Impact of Technological Innovation on Energy Efficiency in Industry 4.0 Era: Moderation of Shadow Economy in Sustainable Development

Chen, Maozhi and Sinha, Avik and Hu, Kexiang and Shah, Muhammad Ibrahim

Chongqing University of Education, China, Goa Institute of Management, India, Chongqing Technology and Business University, China, BRAC University, Bangladesh

2020

Impact of Technological Innovation on Energy Efficiency in Industry 4.0 Era: Moderation of Shadow Economy in Sustainable Development

Maozhi Chen
School of Economics and Business Administration,
Chongqing University of Education, China
Email: calcmz@hotmail.com

Avik Sinha
Centre for Excellence in Sustainable Development,
Goa Institute of Management, India
Email: f11aviks@iimidr.ac.in

Kexiang Hu[1]
School of Business Administration,
Chongqing Technology and Business University, China.
Email: 3115059778@qq.com

Muhammad Ibrahim Shah
BRAC Institute of Governance and Development,
BRAC University, Dhaka, Bangladesh
Email: ibrahimecondu@gmail.com

Abstract: Despite the ongoing research on energy efficiency and innovation in the context of Industry 4.0, little is known on how degree of leakages in economy can impact the energy efficiency-innovation association. This issue has been addressed by the United Nations in their Sustainable Development Goals (SDG) report also. In the era of Industry 4.0, this issue can be crucial from the perspective of sustainable development, and we are analyzing this issue in case of Middle East and North African (MENA) countries over a period of 1990-2016. The second-generation methodological approaches have been adopted. Our results show that technological innovation has a positive impact on energy efficiency, whereas growth in shadow economy has a detrimental impact on energy efficiency. The structural transformation of economy has positive impact on energy efficiency. Based on our results, we have designed an SDG framework, which might help the MENA countries to achieve the objectives of SDG 7, SDG 8, SDG 9, and SDG 4.

Keywords: Energy Efficiency; Technological Innovation; Sustainable Development Goals; Fisher Ideal Index; Lilien Index

[1] Corresponding author

1. Introduction

The world has ushered in the era of Industry 4.0, and in keeping with the structural economic transformation brought forth by the 4th Industrial Revolution, role of innovation is being redefined as an enabler of digital transformation and automation. In such a scenario, the innovations are also directed towards enabling the nations to achieve energy efficiency, either by improving the existing production processes, or by promoting renewable energy solutions. However, despite the continuous efforts to reduce energy consumption, energy demand is increasing globally, while deteriorating the environmental quality. In the era of Sustainable Development Goals (SDGs), this issue is turning out to be more prominent. Therefore, policymakers and stakeholders are increasingly turning their attention towards reducing energy consumption through achieving energy efficiency, and innovation can play a major role in this regard. In order to achieve innovation-led energy efficiency, proper diffusion of innovation is necessary, and various emerging economies are encountering difficulties in that aspect. In this regard, the Middle East and North African (MENA) countries need a special mention. The report by IISD (2017) has discussed that the MENA countries are facing difficulties in achieving the objectives of SDG 7, i.e., affordable and clean energy. In a consecutive report, while pinpointing this issue, Göll et al. (2019) has talked about poor diffusion of technological progression in these nations, due to which they are facing difficulties in attaining objectives of SDG 9, i.e., industry, innovation, and infrastructure.

Economic growth pattern of the MENA countries is heavily dependent on fossil fuel consumption, with crude oil having 45% and natural gas having 47% share in the energy mix (Menichettti et al. 2017). Owing to the continuous increase in population and economic growth, demand for energy is increasing accordingly. During 1990-2016, energy demand in the MENA countries has increased from 4% to 8% (World Bank, 2019). Opposed to the rise in global electricity demand by 2.9% during this period, the MENA countries have accounted an annual increase by 6%. Alongside this, over 100% increase in CO_2 emissions was also observed during 2000-2010 in this region (Shamali et al., 2019). These economies are characterized by the increase in both energy demand and CO_2 emissions, and this might create a predicament for these nations to achieve the objectives of SDG 13, i.e., climate action. Therefore, there is a growing need to increase energy efficiency through technological innovation in these countries (Shahbaz et al. 2019). In a recent conference organized by the United Nations Industrial Development Organization (UNIDO), the importance of innovation for achieving energy efficiency in the MENA countries was discussed (IPI, 2020).

According to Wang and Wang (2020), along with the technological developments, energy efficiency follows sectoral transformation. During the last decade, the MENA countries have experienced structural transformation from agriculture to industrial and finally to service sector (Shahbaz et al. 2019). Consequently, energy efficiency is expected to undergo a transformation. The report by IISD (2018) has discussed the evolution of energy efficiency through economic transition, and its role in ascertaining sustainable development. In a consecutive report by United Nations (2020), the similar aspect has been discussed from the perspective of promoting green energy initiatives through economic transition. From this perspective, the significance of economic transformation in shaping the evolution of energy efficiency can be assumed. However, presence of shadow economy[2] is turning out to be a barrier for the MENA countries to achieve energy efficiency. Due to the limitation of social protection coverage and unstable and low revenues, informal employment amounts to around 68% in the region, with 74% in Yemen, 71% in Lebanon, and 63% in Morocco and Egypt (Gatti et al. 2013, Bonnet et al. 2019, Mabrouk 2020). Moreover, Sheikh (2020) noted that one third of average GDP of MENA countries come from the informal sector. While discussing

[2] According to Smith (1994), shadow economy can be referred to the informal economic activities (legal or illegal) that can escape the detection in GDP accounting.

about the SDG progress report of Latvia (CSCC, 2018) and Poland (GCNP, 2018), the role of shadow economy has been identified as an obstacle to the technological progression and economic development. Hence, it can be said the presence of shadow economy might hinder these nations from achieving the objectives of SDG 7 and SDG 9, and this can have a possible impact on the job creation and quality of life scenario of these nations, which is reflected by the objectives of SDG 8. In view of this, it might be said that the MENA countries might need a policy-realignment or a comprehensive policy framework to address this policy gap, which involves the moderating impact of shadow economy on the Technological Innovation-Energy Efficiency association. There comes the role of the present study.

To sum up, the above discussion corroborates the necessity of a comprehensive policy framework for the MENA countries, which can play an instrumental part in accomplishing the 2030 agenda. In this setting, present study intends to scrutinize the influence of technological innovation on energy efficiency in the MENA countries over the period of 1990-2016, while considering shadow economy to be playing the role of a moderator of this association. As the MENA countries can be taken as the emerging economies, outlining an SDG framework for them is likely to assist other emerging economies in policy reorientation. Consideration of these parameters within a single policy agenda might help to design a comprehensive policy framework for addressing the objectives of SDG 7, SDG 9, SDG 8, and thereafter SDG 4. There is a void in the literature on devising an SDG-focused policy-level approach for addressing the issue of energy security. Closing this void is the key policy-level contribution of this study.

Now, the MENA countries are structurally similar in nature, and they are associated with each other by means of economic spillovers. Therefore, the analytical approach should take care of this aspect for achieving the desired policy-level contribution. In this pursuit, the second-generation methodological approach has been adopted, as this approach is capable of taking the cross-sectional dependence into account. Hence, the cross-sectional autoregressive distributed lag (CS-ARDL) method is utilized in this study. This method can consider the structural resemblances within the chosen countries, while indicating the effects of explanatory policy parameters to vary in terms of response duration. Moreover, Diks and Panchenko (2006) Panel Causality test is also adopted to the look into the bidirectionality in the associative nature of the model parameters. Methodological contribution of the study lies in this complementarity with the policy-level contribution of the study.

2. Literature review

Energy efficiency assumes a critical part in energy framework of sustainable growth and development as it can ensure a country's energy security (Destek and Sinha, 2020; Dogan et al., 2020; Liu et al. 2020). Moreover, energy efficient technology development can result in the reduction of energy intensity at both household and industrial level (Sinha and Bhattacharya, 2016, 2017; Saudi et al., 2019). Based on the policy-level approach adopted this study, we divide this section into three separate subsections: (a) technological innovation and energy sector, (b) shadow economy and energy sector, and (c) structural change and energy sector.

2.1. Technological Innovation and Energy Sector

Our main objective is to see the effect of technological innovation on energy efficiency and here we can distinguish between two strands of literatures. First strand deals with the impact of technology indirectly on energy efficiency, either through energy use, energy consumption or energy intensity. For example, the impact of technological innovation (measured by total factor productivity) on energy efficiency was analyzed by Jin et al. (2018). They utilized a three-stage approach in analyzing the nexus between technological innovation and energy consumption. As opposed to the conventional theory of sustainable development, they found that technological innovation does not necessarily decrease the amount of energy consumption. Therefore, policies should focus on technological innovation to improve energy efficiency rather than solely relying on the reduction of energy consumption. They estimated the aforementioned relationship for 28 Chinese provinces.

Saudi et al. (2019) used three measures of technological innovation to assess their impacts on energy intensity (or energy inefficiency) for Indonesia. Their results from ARDL analysis suggested that all the proxies of technological innovation negatively affect energy intensity in the country. Therefore, Indonesia can reduce energy inefficiency with high research and development (R&D) expenditures, technology exports and number of registered patients. Extending the Marshallian demand framework, Sohag et al. (2015) used patent applications as a proxy for technological innovation to measure its impact on energy use in Malaysia. They found a negative impact of technological progress on energy use, implying that innovation increases energy efficiency of production processes. They suggested that government should substitute old inefficient technologies and increase research and development in energy efficient technologies so as to meet CO_2 emissions reduction target. Fisher-Vanden et al. (2006) analyzed China's energy productivity in terms of the country's industrial sector. They have found that China's total energy use and intensity both are reduced with the high level of research and development expenditures. Based on 35 African countries, a recent study by Owoeye et al. (2020) suggested that technological innovation, measured by patents and trademark registered, has no effect on the reduction of electricity consumption. This implies that Africa's level of innovation is very poor and government efforts must be on technology to improve energy efficiency. Tandon and Ahmed (2016) analyzed the effect of technological improvement (sector wise changes in production technology) on India's energy consumption using input output framework. Their results estimated that about two thirds of energy requirement can be counterbalanced from savings due to improvement in technology. Their decomposition analysis of technological effect on energy use into both non energy and energy inputs proved the continuous improvement of energy inputs in terms of efficiency.

Studies have also focused on technology's impact on renewable and fossil fuel energy consumption. Alam and Murad (2020), for instance, focused on panel data and country level data analysis of OECD countries in order to ascertain the impact of technological progress on renewable energy use and the effect varied according to the estimation method used. While most of the estimation techniques such as pooled mean group (PMG), mean group (MG), dynamic fixed effect (DFE), and dynamic ordinary least square (DOLS) could not get significant result, fully modified ordinary least square (FMOLS) revealed that innovative improves renewable use significantly. The results for individual country also varied. For Netherland and Norway, technology influenced energy use positively but for France, the USA and Iceland, it had a negative impact. On another hand, Fei and Rasiah (2016) in their analysis have found that due to progressive shift towards alternative energy in electricity consumption from fossil fuel, technological innovation cannot explain the variation of fossil fuel powered electricity consumption for South Africa, Norway, Canada and Ecuador. Nevertheless, analysis suggested that technological innovation possibly could raise efficiency of total electricity consumption.

The second strand of literatures focus on the effect of technological innovation directly on energy efficiency and majority of them concentrate on China. With the increase in economic growth as well as in the investment for clean energy technology, China has made significant progress in energy efficiency and it has been well documented in empirical literatures (Wang and Wang 2020). As opposed to Jin et al. (2018), Pan et al. (2019a) used patent applications as a measure of technological innovation and analyzed the nexus of environmental regulation, energy efficiency and technological innovation in 30 Chinese provinces. They have used two types of environmental regulation in their study, command control environmental regulation and market incentive environmental regulation. Applying structural vector autoregression (SVAR) approach, they have found that technological innovation improves energy efficiency in the short run and long run. To achieve energy efficiency, they suggested that the use of environmental regulation depend on two characteristics. First, whether the region has energy intensive or technology intensive industries and second, whether the region has high or low rate of energy consumption. According to them, the regions that have high rate of energy consumption and energy intensive industries, they should use the command control environmental regulation while market incentive environmental regulation should be used in technology intensive industries and low energy consumption regions. Both the regulations had direct impact on energy efficiency but market incentive environmental regulation indirectly affected energy efficiency via technological innovation. In another study for Bangladesh, Pan et al. (2019b) examined the impacts of technological innovation on energy intensity measured by single factor energy efficiency. The analysis revealed that technological innovation promotes energy intensity. An analysis of 284 Chinese cities by Wang and Wang (2020), on the other hand, revealed that energy efficiency is significantly and positively affected by the technological progress at the country level. They divided the Chinese regions into four categories and found that technological innovation is favorable to the eastern, western and northeast regions but it tends to hinder the progress of energy efficiency in the central region. The large differences in energy efficiency of Chinese cities was also observed by Liu et al. (2020). They have found that better allocation of resources through the technological progress is the key towards technology transformation and diffusion, which in turn increases energy efficiency. However, national level policies must also take account of energy efficiency differences across the regions. For example, eastern coastal region is a highly energy efficient region which can in turn can help improve energy efficiency in other three regions (e.g. western, middle and north-eastern). The superiority of eastern region in terms of energy efficiency was also documented by Ouyang et al. (2020) who focused on industrial energy efficiency and said that technological progress is the key factor deriving China's energy efficiency in industrial sector. They recommended that both the central and western regions need to enhance energy efficiency and reduce the gap they have with eastern region in terms of technology.

The neoclassical growth theory postulates that energy efficiency can be enhanced by technological innovation and thus energy consumption will decrease. At this time, producers intend to use more energy rather than considering other input factors and consumers consume more energy. So now additional energy consumption partially offsets energy saving that was generated by energy efficiency. Zhang (2019) analyzed rebound effect for China using the logarithmic mean divisia index (LMDI) decomposition method. They decomposed technological progress from energy efficiency factors by using this method. They have found that although energy efficiency can be enhanced through technological advancements and therefore save energy, rebound effect also exists. In order to formulate energy conservation, hence it is necessary to improve both the technology and energy efficiency.

2.2. Shadow economy and energy sector

There are only a few empirical studies which have linked the informal/shadow economy with energy sector. One of them being Basbay et al. (2016) who hypothesized that countries with higher level of informal sector has lower energy consumption per unit of output because of the fact that informal sector is less energy intensive compared to the formal one. They found a negative association between energy consumption and informal sector, considering that informal economy is labor intensive but not capital intensive. Moreover, their study also detected a nonlinear relationship between the above two variables as well as an asymmetric relationship especially for countries with lower informal economy and G20. In another study, Benkraiem et al. (2019) estimated the nexus between shadow or unrecorded economy and energy consumption for Bolivian economy. Using nonlinear ARDL method, they have found that positive and negative changes of shadow economy increases and reduces energy consumption in the long run. In the short run, a rise in shadow economy is associated with the reduction in consumption of energy and a reduction in shadow economy does not have significant effect on energy consumption. The result also confirmed the conservative hypothesis between energy consumption and unrecorded economy.

2.3. Structural change and energy sector

Decomposition analysis has been widely used in investigating structural change and energy efficiency linkage. Mulder and Groot (2012), for example, found that structural change of the OECD economies can largely explain the aggregate energy intensity pattern. Similar to Mulder and Groot (2012), Cao (2017) found via both theoretical and simulation modeling that growth rate of energy intensity is significantly affected by structural change. However, Farla and Blok (1999) analyzed Netherlands' structural change and energy intensity scenario and their analysis vis decomposition analysis revealed no large effect of structural change on energy intensity. In another study, Hofman and Labar (2006) used three different techniques such as correlation analysis, fixed effect model and two stage fixed effect model to determine the factors responsible for China's energy intensity level. They have found a negative effect of service's share in GDP on energy intensity but no significant effect was discovered from industry share to energy intensity for China. Ali et al. (2019) examined the linkage between structural change and energy use in Malaysia. The Granger causality result revealed that structural change and energy consumption have bidirectional causality with each other in the short run. This is supported by the fact that a more industry intensive economy implies a rise in energy consumption and a more service intensive industry indicates less use of energy resources. Energy consumption Granger causing structural change implies that having abundant energy related resources, a country may be concentrated towards industrial sector and having abundant services and human capital, a country may specialize in services sector.

Lin and Zhu (2020), on the other hand, focused on the role of structural change on energy efficiency of the electricity sector in Chinese provinces. They used different stochastic frontier analysis (SFA) models to estimate electricity efficiency. In their analysis, they found that electricity consumption is largely affected by the proportion of the secondary industry. Their analysis also showed that industrial sector's rationalization leads to an improvement in electricity consumption efficiency while efficiency score decreases with an enhancement of electrification level. More recently, Guang (2020) used Epsilon-based measure of data envelopment analysis to assess electrical energy efficiency. Using random effect Tobit model, the results indicated that industrial structure of the Chinese economy significantly and positively affected the efficiency of the electric energy. However, the results varied when they divided the economy into three regions. For western and eastern regions, a significant positive effect was observed with western region having higher coefficient. But for the central region, they have found a negative effect of industrial structure on electric energy efficiency.

2.4. Research gap

This brief review of literature demonstrates that the studies aiming to assess the possible determinants of energy efficiency have not reached any consensus, and that can be the possible reason behind the existence of the policy gap in this aspect. The IRENA (2020) outlook of 2050 for the MENA countries shows that this region will face a significant boom in its population, accounting to an average of 1.1% annual increase, and this will have a consequential impact on the energy demand. To meet the growing demand of energy, a novel policy level approach might be necessary. By designing an SDG-oriented policy framework for these economies, a roadmap for the other emerging economies can be developed. From the perspective of attaining the SDGs, this policy gap might prove to be crucial for these economies, and there comes the role of this study. The policy-oriented baseline approach adopted in this study has never been addressed in the literature, and the present study aims at addressing this pertaining research gap by developing the multipronged SDG framework for the MENA countries.

3. Empirical model and data

3.1. Theoretical underpinning

In this study, we have intended to analyze the impact of technological innovation, development of shadow economy, and structural transformation of economy on energy efficiency for the MENA countries. In the era of Industry 4.0, a nation needs to depend of the technological innovation, and without innovation, it is not possible to have sectoral transformation. Sinha (2016) and Zafar et al. (2019b) have given emphasis on the aspect of technological innovation, while considering the aspects of economic transformation in the emerging economies. While achieving sectoral transformation, nations try to achieve energy efficiency, either by means of improving production processes, or by substituting fossil fuel-based energy solutions by renewable energy solutions. Therefore, it can be expected that technological innovation might have a positive impact on energy efficiency. Now, while nations are trying to tread on economic growth path, per capita income of the citizens will go up, leading to improvements in the livelihood pattern. For the case of Asia-Pacific Economic Cooperation (APEC) countries, this aspect has bene observed by Zafar et al. (2019a). However, in absence of stringent governance practices, leakages will appear in the circular flow of economy, and causing the growth in the shadow economy. In a context of growing shadow economy, the innovation might not be diffused across the nation effectively, and it might have a detrimental impact on energy efficiency. This issue is a long-standing policy level debate, which has been detailed by Eilat and Zinnes (2002). Now, with the shadow economic growth, it might be difficult to have a control over the depletion of natural resources, and in such a scenario, rise in household energy demand might worsen the situation by resorting to fossil fuel-based solutions, and thereby departing from the achievement of energy efficiency.

Taking a cue from this discussion, the empirical model analyzed in this study is given by:

$$EE_{it} = a_0 + a_1 TECH_{it} + a_2 SE_{it} + a_3 POP_{it} + a_4 LIL_{it} + a_5 TECH_{it} * SE_{it} + \varepsilon_{it} \quad (1)$$

Here, EE is energy efficiency derived by Fisher Ideal Index, TECH is the index of technological innovation, SE is shadow economy, POP is population, LIL is the structural transformation of economy denoted by Lilien Index, i is the individual countries, t is the study period, and ε is the stochastic error. TECH is developed through principal component analysis (PCA), by considering number of patent applications (PAT), number of trademark applications (TM), and technical cooperation grants (GRANT). In the subsequent sections, we will discuss about the development of EE and LIL.

3.2. Computation of energy efficiency

Energy efficiency (EE) has been developed following Fisher Ideal Index (Fisher, 1921). The main reason behind using this index is its capability to encompass sectoral consumption of energy, and thereby, producing a wholesome form of energy efficiency (Sinha et al. 2020a). Following is the working principle of the index:

Considering sectoral energy intensity is given by SEI_{it}, and sectoral composition of nation is SCE_{it}, then composite energy intensity EI_t is given by:

$$EI_t = TN_t / EO_t = \sum_i (TN_{it} / EO_{it})(EO_{it} / EO_t) = \sum_i SEI_{it} SCE_{it} \quad (2)$$

Here, TN_t and EO_t are total consumption of power and gross economic output at time t, respectively. TN_{it} and EO_{it} indicate both the parameters at time t for sector i.

Once EI_t is computed, energy intensity index ENI_t is computed through the proportion of composite energy intensity at time t against that of the base year (t = 0). Considering the latter to be EI_0, the ENI_t is as follows:

$$ENI_t = EI_t/EI_0 = \sum_i SEI_{it}SCE_{it}/\sum_i SEI_{i0}SCE_{i0} \quad (3)$$

To compute the Fisher Ideal Index, Laspeyres (*LI*) and Paasche (*PI*) indices are essential. They are given by:

$$LI_t = \sum_i SEI_{it}SCE_{i0}/\sum_i SEI_{i0}SCE_{i0} \quad (4)$$

$$PI_t = \sum_i SEI_{it}SCE_{i0}/\sum_i SEI_{i0}SCE_{it} \quad (5)$$

Fisher Ideal Index (FI) is the geometric weighted average of LI and PI, and the final value of energy efficiency (EE_t) is given by:

$$EE_t = \sqrt{LI_t * PI_t} \quad (6)$$

3.3. Computation of structural transformation of economy

For encapsulating the structural change in the economy, notwithstanding the approach taken by Dogan and Inglesi-Lotz (2020), this study uses Lilien index, which measures the periodical standard deviation of sectoral employment (see, Garonna and Sica, 2000). It is given by:

$$LIL_{it} = [\sum_{i=1}^{n}(M_{it}/M_t)(\Delta logM_{it} - \Delta logM_t)^2]^{1/2} \quad (7)$$

Here, LIL is the Lilien Index, M is the sectoral employment, i is the sector, and t is the time.

3.4. Data

In this study, we have intended to analyze the impacts of technological innovation, development of shadow economy, and structural transformation of economy, on the energy efficiency for 19 MENA countries over 1990-2016. The annual data on gross capital formation (current USD), total labor force, sectoral share of labor, population, number of patent applications, number of trademark applications, and technical cooperation grants (current USD) have been collected from the World Development Indicators (World Bank, 2019), the data of gross value added by kind of economic activity have been collected from United Nations Statistics Division (UNSD, 2019), the data on final energy consumption by sector have been collected from International Energy Agency (IEA, 2019), and data for shadow economy are collected from the estimations provided by Medina and Schneider (2018). The correlation matrix for the PCA is provided in Appendix 1.

4. Results and discussion

In order to start with the analysis, it is necessary to check for the stationarity property of the model parameters, it will be accomplished through the application of unit root tests. However, depending on the assumption of cross-sectional dependence among the model parameters, there lies a divergence among the unit root tests. This divergence is reflected in terms of the segregation of the unit root test into first and second generation. Hence, in order to choose a suitable unit root test, it is necessary understand the nature of cross-sectional dependence among the model parameters. In this pursuit, we have applied Chudik and Pesaran (2015) cross-sectional dependence test, which has the null hypothesis of weak cross-sectional dependence. The test outcome reported in Table-1 demonstrates that there is a significant cross-sectional dependence among the model parameters. This particular piece of evidence sanctions the applicability of the second-generation unit root tests. In order to check the stationarity property of the model parameters, we have utilized cross-sectional augmented Dickey-Fuller (CADF) test and cross-sectional Im-Pesaran-Shin (CIPS) test by Pesaran (2007). The test results reported in Table 2 demonstrates that the model parameters are stationary at their first differences, and based on this particular piece of evidence we can conclude that the model parameters are first order integrated, i.e. they are I(1) in nature.

<Place for Table 1>

<Place for Table 2>

Once we have determined the order of integration among the model parameters, it is necessary to assess the possible long run Association among them. In order to carry out this assessment, the possibility of cointegrating association among them needs to be analyzed. As the model parameters have demonstrated presence of cross-sectional dependence among them, the cointegration test should encapsulate this aspect. Owing to this reason, we have applied Westerlund and Edgerton (2008) cointegration test. The test outcomes reported in Table-3 divulges that there is a significant cointegrating association among the model parameters. It symbolizes that the members of the MENA countries are associated with each other for the long run, given the presence of economic spillovers. The presence of a significant cointegrating association among the model parameters sanctions to proceed with estimating the long-run coefficients.

<Place for Table 3>

The results of long-run coefficient estimation are reported in Table-4. Let us begin with the impact of technological innovation on energy efficiency. The results show that technological innovation is having a positive impact on energy efficiency. As these nations are highly dependent on fossil fuel-based energy consumption for achieving economic growth, rise in the technological innovation will enable them not only to make a steady shift towards renewable energy solutions, but also to improve their existing production procedures for reducing energy intensity progressively. With the graduation of time, these nations have made significant improvement in technological innovation front, and impact of this improvement can be seen in terms of the advancements in energy efficiency. The recent report published by Göll et al. (2019) showcases that the MENA countries need to depend on technological innovations, as this might help them to achieve the long-run energy efficiency, and thereby, might help them in achieving the objectives of SDG 7. This segment of the results resonates the findings of Sun et al. (2019) for the developing economies, and Galeotti et al. (2020) for the OECD countries. Moreover, this improvement has been experienced along structural transformation of the economy. Therefore, in order to analyze the impact of technological innovation energy efficiency, it is also necessary to look into the impact of transformation of economy, which is translated in terms of Lilien index. Whenever any economy is transformed from agriculturedriven to industry- and service-driven, the nature of energy consumption pattern also goes for a transformation. This transformation is reflected in terms of improving energy efficiency of these nations. This statement is reflected in terms of the impact of Lilien index on energy efficiency, which shows that rise in Lilien index, i.e., a service-oriented sectoral transformation of the economy might catalyze these nations towards having better energy efficiency. This particular segment of the results complements the impact of technological innovation, as structural transformation of the economy shapes the nature of innovation. The UNIDO (2018) report on inclusive and sustainable industrial development has discussed that the industrial transformation in the MENA countries has shaped the nature of technological innovation, and transformational outlook of these nations towards Industry 4.0 might result in the enhancement in energy efficiency. The industrial transformation brought forth by means of Industry 4.0 might help these nations to make a progress towards attaining the objectives of SDG 9, and this advancement might prove to be complement the objectives of SDG 7. This segment of the findings falls in the similar lines with the findings of Fragkos et al. (2017) for the European Union, and Yang et al. (2018) for China.

Now, with the rise in service sector in the economy, more vocational opportunities are created. Largely, these opportunities have improved the standard of living of the citizens by increasing the level of per capita income, and with the improvement in living standard, energy demand might also go up. The existing energy generation infrastructure in these nations might not be able to cater to this rise in energy demand, and therefore, achieving energy efficiency might prove to be difficult for these nations. One of the major reasons behind this scenario can be attributed to the level of renewable energy generation in these nations, which is still at a nascent stage. So, the excess demand of energy might be catered either through fossil fuel-based energy consumption, or by means of energy import. In either of the cases, faster depletion of natural resources is expected to take place, and energy efficiency might not reach its full potential. A reflection of this argument can be visualized in the long-run coefficient of population. For the case of MENA countries, rise in the population might have a detrimental impact on energy efficiency, as the rise in the excess demand of energy might require to be fulfilled by the traditional sources of energy. This situation might prove to be a quandary on the way to achieve the objectives of SDG 7 in these nations. The United Nations (2019) also stresses on rising population as a major issue for the prospect of energy poverty in these regions, which can be viewed as a failure to achieve the energy efficiency. This segment of the results extends the finding of Nepal and Paija (2019) for Nepal, while contradicting the finding of Wasniewski (2020). On the other hand, due to the lack of stringent governance structure, leakages in economic structure can be seen, and these leakages are experienced in terms of the development of shadow economy. As this particular segment of the economy is characterized by tax evasion, players operating in this sector will always try to reduce the cost by exploiting natural resources. Moreover, as this sector is not effectively monitored by the governmental agencies, the firms operating in this sector might resort to non-compliance with the prevailing energy policies within the nation. This might create a predicament for the policymakers in diffusing the innovation across the nation. Hence, prominence of this sector might result in higher fossil fuel consumption, and thereby, causing a detrimental impact on the energy efficiency. A reflection of this argument can be seen in the coefficient of shadow economy in Table-4. The long-run coefficient estimation results demonstrate that the development of shadow economy might have a negative consequence on energy efficiency in case of the MENA countries. Moreover, when the shadow economic development is interacted with technological innovation, it is found to have negative impact on energy efficiency. This segment of the results demonstrates that the growth in shadow economy will impede technological innovation in pursuit of achieving energy efficiency. The OECD (2016) report on "*Better Policies Series*" has focused on this particular issue while discussing about energy security, and they also have attributed the development of shadow economy as one of the major reasons behind this issue. While focusing on Tunisia, Döring and Golli (2019) has discussed this issue for the MENA countries, and they have also stressed on how the growth in the shadow economy might create an obstacle on the way to achieve the objectives of SDG 7, by hindering energy security and energy efficiency. This particular segment of the findings empirically substantiates the arguments put forth by FEPS (2017) and Mlambo-Ngcuka and Alwis (2019). In order to check for the robustness of the results, we have also estimated the long-run coefficients using cross-sectional distributed lag (CS-DL) and common correlated effect-based generalized method of moments (CCE-GMM). The results show that the estimated coefficients are neither changing the signs nor showing significant variation in terms of magnitude, and thereby, sanctioning the robustness of the model outcome.

<Place for Table 4>

Bidirectionality is an inherent aspect of any robust policy design, and a comprehensive policy framework needs to take account of this particular aspect (Sinha et al., 2018). Therefore, in order to gain additional insights regarding the directional nature of the associations among the model parameters, we have carried out Diks and Panchenko (2006) nonparametric panel causality test, and the test outcomes are reported in Table-5. In keeping with the findings of long-run coefficient estimation, the causal impacts of the technological innovation, Lilien index, population, and shadow economic development on energy efficiency are found to be significant. While analyzing the other side the causal association, we found that energy efficiency has significant causal impacts on technological innovation and Lilien index. From this very piece of evidence, it can be inferred that the energy efficiency achieved in the MENA countries is gradually being recognized as a driver of economic transformation, alongside being one of the major tools to achieve energy security in these nations. Moreover, energy efficiency can also be one of major drivers of Industry 4.0, as identified by Malinauskaite et al. (2020)

and Sinha et al. (2020a). These causal associations might be crucial in developing the policies for sustainable development in the MENA countries. The overall model outcomes are demonstrated in Figure-1. Lastly, the model diagnostics are provided in Appendix 2.

<Place for Table 5>

<Place for Figure 1>

5. Conclusion and policy implication

By far, we have analyzed the impact of technological innovation on energy efficiency for the MENA countries over the period of 1990-2016, and how structural transformation of economy and development of shadow economy can moderate this association. Using second generation methodological approach, technological innovation and structural transformation of economy are found to have positive impact on energy efficiency, while development of shadow economy is found to be an obstacle in the way of achieving energy efficiency. These empirical results provide us with significant insights regarding designing a policy framework for the MENA countries, so that they can make progress in pursuit of achieving the SDG objectives.

5.1. Central policy framework

As the MENA countries are experiencing high economic growth, it is necessary to make the employment of labors through formal channels less costly, as this will disincentivize the labors to move towards the shadow economy. In this process, Industry 4.0 can play a major role by bringing forth digital transformation in the economy. This will not only reduce the transaction cost of the labor hiring process, but will also make the process more transparent. While bringing forth process transparency, the policymakers also need to look into bringing forth transparency in the financing mechanism, by making the tax regime more attractive, yet stringent. This will not only help to reduce the growth of the shadow economy, but also reduce the possibilities of further leakages in the circular flow of the economy. However, in order to sustain this tax regime, the policymakers also need to look into making business environment more congenial for investment, so that the formalization of the shadow economy can be initiated. In this way, the MENA countries can progress towards achieving the objectives of SDG 8, i.e., decent work and economic growth.

While restricting and formalizing the shadow economy, the policymakers also need to stress on fostering the innovation. Policymakers should promote public-private partnerships to boost the innovation, while easing the business environment. This initiative might allow the diffusion of technological innovations brought forth by the new business ventures across the member nations. Once these innovations start getting diffused across the nation, it might be easier for the policymakers to implement the renewable energy solutions, so as to reduce the dependence on the fossil fuel-based solutions and enhance energy efficiency. To sustain these initiatives, the renewable energy solutions might be provided to the industrial sector at a pro-rata rate, which is derived by the carbon footprint of the firm (Sinha, 2020 b, c). With a Pigouvian taxation mechanism in place, the industrial players will be compelled to use the renewable energy solutions and employ the technological innovations. In this way, the firms will be able to gradually achieve rise in energy efficiency. This will help the MENA countries to make a move towards achieving the objectives of SDG 7, i.e., clean and affordable energy. Lastly, while treading the path of Industry 4.0, the MENA countries need to bank on rapid technological innovation, as the era of Industry 4.0 is characterized by the rise in information and communication technologies and automation, which can bring about sector-level structural transformation in these nations. Now, by means of different government initiatives and public-private partnerships, if the technological innovation can be diffused across the nation, then it is likely that the MENA countries will be able to take the full advantage of the technological innovation in achieving economic development. This policy level move will help these nations in achieving the objectives of SDG 9, i.e., industry, innovation, and infrastructure.

5.2. Tangential policy framework

While the central policy framework solely depends on the obtained results for designing the policies, the tangential policy framework is designed in order to act as a support mechanism to the central policy framework. While the policymakers are striving to achieve the energy efficiency by promoting technological innovation, they need to focus on providing the quality education to the citizens, so that the innovations can be imbibed at the grassroots level. In order to fulfill this initiative, policymakers need to make amendments to the educational curriculum, so that the knowledge and awareness about environmental benefits of clean energy and energy efficiency can be achieved at the grassroots level (Paramati et al., 2017; Zafar et al., 2020). At the same time, policymakers might resort to people-public-private partnerships to enhance the environmental awareness among the citizens, so that this initiative of curriculum amendment can prove to be helpful in diffusing the knowledge about the renewable energy solutions and technological innovations among the citizens. This particular initiative will help the MENA countries to achieve the objectives of SDG 4, i.e., quality education. Hence, it can be inferred that utilizing SDG 4 as a vehicle, the MENA countries might be able to strategize a multi-pronged SDG framework for attaining the 2030 agenda.

5.3. Policy caveats

While suggesting a policy framework, it is necessary to mention the assumptions and caveats, without which implementation of the policies might not prove to be effective (Roy and Singh, 2017; Roy et al., 2018). The suggested multi-pronged SDG framework for the MENA countries is based on the following assumptions and caveats: (a) the law for protecting the natural resources should be enforced, so that depletion of natural resources can be restricted and energy efficiency can be retained, (b) policymakers should focus on implementing import substitution policies for restricting the import of fossil fuel-based energy solutions, (c) the policymakers need to think about the skill development of the workers, who were earlier involved with the traditional fossil fuel-based energy generation process, so that they can be absorbed in the newly founded technological and renewable energy based startups, and (d) the rent-seeking behavior of the government agencies need to be handled strictly, in order to maintain the environment for ease of doing the business.

5.4. Limitations and scope for future studies

Before putting a conclusion to the study, it needs remembering that no policy framework can encapsulate all possible policy instruments, and the SDG framework designed in this study is not an exception. While talking about the aspect of innovation, this study undermined the possible impact of bilateral trade among the member nations. Disregarding this aspect has become one of the major limitations of the study. Moreover, the spatial dispersion of the innovation pattern has also not been considered, and therefore, the nature of diffusion of innovation has not been captured in an effective manner. While these shortcomings of the study are presented, they might also open up new avenues for future research on this direction. From that perspective, it can be inferred that the present study can act as a baseline approach for designing further refined policy frameworks in future.

References

A. Chudik, M.H. Pesaran, Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors, J. Econom. 188(2) (2015) 393 420.

A. Sinha, Trilateral association between SO2/NO2 emission, inequality in energy intensity, and economic growth: A case of Indian cities, Atmos. Pollut. Res. 7(4) (2016) 647 658.

A. Sinha, J. Bhattacharya, Environmental Kuznets curve estimation for NO_2 emission: A case of Indian cities, Ecol. Indic. 67 (2016) 1 11.

A. Sinha, J. Bhattacharya, Estimation of environmental Kuznets curve for SO_2 emission: A case of Indian cities, Ecol. Indic. 72 (2017) 881 894.

A. Sinha, M. Shahbaz, T. Sengupta, Renewable energy policies and contradictions in causality: A case of Next 11 countries, J. Clean. Prod. 197 (2018) 73 84.

A. Sinha, T. Sengupta, O. Kalugina, M.A. Gulzar, Does distribution of energy innovation impact distribution of income: A quantile-based SDG modeling approach, Technol. Forecasting Social Change 160 (2020a) Article 120224.

A. Sinha, T. Sengupta, T., Saha, Technology policy and environmental quality at crossroads: Designing SDG policies for select Asia Pacific countries, Technol. Forecasting Social Change 161 (2020b) Article 120317.

A. Sinha, M.I. Shah, T. Sengupta, Z. Jiao, Analyzing technology-emissions association in Top-10 polluted MENA countries: How to ascertain sustainable development by quantile modeling approach, J. Environ. Manage. 267 (2020c) Article 110602.

A. Tandon, S. Ahmed, Technological change and energy consumption in India: a decomposition analysis, Innov. Dev. 6(1) (2016) 141 159.

A.A. Shamali, E.I. Bandaly, E. Elmaddah, I.H. Mansour, I. Rouabhia, K.A. Thobhani, N.E. Saim, S. Fawaz, S.A. Harthey, S.A. Serriya, S. Al-Zoghoul, M. Pouget, R. Schiffer, Energy & Climate in the MENA Region: Youth Perspective to a Sustainable Future, Friedrich Ebert Foundation, Bonn, Germany, 2019.

B. Hofman, K. Labar, Structural change and energy use: Evidence from China's provinces, China Working Paper Series No. 6, World Bank, 2007.

B. Lin, J. Zhu, Chinese electricity demand and electricity consumption efficiency: Do the structural changes matter?, Appl. Energy 262 (2020) Article 114505.

C. Diks, V. Panchenko, A new statistic and practical guidelines for nonparametric Granger causality testing, J. Econ. Dyn. Control 30(9-10) (2006) 1647 1669.

C.M. Jarque, A.K. Bera, A test for normality of observations and regression residuals, Int. Stat. Rev. 55(2) (1987) 163 172.

Cross-Sectoral Coordination Centre (CSCC), Latvia - Review on SDG Implementation, UN 2018, Republic of Latvia, 2018.

E. Dogan, B. Altinoz, M. Madaleno, D. Taskin, The impact of renewable energy consumption to economic growth: a replication and extension of Inglesi-Lotz (2016), Energy Economics 90 (2020) Article 104866.

E. Dogan, R. Inglesi-Lotz, The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: evidence from European countries, Environ. Sci. Pollut. Res. 27 (2020) 12717 12724.

E. Göll, A. Uhl, J. Zwiers, Sustainable Development in the MENA Region, Middle East and North Africa Regional Architecture, 2019.

E. Menichettti, A. El Gharras, S. Karbuz, Material factors for the MENA region: Energy trends. Middle East and North Africa Regional Architecture, 2017.

F. Bonnet, J. Vanek, M. Chen, Women and men in the informal economy: A statistical brief. International Labour Office, Geneva, 2019.

F. Guang, Electrical energy efficiency of China and its influencing factors, Environ. Sci. Pollut. Res. 27 (2020) 32829 32841.

Foundation for European Progressives Studies (FEPS), Progressive Lab for Sustainable Development: From Vision to Action, Rue Montoyer, Brussels, 2017.

Global Compact Network Poland (GCNP), SDG implementation in Poland: Progress report 2018, United Nations Global Compact Network, 2018.

H. Liu, Z. Zhang, T. Zhang, L. Wang, Revisiting China's provincial energy efficiency and its influencing factors, Energy 208 (2020) Article 118361.

H. Sun, B.K. Edziah, C. Sun, A.K. Kporsu, Institutional quality, green innovation and energy efficiency, Energy Policy 135 (2019) Article 111002.

H. Wang, M. Wang, Effects of technological innovation on energy efficiency in China: Evidence from dynamic panel of 284 cities, Sci. Total Environ. 709 (2020) Article 136172.

I. Fisher, The best form of index number, J. Am. Stat. Assoc. 17(133) (1921) 533 551.

International Energy Agency (IEA), Capturing the multiple benefits of energy efficiency, OECD, 2014.

International Institute for Sustainable Development (IISD), 2017. Initiatives Enhance Adaptation in the MENA Region. https://sdg.iisd.org/news/initiatives-enhance-adaptation-in-the-mena-region/

International Institute for Sustainable Development (IISD), 2018. PAGE Shows Way to Green Economic Transition through Industrial Policy. https://sdg.iisd.org/news/page-shows-way-to-green-economic-transition-through-industrial-policy/

International Peace Institute (IPI), 2020. IPI MENA Director Highlights Role of Innovation in 2030 Agenda for Sustainable Development. https://www.ipinst.org/2020/09/ipi-mena-role-of-innovation-in-2030-agenda

International Renewable Energy Agency (IRENA), Energy transformation 2050, 2020.

J. Malinauskaite, H. Jouhara, B. Egilegor, F. Al-Mansour, L. Ahmad, M. Pusnik, Energy efficiency in the industrial sector in the EU, Slovenia, and Spain, Energy 208 (2020) Article 118398.

J. Westerlund, D.L. Edgerton, A simple test for cointegration in dependent panels with structural breaks, Oxf. Bull. Econ. Stat. 70(5) (2008) 665 704.

J.B. Ramsey, Tests for specification errors in classical linear least-squares regression analysis. J. R. Stat. Soc. Series B Stat. Methodol. 31(2) (1969) 350 371.

J.C. Farla, K. Blok, Energy efficiency and structural change in the Netherlands, 1980–1995: influence of energy efficiency, dematerialization, and economic structure on national energy consumption, J. Ind. Ecol. 4(1) (2000) 93 117.

J.M. Wooldridge, Econometric Analysis of Cross Section and Panel Data, MIT Press, Cambridge, MA, 2002.

K. Fisher-Vanden, G.H. Jefferson, M. Jingkui, X. Jianyi, Technology development and energy productivity in China, Energy Econ. 28(5-6) (2006) 690 705.

K. Sohag, R.A. Begum, S.M.S. Abdullah, M. Jaafar, Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia, Energy 90 (2015) 1497 1507.

K. Wasniewski, Energy efficiency as manifestation of collective intelligence in human societies, Energy 191 (2020) Article 116500.

L. Cao, The dynamics of structural and energy intensity change, Discrete Dyn. Nat. Soc. 2017 (2017) Article 6308073.

L. Jin, K. Duan, X. Tang, What is the relationship between technological innovation and energy consumption? Empirical analysis based on provincial panel data from China. Sustainability 10(1) (2018) Article 145.

L. Medina, F. Schneider, Shadow economies around the world: what did we learn over the last 20 years?, IMF working paper no. WP/18/17, International Monetary Fund, 2018.

M. Döring, R.E. Golli, Country Fact Sheet Tunisia: Energy and development at a glance 2018, MENA Select, 2019.

M. Galeotti, S. Salini, E. Verdolini, Measuring environmental policy stringency: Approaches, validity, and impact on environmental innovation and energy efficiency, Energy Policy 136 (2020) Article 111052.

M. Shahbaz, D. Balsalobre-Lorente, A. Sinha, Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption, J. Clean. Prod. 217 (2019) 603 614.

M. Sheikh, 2020. A cashless economy could boost the MENA region. Center for international private enterprise. https://www.cipe.org/blog/2020/08/10/a-cashless-economy-could-boost-the-mena-region/

M.A. Destek, A. Sinha, Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries, J. Clean. Prod. 242 (2020) Article 118537.

M.F. Mabrouk, 2020. Egypt's sizeable informal economy complicates its pandemic response. https://www.mei.edu/blog/egypts-sizeable-informal-economy-complicates-its-pandemic-response

M.H. Pesaran, A simple panel unit root test in the presence of cross-section dependence, J. Appl. Econ. 22(2) (2007) 265 312.

M.H.M. Saudi, O. Sinaga, D. Roespinoedji, E.K. Ghani, The Impact of Technological Innovation on Energy Intensity: Evidence from Indonesia, Int. J. Energy Econ. Policy 9(3) (2019) 11 17.

M.M. Alam, M.W. Murad, The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries, Renew. Energy 145 (2020) 382 390.

M.M. Basbay, C. Elgin, O. Torul, Energy consumption and the size of the informal economy, Economics 10(2016-14) (2016) 1 28.

M.W. Zafar, M. Shahbaz, F. Hou, A. Sinha, From nonrenewable to renewable energy and its impact on economic growth: the role of research & development expenditures in Asia-Pacific Economic Cooperation countries, J. Clean. Prod. 212 (2019a) 1166 1178.

M.W. Zafar, S.A.H. Zaidi, A. Sinha, A. Gedikli, F. Hou, The role of stock market and banking sector development, and renewable energy consumption in carbon emissions: insights from G-7 and N-11 countries, Resour. Policy 62 (2019b) 427 436.

M.W. Zafar, M. Shahbaz, A. Sinha, T. Sengupta, Q. Qin, How renewable energy consumption contribute to environmental quality? The role of education in OECD countries, J. Clean. Prod. 268 (2020) Article 122149.

OECD, Better Policies for Inclusive Growth and Economic Integration in the MENA Region, 2016.

P. Fragkos, N. Tasios, L. Paroussos, P. Capros, S. Tsani, Energy system impacts and policy implications of the European Intended Nationally Determined Contribution and low-carbon pathway to 2050, Energy Policy 100 (2017) 216 226.

P. Garonna, F.G. Sica, Intersectoral labour reallocations and unemployment in Italy, Labour Econ. 7(6) (2000) 711 728.

P. Mlambo-Ngcuka, R.D.S.D. Alwis, Redefining Leadership in the Age of the SDGs: Accelerating and Scaling Up Delivery Through Innovation and Inclusion, Center of the Legal Profession, Harvard Law School, 2019.

P. Mulder, H.L. De Groot, Structural change and convergence of energy intensity across OECD countries, 1970–2005, Energy Econ. 34(6) (2012) 1910 1921.

P. Smith, Assessing the size of the underground economy. The Canadian statistical perspectives, Can. Econ. Obs. 11 (1994) 16 33.

Q. Fei, R. Rasiah, Electricity consumption, technological innovation, economic growth and energy prices: does energy export dependency and development levels matter?, Energy Procedia 61 (2014) 1142 1145.

R. Benkraiem, A. Lahiani, A., Miloudi, M. Shahbaz, The asymmetric role of shadow economy in the energy-growth nexus in Bolivia, Energy Policy 125 (2019) 405 417.

R. Gatti, M. Morgandi, G. Rebekka, S. Brodmann, S., Angel-Urdinola, D., Moreno, J.M., Marotta, D., Schiffbauer, M., Mata Lorenzo, E., 2013. Jobs for shared prosperity: Time for action in the Middle East and North Africa. The World Bank.

R. Nepal, N. Paija, Energy security, electricity, population and economic growth: The case of a developing South Asian resource-rich economy. Energy Policy, 132 (2019) 771 781.

S.R. Paramati, A. Sinha, E. Dogan, The significance of renewable energy use for economic output and environmental protection: evidence from the Next 11 developing economies, Environ. Sci. Pollut. Res. 24(15) (2017) 13546 13560.

T. Owoeye, D.B. Olanipekun, A.J. Ogunsola, A.A. Kutu, Energy Prices, Income and Electricity Consumption in Africa: The Role of Technological Innovation, Int. J. Energy Econ. Policy 10(5) (2020) 392 400.

T. Yang, W. Chen, K. Zhou, M. Ren, Regional energy efficiency evaluation in China: A super efficiency slack-based measure model with undesirable outputs, J. Clean. Prod. 198 (2018) 859 866.

T.S. Breusch, A.R. Pagan, A simple test for heteroscedasticity and random coefficient variation. Econometrica 47(5) (1979) 1287 1294.

United Nations, Accelerating SDG 7 achievement: SDG 7 policy briefs in support of the High-Level Political Forum 2019, 2019.

United Nations, Pathways to Sustainable Energy - Accelerating Energy Transition in the UNECE Region, 2020.

United Nations Industrial Development Organization (UNIDO), Accelerating clean energy through Industry 4.0: Manufacturing the next revolution, 2018.

United Nations Statistics Division (UNSD), 2019. UN data. http://data.un.org/.

V. Roy, S. Singh, Mapping the business focus in sustainable production and consumption literature: Review and research framework, J. Clean. Prod. 150 (2017) 224 236.

V. Roy, T. Schoenherr, P. Charan, The thematic landscape of literature in sustainable supply chain management (SSCM), Int. J. Oper. Prod. Manag. 38(4) (2018) 1091 1124.

W. Ali, I.U. Rahman, M. Zahid, M.A. Khan, T. Kumail, Do technology and structural changes favour environment in Malaysia: An ARDL-based evidence for environmental Kuznets curve, Environ. Dev. Sustain. 22 (2019) 7927 7950.

World Bank, 2019. World Development Indicators. https://data.worldbank.org/indicator

X. Ouyang, J. Chen, K. Du, Energy efficiency performance of the industrial sector: From the perspective of technological gap in different regions in China, Energy (2020) Article 118865.

X. Pan, B. Ai, C. Li, X. Pan, Y. Yan, Dynamic relationship among environmental regulation, technological innovation and energy efficiency based on large scale provincial panel data in China, Technol. Forecasting Social Change, 144 (2019a) 428 435.

X. Pan, M.K. Uddin, C. Han, X. Pan, Dynamics of financial development, trade openness, technological innovation and energy intensity: Evidence from Bangladesh, Energy 171 (2019b) 456 464.

Y. Eilat, C. Zinnes, The shadow economy in transition countries: Friend or foe? A policy perspective, World Dev. 30(7) (2002) 1233 1254.

Y. Zhang, Energy Rebound Effect Analysis Based on Technological Progress, IOP Conf. Ser. Earth Environ. Sci. 300(4) (2019) Article 042035.