1.394% per year and it is used to estimate energy demand for 2020, 2025 and 2030 business as usual (BAU) scenarios. Total energy demand for BAU 2030 is calculated as 1,447.03 million GJ which is obtained as a close value to low energy demand projection of Chilean government for 2030 (mentioned in Section 1) (Ministerio de Energía, 2017). Also, due to approximately 16 million GJ additional energy requirement, energy demand for 2030 SDGs was obtained as 1,463.08 million GJ.

In addition to BAU and SDGs scenarios, Target 7.3 and 8.1. are taken into account for benchmarking. When the global energy intensity target (3.422 MJ/2011 PPP GDP) is considered, the total energy demand for Chile is calculated as 1,618.87 million GJ by 2030, which is within the demand values estimated by the Chilean government (mentioned in Section 1) (Ministerio de Energía, 2017). It must be noted that if there is no future target for a specific indicator in Chile, additional energy is not considered for that target such as Target 2.4, Target 12.5, and Target 11.2. However, Target 2.4 and Target 12.5 may save energy if sustainable agriculture and recycling targets exist in Chile, in contrary, Target 11.2 may require extra energy, if public transportation is improved to encourage people to use public transportation in 2030. The differences between the results of benchmarking and 2030 SDGs energy projection may come from these targets, which are not taken into account in the 2030 SDG scenario.

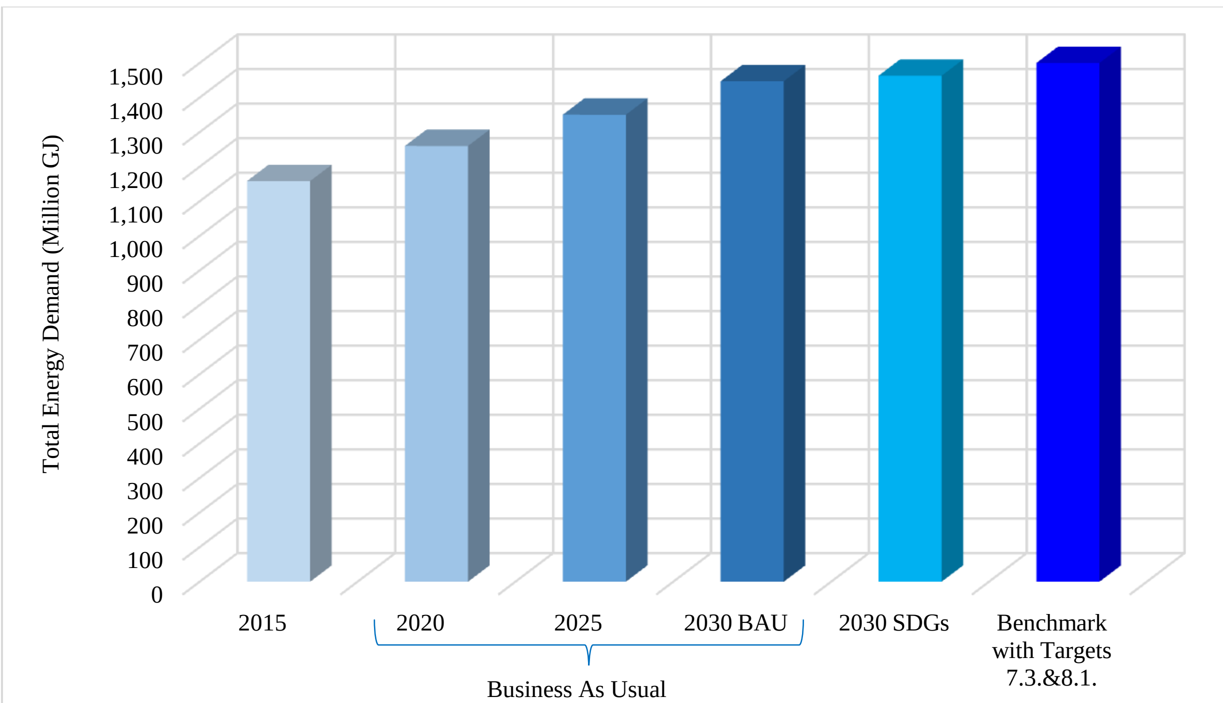

Figure 7. Total energy demand and future projections for different scenarios and benchmarking results in Chile

Source: The figure was constructed based on calculations in this study and reference (Comision Nacional de Energia, 2019)

4. Discussion

The main findings showed that Target 12.3, which is about halving per capita global food waste by 2030, requires much more energy than other targets in Chile. In the analysis, the prevention of food losses calculation is assumed as a function of energy consumption for storing and retailing which are assumed 2 MJ/kg and 2.5 MJ/kg, respectively (Smil, 2008). Energy efficient technologies and the most appropriate renewable energy solutions for cold storage and refrigeration should be investigated to reduce the additional energy demand to meet this target for Chile as mentioned in the literature (Büyüközkan et al., 2018;

Puig et al., 2018), which will also make contribution to meet SDG 7. Moreover, Target 13.1 needs a significant amount of energy to be met because Chile is one of the countries with the highest natural disaster potential in the world. In order to reduce the impact of disasters on national energy demand, countries under a highly vulnerable category like Chile must adopt disaster preventive actions besides post-disaster plans. The United Nations published Sendai framework to guide the multi-hazard management of disaster risk by preventing new and reducing existing disaster risk (United Nations, 2015). The Chilean Government has also agreed on developing the National Platform for Disaster Risk Reduction under National Strategic Policy and Plan. Moreover, it was highlighted the importance of international cooperation to share good practices and disseminate learning and reiterated Chile's commitment to the Sendai Framework for Disaster Risk Reduction and its indissoluble link with sustainable development and climate change agendas (UNISDR, 2019).

The benchmarking calculation mentioned in the result section is done by considering the suggested global energy intensity target (3.422) for 2030 (The World Bank, 2017). On the other hand, when energy intensity for 2030 is calculated based on the growth rate, it is obtained 3.058 MJ/2011 PPP GDP for Chile, which means that Chile will meet the global energy intensity target before 2030 (Figure 5). Table 2 compares the global and calculated energy intensity, total primary energy supply (TPES) and demand for Chile. When the calculated energy intensity value for Chile is considered, the total energy demand is obtained 1,446.67 million GJ, which is closer to BAU 2030 scenario. It means that if Chile achieves its calculated energy intensity target by 2030 instead of the global target, energy demand and supply will be less than the global target. Thus, Target 7.3 will be achieved by Chile due to having less or equal energy intensity to 3.422 MJ/2011 PPP $ by 2030.

Table 2. The comparison of global and calculated energy intensity, TPES and demand for Chile

	When global energy intensity target considered by Chile for 2030	**When energy intensity calculated for Chile by 2030**
EI (MJ/$ 2011 PPP)	3.422	3.058
TPES (Million GJ)	2,312.67	2,066.67
Demand (Million GJ)	1,618.87	1,446.67

Additionally, energy use per capita is calculated for Chile for 2015 and 2030 SDG scenario and presented in Table 3. Also, the results are compared to global primary energy supply average value (73.08 GJ/cap) which is assumed based on suggested global targets of 7.3 and 8.1 (Santika et al., 2020). The primary energy supply of Chile per capita showed 8.69 GJ/cap increase in fifteen years and reached 100.8 GJ/cap by 2030. It shows that by meeting SDG targets, Chile will consume much more energy than the expected global average of 73.08 GJ/cap. Chile needs to consider reducing per capita energy consumption by decoupling energy use from the economic growth, reducing the carbon intensity of energy, improving energy efficiency, and reducing energy demand by considering sectoral solutions such as having electric and more efficient vehicles in the transport sector, high efficiency in process technologies in industry and mining etc.

Table 3. Comparisons of per capita energy use in Chile and suggested global targets

	2015	2030 SDG scenario
Energy demand of Chile (million GJ)	1,158.61	1,463.08
Population of Chile (million people)	17.97	20.74
Energy demand of Chile per capita (GJ/cap)	64.48	70.56
*** Primary energy supply of Chile per capita (GJ/cap)**	**92.11**	**100.80**
Global primary energy supply as suggested under Targets 7.3 and 8.1 (GJ/cap)	-	**73.08**

* The ratio between primary energy supply and demand of Chile is assumed 0.70 (Comision Nacional de Energia, 2019).

Moreover, in order to understand that Chile´s current situation to meet SDGs, a similar analysis which is realized for Indonesia (Santika et al., 2020) is compared to Chile case study. Table 4 shows the additional energy requirement of Chile and Indonesia for each target. The additional energy requirement to meet energy-related SDGs for Indonesia is calculated almost 474 million GJ when it is obtained approximately 16 million GJ for Chile. Both countries do not have a target to make agriculture more sustainable; therefore, Target 2.4 cannot be considered in both analyses. When Chile meets several targets as business as usual, Indonesia requires much more effort to meet energy-related sustainable development goals by 2030. While Indonesia requires the highest extra energy (169 million GJ) to meet Target 9.1 which is about rural population access to roads, Chile achieves this target by business as usual in 2030. Also, the results showed that both countries must focus on halving food losses and require more energy to meet Target 12.3. It is interesting to obtain that only target which requires more energy for Chile than Indonesia is Target 13.1 which is about replacing affected people after the disaster. Due to having the highest natural disaster potential in the world, Chile requires three times more energy than Indonesia to achieve this target.

Table 4. The comparison of additional energy requirement/savings to meet energy-related SDGs for Chile and Indonesia

Energy-related SDGs	Chile (million GJ)	Indonesia (million GJ)
Target 2.1	0.265	5.217
Target 2.3	0.00	14.061
Target 2.4	-	-
Target 3.8	0.00	2.223
Target 4.1	0.00	6.881
Target 4.2	0.00	1.294
Target 4.3	0.00	0.00
Target 5.b	0.027	0.220
Target 6.1	0.00	5.175
Target 6.3	0.00	5.437
Target 7.1	0.00	83.225

Target 7.2	0.00	0.00
Target 7.3	-	-
Target 8.1	1,618.870	13,766.215
Target 9.1	0.00	169.410
Target 9.c	0.00	10.852
Target 11.1	0.00	5.159
Target 11.2	-	87.440
Target 11.6	0.00	2.788
Target 12.3	10.264	76.028
Target 12.5	-	-8.508
Target 13.1	1.565	0.546
Target 17.6	3.928	7.277
Target 17.8	0.00	0.00
Total	**16.048**	**474.723**

The energy demand to achieve SDGs can vary significantly across countries, as shown in the comparison between Chile and Indonesia. The reasons for these differences may arise from various factors such as the population of Indonesia is almost fourteen times higher than Chile (The World Bank Group, 2019b), the total GDP in Indonesia is about 3.5 times more than Chile (The World Bank Group, 2018) and benchmarking results showed that Indonesia would have 8.5 times more energy demand than Chile in 2030. In order to make a more inclusive comparison, per capita energy use of Chile and Indonesia are compared for SDG scenario and presented in Table 5. Additional energy demand per capita to meet SDGs for Indonesia is obtained almost 1.8 times more than Chile because Indonesia requires much more effort to meet energy-related SDGs by 2030 (Santika et al., 2020). However, when the total demand and supply per capita by 2030 for SDG scenarios are considered, Chile is obtained approximately two times more than Indonesia. In 2030, Indonesia will have almost 31% less primary energy usage per capita than suggested global primary energy supply value (73.08 GJ/cap) when Chile will exceed global value with approximately 39%. Therefore, until 2030, when Chile needs to consider reducing per capita energy consumption, Indonesia should increase energy usage per capita.

Table 5. Comparison of per capita energy usage in Chile and Indonesia for SDG scenario

	Chile	**Indonesia**
Additional demand per capita to meet energy-related SDGs by 2030 (GJ/cap)	**0.893**	**1.602**
Total energy demand per capita in 2030, SDGs scenario (GJ/cap)	70.56	36.32
Total primary energy usage per capita in 2030, SDGs scenario (GJ/cap)	**100.80**	**50.45***

* The ratio between primary energy supply and demand of Indonesia is assumed 0.72 (Santika et al., 2020)

5. Conclusion

This study has investigated the energy-related SDGs indicators and calculate the additional energy requirement or saving of each target when an intervention needs to meet the target for 2030 in Chile. The main findings of the research are: by considering growth rates obtained from available historical data, Chile meets fourteen targets without needing any interventions by 2030 between twenty-four energy-related sustainable development targets. The main findings show that Target 2.1, Target 5.b, Target 12.3, Target 13.1, and Target 17.6 require extra energy to be encountered by 2030.

Energy demand for BAU 2030 is calculated as 1,447.03 million GJ. When SDGs are considered to be met by 2030, it is found that energy demand for 2030 SDGs will reach 1,463.08 million GJ due to 16 million GJ additional energy requirement to meet SDGs. Thus, in order to meet SDGs in Chile, more energy is required by 2030 than the BAU scenario. When benchmarking is considered with Targets 7.3 and 8.1, total energy demand is calculated as 1,618.87 million GJ by 2030. In this study, if there is no target for a specific indicator in Chile, additional energy is not considered. However, Target 2.4 and Target 12.5 may save energy or Target 11.2 may require more energy by 2030, which means that the SDGs scenario could result in more or less energy than BAU by 2030.

Additionally, the total additional energy requirement to meet energy-related SDGs for Chile is compared to Indonesia results. Indonesia requires much more effort than Chile to meet energy-related sustainable development goals by 2030. When Indonesia requires almost 474 million GJ extra energy to meet the targets, Chile needs approximately 16 million GJ. Both countries do not have sustainable agriculture target; thus, Target 2.4 is not considered in the comparison. Indonesia and Chile must concentrate on halving food losses and require more energy to meet this Target 12.3. Only Target 13.1 requires more energy for Chile than Indonesia to be met by 2030 due to having the highest natural disaster potential in Chile.

By meeting SDG targets in 2030, Chile resulted in consuming much more per capita energy (100.80 GJ/cap) than the expected global average 73.08 GJ/cap when Indonesia is obtained approximately 50.45 GJ/cap. Therefore, when Chile needs to consider reducing per capita energy consumption, Indonesia should increase energy usage per capita until 2030.

This study includes some limitations due to assumptions and unavailable information as follows:

- This study focuses on secondary data and literature reviews.
- These analyses are formed based on the conditions of the country studied, considered SDG assessment indicators, and energy requirement calculations based on literature review. It may vary significantly from one country to another.
- In some indicator assessment, data were available for only a few years, and the growth rate is calculated based on existing data sets. The result can vary due to considering data sets for different years.
- Also, if there is no target for a specific indicator in Chile, additional energy is not considered for that target. However, Target 2.4 and Target 12.5 may save energy, in contrary, Target 11.2 may require extra energy in 2030.
- This study only predicts the total national energy demand. The current energy policy impact on demand-side in Chile is not considered for scenarios.
- The methodology including growth rate calculation for indicator assessment can bring very different results if another approach is applied in the calculations.
- This modelling approach is potentially limiting because it provides results for all Chilean energy demand by 2030, not regional analysis. Also, this study does not consider the impact of SDGs on sub-sectors of energy demand in Chile.

Further studies are planned to investigate the contribution of the calculated additional energy from SDGs to the sectors and to distribute this energy according to the fuel type for national energy balance in 2030. Finally, the discussion in this paper can support the provision of recommendations and insights for energy researchers working on implementing energy-related SDGs to the long-term sustainable energy planning of developing countries, and policy prioritization to find the right pathway to meet SDGs.

Acknowledgement

Y. Simsek acknowledges the financial support of the Chilean National Commission for Scientific and Technological Research under scholarship CONICYT-PCHA/ Doctorado Nacional/ 2018–21181469.

Abbreviations

BAU	Business as usual
CAGR	Compound annual growth rate
Cap	Capita
EI	Energy intensity
GDP PPP/cap	Real GDP purchasing power parity per capita
GJ	Gigajoule
MJ	Megajoule
RAI	Rural Access Index
SDGs	Sustainable Development Goals
TPES	Total Primary Energy Supply
UN	United Nations (UN)

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*Declaration of Interest Statement

Declaration of interests

16.02.2020

I testify on behalf of all co-authors that:

- We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work. [OR] We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome,
- This material has not been published in whole or in part elsewhere,
- After submitting Journal of Cleaner Production, the manuscript is not being considered for publication in another journal,
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