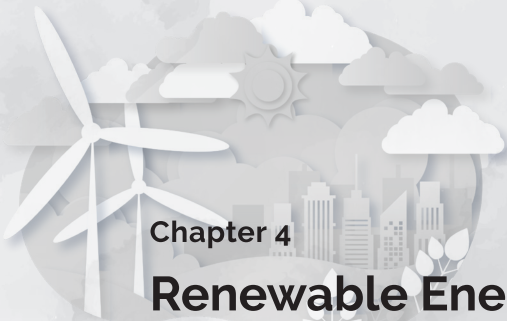

Chapter 4

Renewable Energy and Sustainability: Assessment Based on the United Nations Sustainable Development Goals

Yogi Sugiawan, Falikul Fikri, Shunsuke Managi

A. Introduction

The world has witnessed remarkable technological advances that have enabled us to explore new frontiers and tap into previously inaccessible energy sources. However, these achievements have not solved the pressing challenges of environmental degradation and climate change. As a result, the global development agenda has shifted from a narrow focus on the limits of growth imposed by resource scarcity to a broader and more holistic vision of sustainability that balances economic, social, and environmental objectives (Ekins, 1993; Kaika & Zervas, 2013; Naveed et al., 2022). The notion of sustainability requires that the pursuit of well-being should be carried out within planetary boundaries so that intergenerational equity will be main-

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tained over time (Managi & Kumar, 2018). Nevertheless, the prevailing trend in worldwide economic advancement, which demonstrates a strong correlation with the swift exhaustion of natural resources and escalating carbon dioxide emissions caused by human activities, has resulted in the transgression of these boundaries (Sugiawan & Managi, 2019). Such an unsustainable development pattern stems from the high dependency on fossil fuels in most of the world's economy. In 2019, less than 16% of the world's primary energy consumption came from nonfossil or low-carbon energy sources, of which around 4% came from nuclear energy and more than 11% came from renewables (Ritchie et al., 2022).

Improving access to affordable, reliable, and modern energy services is essential for economic development. However, with the domination of fossil fuels in the global energy mix, increasing levels of energy consumption are positively correlated with increasing levels of carbon dioxide emissions and rapid depletion of natural capital, creating a strong interrelationship between economic development, energy consumption, and environmental degradation (Sugiawan et al., 2019). This has led to a so-called ethical dilemma between economic growth and environmental sustainability (Antonakakis et al., 2017). For instance, policies aiming to boost economic growth by promoting higher levels of energy consumption might be beneficial for improving the well-being of the current generation, yet they might pose a serious threat to the environment and the well-being of future generations. Similarly, policies aiming to restrain energy consumption might be beneficial for preserving the nature and well-being of future generations, but they might be harmful to the economy, which is unfavorable for the well-being of the current generation. As a result, efforts to decouple environmental degradation from economic growth and to find a balance between economic and environmental goals remain elusive.

Shifting to low-carbon energy sources is believed to be one of the most feasible options to detach environmental degradation from economic growth so that the well-being of the current and future generations can be achieved simultaneously (see, for instance, Pahle et al., 2016 and Bogdanov et al., 2021). However, the renewable energy sector still faces noteworthy challenges, making it grow slowly and unable to catch up with the rapid growth of global energy consumption. The intermittent nature and the economic competitiveness are the two main reasons why renewable energy sources are less favorable compared to fossil fuels, particularly in developing countries (Ang et al., 2022). Additionally, Diesendorf and Elliston (2018) argue that political, institutional, and cultural aspects are also responsible for the slow growth of renewable energy sources. As a result, the world still burns more and more fossil fuels each year, resulting in an increasing level of carbon dioxide emissions.

In light of the aforementioned context, the primary objective of this chapter is to evaluate the sustainability of energy consumption from the perspective of the United Nation's sustainable development goals (SDGs). The primary academic contribution of this chapter is to present empirical evidence with regards to the effects of low-carbon energy consumption, specifically renewable energy, on the sustainability of energy systems and sustainable well-being. Despite the extensive literature on this subject, there appears to be no prior empirical investigation from the UN SDGs perspective. For this purpose, the present chapter will utilize the nonparametric machine learning technique, renowned for its exceptional predictive performance. The subsequent section of this chapter is structured in the following manner. Section B assesses the environmental Kuznets curve (EKC) hypothesis as a means of determining whether it is possible to separate environmental degradation from economic growth. Section C aims to develop an empirical strategy to link the footprint of energy consumption with the SDGs framework. Section D delves into the significance of renewable energy sources in ensuring sustainable and affordable energy access. Section E sheds light on the crucial role that renewable energy sources play in advancing sustainability with respect to the SDGs. Section F concludes the discussion and provides policy recommendations.

B. Endless Quest for Decarbonizing the Economy

The environmental Kuznet curve (EKC) hypothesis proposes a positive outlook towards sustainability. The EKC hypothesis challenges the conventional wisdom that economic development leads to environmental degradation. Instead, it proposes that once a certain income threshold is reached, further economic growth can actually lead to environmental improvements. The hypothesis was inspired by the empirical findings of Grossman and Krueger (1991), who observed an inverted U-shaped relationship between income per capita and some pollutants. Later, Beckerman (1992) argued that poverty is the main cause of environmental problems and that becoming rich is the best solution. Panayotou (1993) coined the term EKC to distinguish this hypothesis from the Kuznets hypothesis, which describes a similar relationship between income inequality and economic development. The EKC hypothesis has attracted much attention and debate in the literature since its emergence in the early 1990s, as it implies that sustainability can be achieved by pursuing economic development.

The nexus between energy and growth is a subject of great interest in sustainability research, as it encompasses four primary hypotheses: the growth, conservation, feedback, and neutrality hypotheses (see, for instance, Hajko et al. (2018) for a detailed explanation regarding the four hypotheses of the energy-growth nexus). Out of the four primary hypotheses regarding the nexus between energy and growth, the EKC hypothesis stands out as a promising pathway towards sustainability, regardless of the type of causal relationship between energy consumption and economic growth. Within the literature on the energy-growth nexus, a more sustainable economy is depicted by either conservation or neutrality hypotheses since energy and environmental conservation policies, which may limit the consumption of fossil fuels, can be pursued without negatively impacting economic growth (Menegaki & Tugcu, 2017). However, the EKC hypothesis challenges this notion and suggests that energy-dependent economies, which are represented by growth or feedback hypotheses, can also trail the sustainable development path. While energy consumption is a significant driver of economic growth in such economies, the EKC hypothesis posits that as countries become wealthier, new and cleaner energy technologies, such as renewable energy sources and nuclear energy, become more affordable. Consequently, the detachment of environmental degradation from energy consumption can pave the way for economic growth that is sustainable and eco-friendly.

Understanding the EKC phenomenon requires an explanation of the three key impacts of economic progress, namely, the scale effect, the composition effect, and the technique effect (Stern, 2004). The scale effect pertains to the escalation in contamination emanations as a result of the amplification of economic activities and the persistent depletion of natural resources beyond their replenishment capacities (Panayotou, 1993). This effect is particularly striking in the early stages of development as the economy moves from an agrarian to an industrialized form. In relation to energy consumption, the scale effect is characterized by the extensive use of fossil fuels, notably coal, which is relatively low-cost but highly polluting. The composition effect relates to the alteration of a nation's economic structure, where the emphasis is shifted from industries that rely on resources to those that are based on knowledge and services. This transition positively affects the environment by decreasing the environmental impacts associated with the latter sectors (Dinda, 2004). This effect is more evident at the later stage of development when income per capita is high enough to afford cleaner and more efficient technologies. The technique effect refers to the improvement in environmental quality due to technological innovation and diffusion, which reduce the pollution intensity of production and consumption (Dinda, 2004). This effect depends on the level of investment in research and development, which is usually higher in developed countries. A good example of the composition and technique effect is the transition to relatively expensive low-carbon energy sources, which have replaced some of the more polluting and relatively cheaper coal. According to Our World in Data (Ritchie et al., 2022), in 2020, coal accounted for more than 27% of the global primary energy or decreased by around 3%

over the last decade. The EKC hypothesis suggests that environmental degradation will decrease as income exceeds a certain threshold, with composition and technique effects having a more positive impact than the scale effect. However, Al-Mulali et al. (2016) argued that the attainment of a particular income threshold necessitates a substantial portion of renewable energy sources integrated into the energy mix.

The EKC hypothesis presents a compelling framework for reducing carbon emissions in the economy; however, it is not devoid of shortcomings and critiques. One important consideration to bear in mind with the EKC hypothesis is that the point at which environmental degradation declines may only occur at extremely high levels of income per capita. These levels may be so high that they are unrealistic or even impossible to reach for many countries. For instance, Sugiawan and Managi (2016) estimated a turning point of the EKC at an income level of 7729 USD per capita for the case of Indonesia, or twice as much as the per capita income level of Indonesia in 2021, suggesting that this turning point is not likely to be achieved in the short-term. Moreover, Sugiawan et al. (2022) forecasted that despite the significant reduction in carbon dioxide emissions, the carbon peak in Indonesia's economy was not observed until 2050. Similarly, Bölük and Mert (2015) found that Turkey's economy will be decarbonized at an income level of 9920 USD per capita, which was considerably higher than the income level of Turkey in 2010. Nevertheless, all of the aforementioned studies have identified the significant role of renewable energy sources in reducing carbon dioxide emissions.

Regardless of the ongoing arguments regarding the validity of the EKC hypothesis and its appropriateness for sustainable development, it is imperative to evaluate the influence of renewable energy sources on a broader set of sustainability measures within the SDG framework. The SDG framework diverges from the EKC hypothesis in that it necessitates the attainment of socioeconomic and environmental objectives in every phase of development. Consequently, environmental deterioration that typically arises during the initial stages of economic growth is deemed unacceptable and constitutes a threat to sustainability. Nevertheless, economies have made greater strides in achieving socioeconomic-related SDGs compared to environmental-related SDGs (see, for instance, Halkos & Gkampoura, 2021), suggesting the existence of the EKC hypothesis. Bandari et al. (2022) argued that this prioritization is inevitable due to the unique resource constraints and varying stages of economic development of each nation. The impact of renewable energy consumption on sustainability will be rigorously discussed in the succeeding sections.

C. Empirical Strategy: Linking the Footprint of Energy Consumption with Sustainability in the SDG Framework

The SDGs provide a comprehensive framework for guiding humanity toward a more equitable and sustainable future. Among the 17 goals, SDG-7 aims to ensure access to affordable, reliable, sustainable, and modern energy for all. Furthermore, SDG-7 is specified further into five targets, i.e., (7.1) universal access to modern energy; (7.2) increase the global percentage of renewable energy; (7.3) double the improvement in energy efficiency; (7.4) promote access to research, technology, and investments in clean energy; and (7.5) expand and upgrade energy services for developing countries. To achieve this goal, a radical transformation of the current energy system, from fossil fuels to low-carbon energy sources, is required to create a balance between economic, social, and environmental goals. This, in turn, will accelerate the progress toward well-being in the SDG framework. However, the Sustainable Development Report 2022 (Sachs et al., 2022) reported that except for Latin America and the Caribbean, all regions in the world, on average, were not on track to achieving SDG-7. Additionally, He et al. (2022) estimated that despite the noticeable progress in SDG-7, the expected targets of SDG-7 are not likely to be achieved by 2030.

The SDGs were crafted as an integrated and indivisible set of 17 goals and targets with the intention of achieving them all simultaneously (Le Blanc, 2015). Notwithstanding this fact, the goals and targets were developed in a compartmentalized manner, resulting in inevitable trade-offs and synergies between the SDGs. The potential trade-offs across and within the SDGs are believed to be the main cause that hindered the simultaneous achievement of all 17 SDGs (see, for instance, Hametner, 2022). For instance, to expedite the advancement towards Target 7.1, underprivileged economies could potentially resort to more cost-effective energy sources, such as coal, to guarantee the accessibility and reasonable pricing of energy for all. Nevertheless, this strategy could prove detrimental to the realization of Target 7.2, which aims to enhance the worldwide proportion of renewable energy, as well as other environmental-related goals such as SDG-12 and SDG-13 (Sugiawan et al., 2023). It is, therefore, crucial to carefully evaluate the potential trade-offs between short-term gains and long-term sustainability while pursuing these targets.

In the light of sustainable development agenda, this chapter aims to explore the impacts of renewable energy sources on the SDGs by establishing the link between the footprint of energy consumption and the progress of SDGs. The first step of the analysis will be based on the following empirical relationship of the energy-SDG7 model:

$$SDG7_{it} = f\ (Fossil_{it}, Renewable_{it}, Nuclear_{it}) \qquad (4.1)$$

where *SDG7* is the progress of Goal 7 which is proxied by the SDG-7 Index score from the Sustainable Development Report 2022; *Fossil* is the aggregate of energy consumption from oil, coal, and gas; *Renewable* is the aggregate of energy consumption from hydropower, wind, and solar; and *Nuclear* is the total energy consumption from nuclear energy. To encompass a broader context of sustainability, the next step of the analysis will involve the following empirical relationship of the energy-SDGs model:

$$SDGS_{it} = f\ (Fossil_{it}, Renewable_{it}, Nuclear_{it}) \qquad (4.2)$$

where *SDGS* is the overall performance of SDGs which is proxied by the SDG Index score from the Sustainable Development Report 2022.

The data on energy consumption is measured in TWh and it was obtained from Our World in Data (Ritchie et al., 2022). The SDG Index score is a value from 0–100 which measures the country's progress in achieving the SDGs and it was obtained from https://dashboards.sdg-index.org/explorer. It is important to note that the calculation of the SDG-7 Index score only took into account Target 7.1 and 7.2. Hence, the SDG-7 Index score might not represent the actual performance of Goal 7. Similarly, the overall SDG Index score might deviate from the actual performance of all 17 SDGs, since the calculation of the SDG Index score did not take into account all the targets of the 17 SDGs. However, compared to other possible proxies, the SDG Index score is still a better proxy since it offers a more comprehensive and longer period of data. The present chapter undertakes an examination of a balanced panel comprising of 77 countries that spans the time period from 2000 to 2020. The selection of countries and the duration of the analysis were determined by the available data. To improve the model's predictive power and to make the model converge faster, the data on energy consumption is transformed into logarithmic forms.

Equations (4.1) and (4.2) are estimated by using the boosted regression trees (BRT) method, a widely recognized machine learning technique for its remarkable predictive performance (Elith et al., 2008). To prevent model overfitting, the sample is separated into two sets—the training set and the test set—based on the year. The training set comprises data from 2000 to 2015, whereas the test set comprises data from 2016 to 2020. This separation ensures that the model's accuracy is not compromised by its ability to fit itself to the sample data. To find the best model specification, this chapter relies on the automated machine learning (AutoML) tool which is available in the *forester* package in R. This tool will automatically find the best model specification by training the model with five different BRT methods, i.e., *decision tree*, *random forest*, *xgboost*, *catboost*, and *lightgbm*, and three different parameter optimizations, i.e., default, random search, and Bayesian optimization. The selection of the final model was determined by evaluating its predictive performance stability, which was determined by comparing the mean absolute error (MAE) with the lowest possible value and examining the smallest difference between the training and test set's MAE. Additionally, a reliable model should have an excellent predictive performance which is indicated by a mean absolute percentage error (MAPE) value of less than 0.1 (Sugiawan et al., 2019). Furthermore, to shed light on the "black box" characteristic of the BRT method, this chapter will rely on the *Shapley Additive exPlanations* (SHAP) method, developed by Lundberg and Lee (2017) to enhance the comprehensibility of the *xgboost* method. The SHAP method is available in *R* through the *SHAPforxgboost* package (Liu et al., 2021).

D. Promoting Access to Affordable and Clean Energy: Should We Invest More in Renewable Energy?

The impact of renewable energy consumption on the achievement of Goal 7 of the SDGs is assessed by using the energy-SDG7 model which is represented by Equation (4.1). Our analysis commences with evaluating the predictive performance of the model. The overall good fit of the model, for both the training and test set, is provided in Figure 4.1. The accuracy of the model is determined by the ratio between the predicted and the actual value. A value equal to 1 indicates a good fit, i.e., the forecasted value is equal to the actual value. The best model specification was found for the *lightgbm* method which was optimized by using the random search approach. Figure 4.1 shows that the progress in the SDG-7 Index score is well-predicted by our model with an in-sample MAE value of 1.378 and MAPE value of 0.020. For the test data set, as expected, the out-of-sample MAE and MAPE values dropped to 3.486 and 0.051, respectively. However, the MAPE values for both the training and test set are still below 0.1. Thus, it can be concluded that our model has excellent predictive performance and can be used for the subsequent analysis.

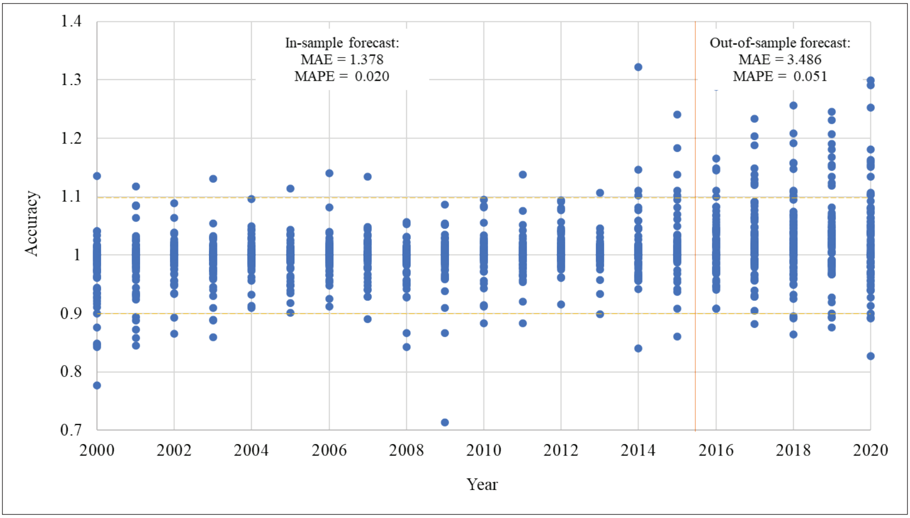

Figure 4.1 The Predictive Performance of the Energy-SDG7 Model

After confirming the reliability of the models, we carry on our analysis further by examining the SHAP importance plot as depicted in Figure 4.2. The vertical axis of the plot denotes the energy sources, whereas the horizontal axis denotes the SHAP value. The dots in the plot are indicative of SHAP values pertaining to particular energy sources, with orange dots denoting low feature value and purple dots denoting high feature value. The distribution of the dots in the plot portrays the correlation between energy sources and Goal 7 in the model. A positive correlation exists if the orange and purple dots are distributed in a pattern that resembles the color gradation of the feature value box (see the legend at the bottom part of the plot). On the contrary, a negative correlation exists if the orange and purple dots are distributed in an opposing pattern with the color gradation of the feature value box. If the orange and purple dots are distributed in a random pattern, then no inference regarding the direction of correlation can be made from the plot. The order of variables on the plot indicates the rank of importance, i.e., how significant the changes in variables will affect the progress of Goal 7.

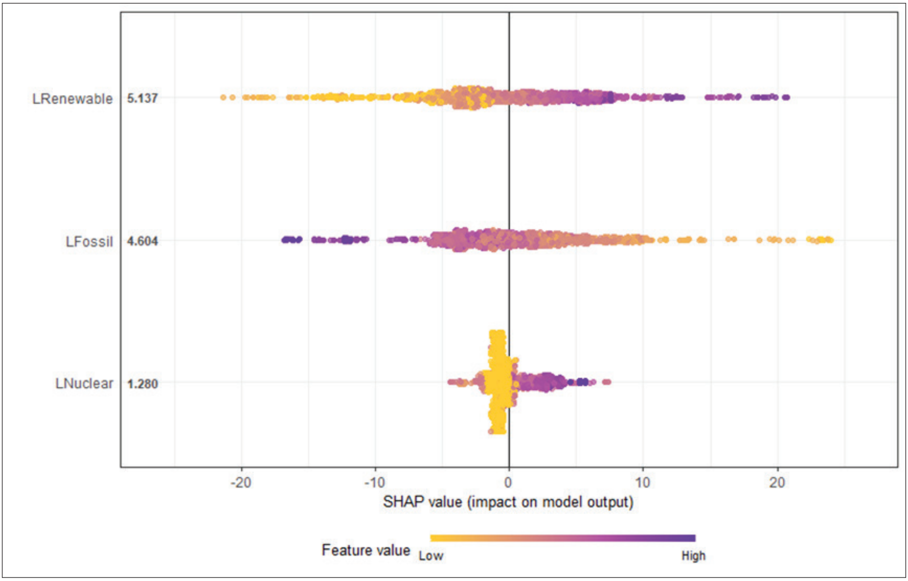

Figure 4.2 The SHAP Importance Plot of the Energy-SDG7 Model

From Figure 4.2, it can be seen that renewable energy sources are the most influential predictor of Goal 7, followed by fossil fuels and nuclear energy, with a SHAP value of 5.137, 4.604, and 1.280, respectively. Hence, compared to other energy sources, a small change in renewable energy consumption will have a more significant impact on the Goal 7 score. Figure 4.2 also captures the different impacts of each energy source in promoting the achievement of Goal 7. Unlike fossil fuels, high consumption of low-carbon energy sources is positively correlated with a high score of Goal 7. Additionally, Figure 4.2 also shows that among low-carbon energy sources, the impact of renewable energy sources on promoting Goal 7 is more prominent than that of nuclear energy. This is not a surprising result since the global consumption of renewable energy sources was almost three times higher than that of nuclear energy.

In order to fully grasp the relationship between energy sources and Goal 7 in terms of their functional structure, it is essential that the

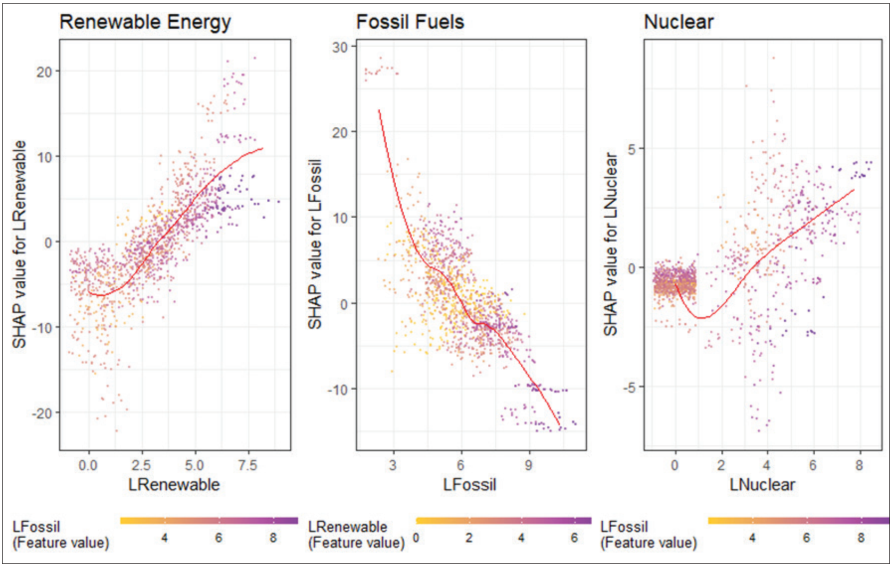

Figure 4.3 The Partial Dependence Plot of the Energy-SDG7 Model

importance plot is complemented with a partial dependence plot. This plot illustrates the model's fitted values in relation to individual predictors with great accuracy (Miller et al., 2016), as provided in Figure 4.3. Figure 4.3 shows that, to some extent, the relationship between energy consumption and the progress in Goal 7 can be approximated by a linear function. Additionally, consistent with the finding from the SHAP importance plot, we also found distinct effects of each energy source on the attainment of Goal 7, as evidenced by their respective slopes in the partial dependence plot. Positive slopes were found for low-carbon energy sources, while a negative slope was displayed for fossil fuels. The partial dependence plot is also able to portray the most significant interaction between energy sources that occurred in our model. From Figure 4.3, we found significant interactions between renewable energy and fossil fuels and between nuclear energy and fossil fuels. However, we found no evidence of significant interaction between low-carbon energy sources, i.e., between renewable and nuclear energy in promoting Goal 7.

The aforementioned findings suggest that the energy transition towards low-carbon energy sources is beneficial for accelerating the achievement of a sustainable energy system, as depicted by Goal 7 of the SDGs. Furthermore, in the framework of inclusive wealth (see, for instance, Managi & Kumar, 2018) for a detailed explanation of the notion of inclusive wealth), Sugiawan et al. (2023) showed that progress in Goal 7 will positively influence wealth accumulation, which is a necessary condition for achieving long-term sustainability. Thus, investing in low-carbon energy sources will be beneficial, not only for providing greater access to affordable and clean energy for all but also for achieving long-term sustainability in the framework of inclusive wealth.

Our findings also show that the interactions between each energy source were found to be complementary instead of substitutive. From Figure 4.3, we can see that high consumption of renewable energy is associated with a high score of Goal 7. However, this high score is still associated with the high consumption of fossil fuels, implying that renewable energy sources have not been able to substitute fossil fuel yet. For instance, a particular country may opt to boost new investments in renewable energy to achieve carbon neutrality. This obviously will result in an increase in the score of the SDG-7 Index, particularly for Target 7.2. However, such a policy might not be compatible with Target 7.1, which aims to provide greater access to electricity. Thus, at the same time, that particular country also invests in new fossil fuel power stations to provide affordable electricity. Such a policy will lead to a higher level of carbon dioxide emissions, resulting in a lower score of Goal 7. As a result, the final score of the SDG-7 Index will be determined by the net effect of the two policies. Hence, while investing in low-carbon energy sources can positively contribute to the achievement of Goal 7, the prevalent use of fossil fuels in the global energy supply has made the benefits less noticeable or even diminished.

E. Does Carbon Neutrality Matter to SDGs?

In the previous section, we established the link between energy consumption and Goal 7 of the SDGs and found that energy transition to low-carbon energy sources will be beneficial for promoting the achievement of Goal 7. While carbon neutrality is a crucial goal, it may not be adequate to guarantee sustainable development, and additional measures may be necessary to ensure intergenerational well-being (see, for instance, Sugiawan et al., 2019). The notion of sustainability requires intergenerational well-being to be maintained from being declined over time. Thus, evaluating the alignment of energy consumption with sustainable well-being, as proxied by the SDG Index score in this particular research, is of utmost importance. For this purpose, this chapter relies on the energy-SDGs model, which is provided in Equation (4.2). By doing so, this chapter will be able to discover whether energy consumption promotes or hinders the simultaneous achievement of the SDGs.

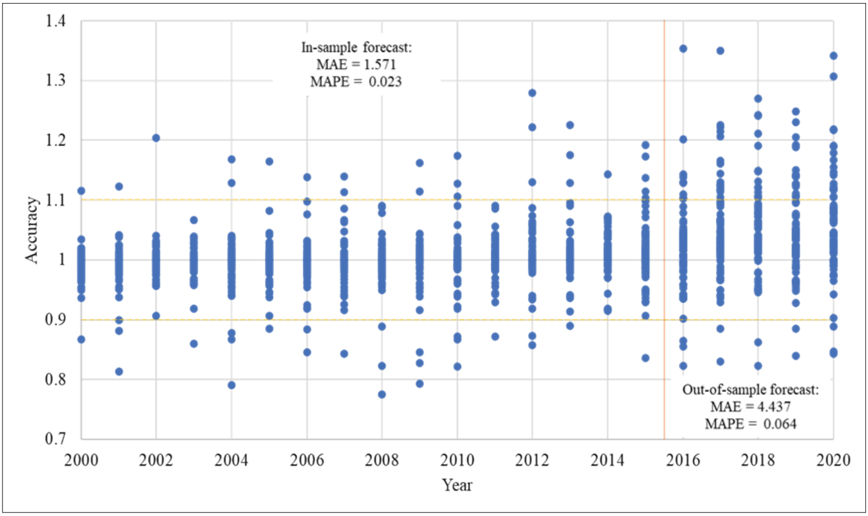

Figure 4.4 The Predictive Performance of the Energy-SDGs Model

Before commencing with the analysis, it is necessary to evaluate the reliability of the energy-SDGs model by looking at its overall performance. The graph shown in Figure 4.4 demonstrates that our model is a good fit, as it accurately predicts the progress of the SDG Index score with an in-sample MAE value of 1.571 and MAPE value of 0.023. Our model also shows a good predictive performance for the out-of-sample data with MAE and MAPE values of 4.437 and 0.064, respectively. This model specification was obtained from the *lightgbm* method which was optimized by using the Bayes optimization. Furthermore, in order to identify the significant predictors of SDGs, the next phase of the analysis will focus on the SHAP importance plot of the energy-SDGs model.

Figure 4.5 shows that fossil fuel is the most influential predictor of the SDG Index score, followed by nuclear and renewable energy, with a SHAP value of 2.694, 2.583, and 2.429, respectively. However, with such a slight difference in the SHAP values, it can be inferred

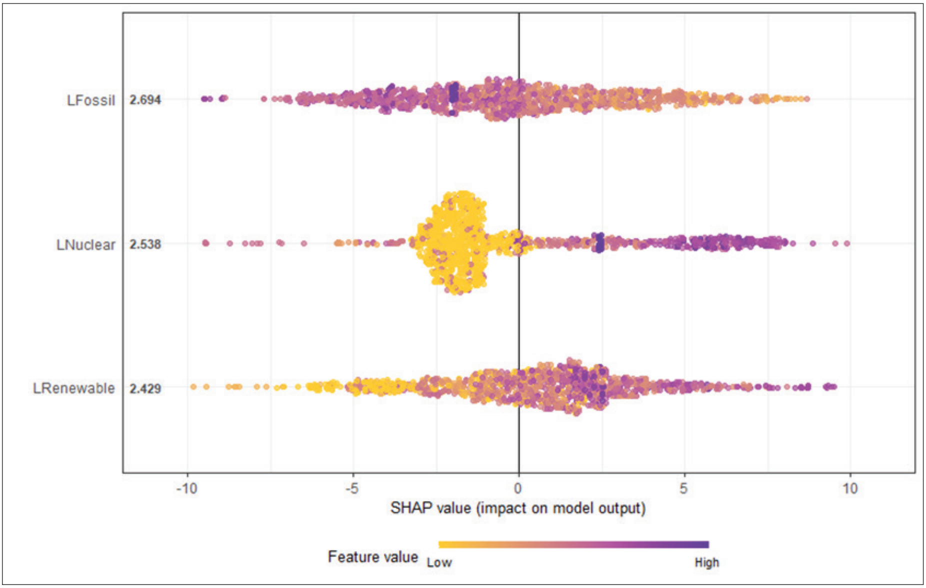

Figure 4.5 The SHAP Importance Plot of the Energy-SDGs Model

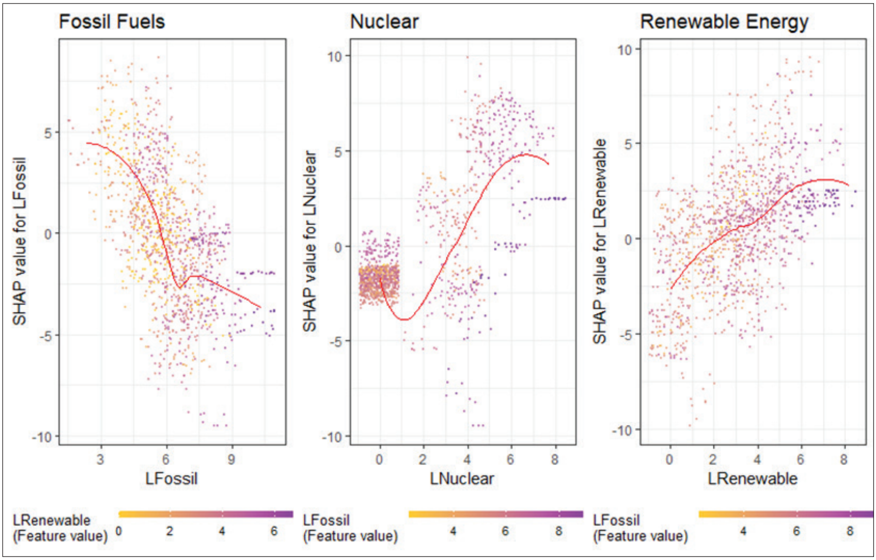

Figure 4.6 The Partial Dependence Plot of the Energy-SDGs Model

that no each energy source has a dominant impact on the SDG Index score. Figure 4.5 also shows that higher consumption of fossil fuels is associated with lower SDG Index scores, although the pattern is rather subtle. A contradictory yet more recognizable pattern is found for low-carbon energy sources, where higher consumption of nuclear and renewable energy is associated with higher SDG Index scores. To complement the results from the SHAP importance plot, we will evaluate the partial dependence plot which is provided in Figure 4.6.

The relationships between energy consumption and the progress in SDGs are rather complex and cannot be approximated by a simple linear function, except for the case of renewable energy. Consistent with the finding from the SHAP importance plot, we found positive correlations between nuclear energy and SDGs, and between renewable energy and SDGs. However, a positive correlation between nuclear energy consumption and SDGs occurred only temporarily around some threshold points. Confirming the preliminary findings from the SHAP importance plot, we also found a negative correlation between fossil fuels and the SDG Index score. Furthermore, similar to the case of the energy-SDG7 model, significant interactions between energy sources were found only between fossil fuels and either nuclear or renewable energy.

Complementing the previous section, the main findings in this section highlight the beneficial impacts of energy transition towards low-carbon energy sources in a more comprehensive context of sustainability. Our research findings suggest that the adoption of low-carbon energy sources is an advisable approach to simultaneously achieving socioeconomic and environmental objectives within the SDG framework. However, our findings are not without caution. According to York and Bell (2019), energy transition takes place if the deployment of renewable energy sources has managed to reduce or even replace the use of fossil fuels. Figure 4.6 suggests that higher SDG Index scores cannot be detached from the growth in fossil fuel consumption. In other words, the positive impacts of renewable and nuclear energy consumption on SDGs are achieved along with the increasing consumption of fossil fuels, implying that the role of fossil fuels in the global economy is still irreplaceable by low-carbon energy sources. Hence, Figure 4.6 provides no evidence of an energy transition towards carbon neutrality. Instead, it provides strong evidence of energy addition, which, according to York and Bell (2019), is not preferable for sustainability.

Energy addition portrays a phenomenon in which the deployment of low-carbon energy sources is intended to expand energy production from new sources while maintaining the use of fossil-powered energy sources (York & Bell, 2019). As a result, the prevalent use of fossil fuels in the global energy mix will create constant pressures on sustainability. Despite the persistence of fossil fuels, low-carbon energy sources are required to hold back the growth of fossil fuel consumption and ameliorate the externalities of the excessive use of fossil fuels. This is evident from Figure 4.6, where the negative slope of fossil fuels became less steep on a high amount of renewable energy consumption. Additionally, Figure 4.6 also shows that the mix between low-fossil and high-renewable will result in a higher SDG Index score compared to the mix between high-fossil and high-renewable. However, despite the multiple benefits that renewable energy can offer, energy transition from fossil fuels remains elusive. With the rapidly declining cost of renewable energy in recent years, one of the major challenges of transitioning to carbon neutrality is related to either social or regulatory barriers (Diesendorf & Elliston, 2018; Seetharaman et al., 2019).

F. Closing

This chapter aimed to assess the sustainability of energy consumption, particularly renewable energy, from the UN SDGs perspective. We opted to use the SGDs as our assessment tool since it provides comprehensive indicators that measure the progress toward well-being. By doing so, we can comprehensively assess the impacts of energy consumption on socioeconomic and environmental goals and ensure that those goals can be achieved simultaneously. For the proxy of SDGs, we employed the SDG Index score since it provides a more comprehensive and longer period of data. Our analysis was conducted in two steps. The first step of the analysis aimed to assess the impact of energy consumption on the sustainability of the energy system through the energy-SDG7 model. The second step of the analysis involved a more comprehensive assessment of sustainability through the energy-SDGs model. The nonparametric machine learning method, renowned for its exceptional predictive capabilities and ease of comprehension, was employed to scrutinize our models. Our analysis involved a balanced panel comprising 77 countries that span the period from 2000 to 2020.

We found beneficial impacts of low-carbon energy sources on the energy systems' sustainability and sustainable well-being. The beneficial impact of renewable energy was more pronounced in the case of the energy-SDG7 model, i.e., in promoting greater access to affordable and clean energy. The beneficial impact of nuclear energy was more pronounced in the case of the energy-SDGs model, i.e., in promoting the achievement of all 17 SDGs. We also found unfavorable impacts of fossil fuels on sustainability for both models. In the context of sustainable well-being, which is depicted by the energy-SDGs model, the detrimental effects of fossil fuels were even higher since fossil fuels were found to be the most significant predictor of SDGs. With the ongoing domination of fossil fuels in the global energy mix, the benefits from low-carbon energy sources became less noticeable or even diminished. Additionally, we found no evidence that the global energy transition towards low-carbon energy sources has been accomplished. Instead, we found evidence of energy addition, suggesting that the role of fossil fuels in the global energy mix remained irreplaceable.

While it is not within the purview of this chapter to propose novel policies, our results underscore some critical implications for policymaking. Firstly, in the pursuit of the 2030 Agenda for Sustainable Development, policymakers need to identify the barriers that hamper the deployment of renewable and/or nuclear energy since the energy transition towards low-carbon energy sources will provide multiple benefits, not only for the sustainability of energy system but also for the intergenerational equity of well-being. Secondly, in addition to boosting new investment in low-carbon energy sources, policymakers need to ensure the phase-out of fossil-powered energy sources so that the energy transition can be utterly achieved. Finally, to expedite the simultaneous achievement of sustainable development goals, this chapter suggests the necessity to formulate a balanced energy mix comprising both renewable and nuclear energy while taking into consideration the availability, affordability, accessibility, and acceptability of each energy source.

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