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Analyzing Global Inequality in Access to Energy: Developing Policy Framework by Inequality Decomposition

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Abstract

Energy poverty is a critical policymaking problem in the world, while the outlined solutions in academic and policy literature talks about the solutions, without addressing the possible cause of the problem. The interaction between labor and energy market might pave a way to address the issue. Within the context of energy poverty, this interaction might turn out to be a major roadblock in the way to attain the objectives of Sustainable Development Goals (SDGs). From this perspective, this study aims at analyzing the constituents of inequality in access to energy, and in that pursuit, it has employed Kaya-Theil Decomposition method. The study is carried out at the global level over the period of 1990-2019. The study outcomes demonstrate all the inequality components to be rising during the study period. Presence of a possible feedback loop in the association might create the Vicious Circle of Energy Poverty around the globe. This study contributes to the literature by addressing the demand-side dimension of the energy poverty issue, while using the Kaya-Theil Decomposition method as an estimator of demand-side factors. Based on the study outcomes, a policy framework has been recommended, and it is aimed at helping the nations to achieve the objectives of SDG 7, SDG 8, and SDG 10.

Keywords: Energy poverty; Energy intensity; Labor productivity; Labor force participation; Theil index

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1. Introduction

The growing variances in per capita income across economies have highlighted the differences in access to resources that contribute to national income. Since literature has acknowledged a substantial and prominent role of energy resources in productivity, access to energy resources has posed a new challenge in sustaining that productivity. Recently, many economies and regional development organizations have heavily invested for improving the access to energy resources (IEA, 2020). However, provision of affordable energy mix to nearly 2 billion global rural population by 2030 demands policy intervention besides investment management.

The access to affordable energy invariably leads to the discussion on energy poverty. Recent debate over the increasing energy poverty and consumption inequalities across countries have posed a new challenge to shared prosperity targets described by the objectives of Sustainable Development Goal (SDG) 7, i.e., affordable and clean energy. According to the World Bank (2019), the annual global demand for energy has exceeded 170 million gigawatts (GW), as the world's population has surpassed 7 billion. Knowing the population growth rate, world's population might be anticipated to rise up to 9 billion by the end of 2040, facing a margin of 27% energy deficit. Currently, 1.2 billion population has little or no access to energy resources, and it is itself a challenge and hurdle in reaching the objectives of SDGs by 2030. However, only population growth cannot be blamed for this growing deficit. Digitalized civilization demands more energy resources due to increase in per capita income and innovations. Using energy transformation index, Duro and Padilla (2011) have assessed the long-term effects of energy inequalities across countries, which was later assessed by Sinha (2017) for renewable energy generation. Employing Theil decomposition approach, both the studies have maintained that energy inequality might hamper productivity by curtailing economic growth rate and labor productivity. However, growing population burden increases the long run complications and detriments of existing energy inequality. For the context of the Eurasian Economic Union, the recent work of Bianco et al. (2021) says that a sustainable energy policy will entail decoupling the economic growth from energy consumption, as the population-related inequality in energy consumption is showing an increase.

The access to energy is a multidimensional concept involving the incidence of energy poverty and inequality across economies and communities. The pioneer work of Boardman (1991) highlights the importance of public investment to reduce energy poverty through focusing on means to augment production and access to energy resources. The study has demonstrated that lack of access to energy impedes and undermines the long run economic productivity. However, fuel choice for production is directly correlated with set of skilled labor force and efficient scale of capital (Keen et al., 2019). It is also highlighted by several studies that labor productivity is higher in economies with better access to energy (Rafindadi and Ozturk, 2017). It implies that sophisticated machines and efficient energy inputs contributes to production system and enhance skills of labor to use capital more efficiently.

The economies with lower resources suffer due to inequality in access to energy, as it results in swelling the gap between per capita income across nations. However, this characterization remains same while measuring inequality in access to energy within an economy, as it may result in several socio-economic challenges. This inequality might also remain among a group of countries. This persisting disparity might be arising out of the disproportionate development and diffusion of energy technologies. While this inequality persists at the broad consumption level, it will be translated into the economic output, as well. While energy inequality is translated into the economic output, the inequality might get reflected in intensity terms.

Energy being a factor of production, disproportionate distribution of energy intensity might affect the distribution of other factors of production. In case the firms invest in the technological development for improving energy intensity, then given the *ceteris paribus* condition, the investment on the labors might decline. In order to achieve the energy efficiency by reducing the energy intensity, the capital-intensive investments will start replacing the labor-intensive investments. Though it might improve the productivity of the firms in the short run, the shift of investment focus might create a demand pressure on the labor force. A rise in the returns to scale might decrease the demand of labors, and consequently, the access to job might be driven by the higher technological skills. As a result, the income of the unemployed labor force will start shrinking, and the accumulation of wealth will start showing disparity. This disparity might be reflected in the access to the basic needs, e.g., energy. Hence, while the unequal distribution of technological innovations will lead towards a possible inequality in energy intensity, the labor productivity and labor participation might also show signs of inequality. This entire scenario might give rise to the incidents of energy poverty. A possible incidence of this scenario has been indicated in the work of Sovacool (2017). In this view, the possible interaction between energy and labor market can give rise to policy dilemma, which can create a hinderance in achieving the objectives of SDG 7.

In this connection, the solution provided by the European Union (EU) based on renewable energy resources might also be questioned. The recent work of Bianco et al. (2019) shows that the effectiveness of the European energy policy should target reducing the inequality in energy intensity. Reviewing the current energy mix composition and future prospective, renewable energy would not be enough to reduce demand-supply gap for all economies due to financial constraint. The micro supply mechanism of energy poverty implies that new era of industrial expansion has reduced the access of household on energy resources in middle- and low-income economies. Low infrastructure investment to provide energy resources to industrial areas hampers the marginal productivity of labor at firm level. Whereas, absence of affordable energy affects the purchasing power of households and make them spend a bigger portion of relative share of income on energy (Montalbano and Nenci, 2019). However, firm shifts this price burden on consumer and this micro demand mechanism surges poverty and diminishes living standard (Porter and Van der Linde, 1995).

Given this background, it is evident that the incidents of energy poverty are closely associated with the interaction between inequality in energy consumption and labor market. From this perspective, it might be necessary to look into this association from the lens of sustainable development. Now, when the discussion on sustainable development is considered, it is necessary to look into the issue of energy poverty from both economic and social dimensions, which can be achieved by analyzing the international inequality in access to energy. The energy poverty issue is addressed in the existing literature and in the policy documents majorly from the perspective of energy access. The approach of the Rockefeller Foundation (2021) to address energy poverty issues largely talks about addressing the access to electricity, which is a supply side solution to the problem. This solution is largely similar with the approach outlined by the Energy Sector Management Assistance Program (ESMAP, 2015). The policy documents show the solutions to this problem without addressing the demand-side dynamics of the problem. While the existing literature talks about 'how' and 'what', the present study aims at answering the question 'why'. This particular aspect has been mentioned by the United Nations (2018) in their global review report on the assessment of SDG 7, while talking about the global scenario of energy inequality. With the persisting inequality in access to energy resources, the negative consequences of the disparity in economic output might have its spillover effects on the labor market. The technological developments are expected to bring forth a paradigm shift in production processes, and this transformation might have an impact on the labor market, as these technologies are expected to enhance the returns to scale on the capital employed. Taking a cue from the seminal work of Arrow el al. (1961), it can be inferred that the capital-intensive technologies might gradually replace the labors, and therefore, certain disparity in the labor productivity and labor force participation can be expected across the nations. The recent report on renewable energy access by the World Economic Forum talks about reducing the price of renewable energy to solve the problem of energy poverty (Wells, 2021). This is a classic condition, which conceived the concept of the *Keynesian Economic thought*, as the prevailing policy paradigm does not account for the demand side dynamics of the problem, i.e., rather than making energy affordable, why not enabling people to earn more by reducing inequality in the labor market? This question bears the theoretical ground of the study. In this context, the objective of the present study is to analyze the global inequality in access to energy over the period of 1990-2019. Based on the findings of the study, an indicative policy framework has been recommended, so that the nations can make a progress towards achieving the objectives of SDG 7, while maintaining the social order by ensuring employment, and thereby attaining the objectives of SDG 8, i.e., decent work and economic growth. There lies the policy-level contribution of this study. Theoretically, this study contributes to the literature by analyzing the demand-side dynamics of the energy poverty, by discovering the linkage between labor and energy market. This study shows how the spillover of inequality in labor market is responsible for the inequality in energy intensity, and thereby, causing the issue of energy poverty. While the academic and policy literature is in pursuit of reducing the energy price, this study is aimed at finding out why people cannot pay for the energy prices. Answer to this question defines the theoretical contribution of the study.

Determining the demand side of the energy poverty issue entails breaking the energy poverty into measurable forms. This is required to understand the possible determinants of the energy poverty and how these determinants are associated with each other. To achieve this research objective, the inequality in access to energy has been decomposed into three components, namely inequality in energy intensity, inequality in labor productivity, and inequality in labor force participation. In this pursuit, following the approach of Duro and Padilla (2006), Kaya-Theil decomposition approach has been utilized. By means of this analytical approach, driving forces behind the global inequality in access to energy have been analyzed. By far, this method has been largely utilized as a tool for inequality decomposition, in the literature. This study has revealed that this particular method is also capable of determining the demand-side dynamics. Along with the methodological complementarity with the research objective, this aspect of the methodological adaptation thus defines the methodological contribution of the study.

Rest of the paper is divided in the following manner: section 2 discusses the relevant literature, section 3 outlines the analytical schema, section 4 discusses the results, and section 5 concludes the study with policy implications.

2. Literature review

2.1. Review of factors causing energy poverty

In the forthcoming decades, the energy industry will have to assume the most significant transformations concerned to the security of supply, energy poverty and environmental degradation. Though ecological degradation and energy supply have been extensively explored in the economic literature, there has been less focus on energy poverty. The study by Simcock et al. (2017) reveals the need of awareness regarding energy poverty. Numerous reports have engaged intergovernmental initiatives joined with civil society actors to achieve the agenda 2030 for worldwide access to developed energy services, reducing energy intensity by 40%, and incrementing the share of renewable energy use till 30% (CSTD, 2010). These goals aimed to control energy poverty and to promote access to clean energy sources. The openness to advanced energy services implies actions on the energy sector and economic security, which depends mainly on socioeconomic factors and energy policy regulations (WHO, 2006, 2009). Different studies show that government regulations directly impact the energy sector and the appearance of poverty problems (Martínez and Ebenhack, 2008). So, disparities cannot be explained entirely by economic or geographical structure, or environmental-related factors. However, Newman and Kenworthy (1989) have shown that it is necessary for active policies, especially in the energy sector, for correcting these inequalities.

Empirical evidence has shown that poor people spend a higher share of their income on energy than the non-poor, assuming that it is necessary to emphasize the linkage between energy access poverty and inequality (Bhatia and Angelou, 2015). In continuation to this discussion, literature also considers various paths leading to energy poverty, and certain conditions have to be deemed for explaining the problem of energy poverty. Consequently, energy poverty can be defined as the absence of electricity access and the dependence on traditional fossil sources (IEA, 2015). Some studies have quantified energy poverty from an income perspective. Based on the finding of Reddy (2000), energy poverty is conceptualized as the absence of alternatives sources and inadequate access to advanced and environment-friendly energy services, consistent with sustainable development. The study also showed that eradicating energy poverty is dependent on the type of technologies applied in energy services and fitted to the geographical attributes. It also depends on the knowledge base and societal structure of a region, where technological advances will displace low-quality fuels due to ascending income levels.

The correction of energy poverty is also based on the quality and versatility of energy sources, under the notion of "*Energy Ladder Hypothesis*" (Van der Kroon et al. 2013). It proposes that higher-quality, more versatile fuels. The ladder is ranked in terms of efficiencies, where the most efficient fuels or sources placed the top on the ladder. On the other hand, energy ladders and energy equity notions are debated in the energy poverty literature. For example, Foster et al. (2000) found that traditional fuel sources might even be more expensive due to the absence of alternatives, generating that poor people consume more expensive energy, which implies an increase in inequality.

Even it is recognized that eradicating extreme poverty is essential to improve living conditions and generate sustainable development (United Nations, 2000), being fundamental to create a more efficient energy sector. In this sense, energy poverty is associated with deficient access to energy infrastructures, which generates an unsustainable developmental trajectory. In this sense, energy poverty has gained its relevance in the policy debate not only from economic perspective, but also from social perspective (Walker and Day, 2012). United Nations Commission on Science and Technology for Development (CSTD, 2010) proposed a multidimensional perception of poverty based on education levels or living conditions. In the same line, various reports substantiated that the main pernicious effects are connected with health and socioeconomic aspects. Belaïd (2018) suggested that energy poverty falls into socioeconomic and demographic considerations and housing factors. In the same line, studies conducted by Thomson and Snell (2012) and Reames (2016) reflected that many factors contribute to energy poverty, such as energy innovation, domestic energy efficiency, and clean energy regulations. Studies have further validated that these factors are relevant for detecting the main forces and recognizing the complexity of the energy poverty challenge (Simcock et al. 2017).

The study conducted by Hills (2011) concluded that environmental regulation has its impact on energy costs and this process impacts low-income households, which are over-affected by ascending energy prices and energy expenses. Further empirical evidences support that energy poverty problems are based on housing type and socio-demographic characteristics. For instance, Scarpellini et al. (2015) concluded that the leading causes of energy poverty are inequality, low-income levels and unemployment. Romero et al. (2018) showed that the leading causes of energy poverty are economic vulnerability due to low-income households, job instability, or unemployment. Sen (1999) concluded that development does not only achieve certain actions but also implies access to advanced energy services. The empirical literature provides an overview of the energy-related aspects of poverty, a concept which has come to be known as "*Energy Poverty*" (IIASA, 2012). Some reports assume that energy poverty adopts a multidimensional dimension covering caloric intake, life expectancy, housing condition, literacy, or access to energy, among an exhaustive battery of factors (CSTD, 2010).

This brief review of the factors causing energy poverty largely indicates towards the incidences of poverty and low-income level to the major reasons behind energy poverty. Hence, it gives an impression that the solutions aimed at energy poverty eradication also need to aim at poverty eradication. Now, eradication of poverty necessitates access to income, which can be realizable by access to jobs. So, prevalence of inequality in the job market will have its consequence on the inequality in the labor market, and subsequently on the income inequality. This inequality might be reflected in the inequality in access to energy, causing the issue of energy poverty. This dimension of energy poverty is still unaddressed in the literature.

2.2. Interaction between labor and energy markets

While the issue of energy poverty in considered, it evidently takes to the issue of energy innovation, due to which the labor market can be influenced directly. On the other hand, possible hindrance in the income generation process for the labors might have a direct impact on the energy poverty scenario. Therefore, it can be assumed that by means of technological spillovers, labor market and energy poverty might be associated. However, there is a dearth of studies on this aspect, as this association has not been given much preference in the literature.

Studies show that industrial structure changes might alter the energy intensity through the sector transfer effect. Shen and Lin (2020) showed that industrial structure is considered as a primary driving force of economic development. Industrialization and labour productivity have been considered in terms of output and employment shares. The industrial structure is fundamental for energy consumption pattern and environmental variations in economic systems. On the other hand, if the structural distortions are assumed in industrial structure and disparities in labour productivity, it could imply adverse effects on energy resources allocation efficiency (Chen et al., 2021). So, it can be debated that energy intensity reduction is crucial in ascending labour productivity and environmental correction processes, and various studies have observed this aspect. Garbaccio et al. (1999) found that the main reason behind the decline of energy intensity in China was the technological progression, which was catalyzed by the sectoral reforms and labour productivity. There is evidence of a linkage between industrial structure, labour productivity and energy intensity (Grossi and Mussini, 2017). This connection implies an inverse correlation between technological advances and energy intensity. Balsalobre et al. (2015) documented that innovation is an efficient route for correcting energy intensity.

With the advent of technological innovations, a pressure is expected on the labor market, as the demand of labors might start shrinking. In such a scenario, the unemployment might rise, with a rise in the labor surplus. Hence, the access to job and income might start reducing, and as a consequence, the labors might not get access to energy sources, owing to the inability to pay the energy prices. This might create a demand shrinkage in the goods market, resulting in a shrinkage in the energy demand. So, there are possibilities that the energy poverty in terms of the inequality in the access to energy might set in. This dimension can prove to be critical from the policymaking perspective for addressing energy poverty issues, and this aspect has been largely ignored in the literature.

2.3. Research gap

Based on the brief review of literature, it is evident that energy poverty is a developmental issue, which might have both economic and social consequences. A synthesis of the reviewed articles is given in Table 1. This brief review of the literature gives out two distinct research gaps:

(a) The policy research endeavors towards solving the energy poverty issue shows that the prevailing policy measures are aimed at improving the access to energy. Though these measures are important, they might be inconclusive in nature, as these policy measures aim at the supply side of the problem. The attempt to eradicate the problem of energy poverty needs to take account of the reasons behind the problem, and it requires a demand side analysis of the issue. Without having sufficient disposable income, it will be difficult for the citizens to bear the energy price, and this requires access to job opportunities. By far, the literature has not focused on analyzing this aspect of energy poverty, and there lies the first research gap.

(b) Given the technological advancements driving the economic growth trajectory around the world, the energy intensity might undergo a transformation, but it might have a consequence on the labor market, as well as on the income generation. Therefore, the energy consumption might be skewed due to the disproportionate distribution of income, which might lead to inequality in access to energy. Considering the context of energy poverty, this inequality might be influenced by the dynamics between energy intensity, labor productivity, and labor force participation. This aspect of energy poverty has not been discussed in the literature. Looking at this issue from policymaking perspective also, there has been a void, for which the nations might encounter difficulties in attaining the objectives of the Sustainable Development Goals (SDGs). There lies the second research gap in the literature.

Place for Table 1

3. Methodology

3.1. Decomposition of indictors

In mathematical terms, multiplicative factorial decomposition has been employed in this study. This approach allows the decomposition of an indicator into the summation of multiple factors.

As an initial step, following Kaya (1989) equation, the per capita access to energy in country i and time t (A_{it}) can be decomposed as per the following:

$$A_{it} = E_{it}/P_{it} = E_{it}/G_{it} * G_{it}/P_{it} = I_{it} * Y_{it} \quad (1)$$

Where E_{it} is energy consumption, P_{it} is population, and G_{it} is gross domestic product in country i and time t. The access to energy is decomposed into two factors, i.e., energy intensity (I_{it}) and per capita income (Y_{it}). Here, energy intensity is calculated in terms of total energy consumption per unit of GDP (measured in nominal purchasing power parity terms). It is expressed in terms of TWh/$2010 PPP GDP. Taking natural logarithm on both sides and calculating the respective values with respect to time differentials (t and t-1) gives:

$$\ln A_{it} - \ln A_{it-1} = (\ln I_{it} - \ln I_{it-1}) + (\ln Y_{it} - \ln Y_{it-1}) \quad (2)$$

Hence, this decomposition pattern allows to quantify the transformation in A_{it} by quantifying the transformations in energy intensity and per capita income, respectively.

In the next step, the per capita income (Y_{it}) is further decomposed in order to identify the impacts of labor productivity and labor force participation. Here, labor productivity is calculated in terms of total GDP (measured in nominal purchasing power parity terms) per labor, and it is expressed in terms of $2010 PPP GDP/labor. On the other hand, labor force participation is calculated in terms of total number of labors per unit of population, and it is expressed in terms of total labor/population. The expression in Eq. (1) therefore can be decomposed in the following manner:

$$A_{it} = E_{it}/P_{it} = E_{it}/G_{it} * G_{it}/L_{it} * L_{it}/P_{it} = I_{it} * S_{it} * F_{it} \quad (3)$$

Where L_{it} is labor force in country i and time t. In this mathematical representation, per capita income is decomposed into two factors, i.e., labor productivity (D_{it}) and labor force participation (F_{it}). Taking natural logarithm and time differentials, Eq. (3) can be expressed as:

$$\ln A_{it} - \ln A_{it-1} = (\ln I_{it} - \ln I_{it-1}) + (\ln D_{it} - \ln D_{it-1}) + (\ln F_{it} - \ln F_{it-1}) \quad (4)$$

3.2. Inequality assessment by Theil Index

Once the indicators are decomposed, this mathematical representation will permit in analyzing the existing global differences by forming inequality indicators. For this purpose, this study employs Theil (1967) Index. This index is superior to the other inequality measures: (1) Mean deviation takes uniform weightage for all the cross-sections, and thereby the heterogeneity of the panel members is ignored, and (2) Gini index, Kakwani index, logarithmic mean Divisia index (LMDI) cannot consider the within and between group dimensions of the inequality. The Theil index allows the inequality components to be divided into within- and between-group components. The main motive behind using this index is based on the assumption that the inequality might not exist because of the disparity between the groups of countries, but also within a specific group of countries. Theil index is capable of bifurcating the inequality into the between-group and within-group inequality components, which can capture the dynamics of inequality across the groups, as well as within a particular group. Following Bhattacharya and Sinha (2016) and Sinha and Bhattacharya (2016), the inequality in access to energy can be represented as:

$$T_a = \sum_i p_i \ln(\bar{a}/a_i) \quad (5)$$

$$T_a = T_{a,WG} + T_{a,BG} = \sum_j p_j T_{aj} + \sum_j p_j \ln(\bar{a}/a_j) \quad (6)$$

Here, T_a is the inequality in access to energy, i represents a group of countries, j represents the member countries within the i^{th} group, $T_{a,WG}$ and $T_{a,BG}$ are the within-group and between-group inequality components, and p is population of the j^{th} member country within the i^{th} group.

Now, following Kaya-Theil decomposition approach indicated by Padilla and Duro (2013), the three components of the decomposed indicator can be analyzed. Before that, the individual contribution of the components in access to energy can be represented as per the following:

$$A_{it}^{I} = I_{it} * \bar{D} * \bar{F} \quad (7)$$
$$A_{it}^{D} = \bar{I} * D_{it} * \bar{F} \quad (8)$$
$$A_{it}^{F} = \bar{I} * \bar{D} * F_{it} \quad (9)$$

Where A_{it}^{I}, A_{it}^{D}, and A_{it}^{F} indicate the access to energy given the variations in energy intensity, labor productivity, and labor force participation, respectively. $\bar{I}$, $\bar{D}$, and $\bar{F}$ indicate the regional averages of energy intensity, labor productivity, and labor force participation, respectively. Now, the Theil index will be developed to capture the contributions of these three components, so that the disaggregate components of the inequality can capture the aggregate movement in the inequality in access to energy at a global level.

Taking the interaction between the inequality components into account, the Theil indices can be represented as per the following:

$$T_{A,i} = \left[\sum_i P_{it} * \ln\left(\overline{A_t^I}/A_{it}^I\right) + \ln\left(\bar{A}/\overline{A^I}\right)\right] + \left[\sum_i P_{it} * \ln\left(\overline{A_t^D}/A_{it}^D\right) + \ln\left(\bar{A}/\overline{A^D}\right)\right] + \sum_i P_{it} * \ln\left(\overline{A_t^F}/\overline{A_{it}^F}\right)$$
$$\text{or}, T_{A,i} = \left|T_{A,i}^{I} + \text{inter}_{I,DF}\right| + \left|T_{A,i}^{D} + \text{inter}_{D,F}\right| + T_{A,i}^{F} \quad (10)$$

Once, the overall Theil index has been obtained, it can be seen that the three components of inequality are contributing to the inequality. Now, following the additivity principle given by Shorrocks (1980), these three components can be expressed in terms of three effects, which are affecting the overall inequality in access to energy:

a. Energy intensity effect:

$$TI = T_{A,i}^{I} + (1/2) * \text{inter}_{I,DF} = \sum_i P_{it} * \ln\left(\overline{A_t^I}/A_{it}^I\right) + (1/2) * \ln\left(\bar{A}/\overline{A^I}\right) \quad (11)$$

b. Labor productivity effect:

$$TD = T_{A,i}^{D} + (1/4) * \text{inter}_{I,D,F} + (1/2) * \text{inter}_{D,F} = \sum_i P_{it} * \ln\left(\overline{A_t^D}/A_{it}^D\right) + (1/4) * \ln\left(\bar{A}/\overline{A^I}\right) + (1/2) * \ln\left(\bar{A}/\overline{A^D}\right) \quad (12)$$

c. Labor force participation effect:

$$TF = T_{A,i}^{F} + (1/4) * \text{inter}_{I,D,F} + (1/2) * \text{inter}_{D,F} = \sum_i P_{it} * \ln\left(\overline{A_t^F}/A_{it}^F\right) + (1/4) * \ln\left(\bar{A}/\overline{A^I}\right) + (1/2) * \ln\left(\bar{A}/\overline{A^D}\right) \quad (13)$$

In view of these three effects, the overall Theil index can be denoted as per the following:

$$T_A = TI + TD + TF \tag{14}$$

3.3. Data

The study has considered the data for 135 countries[2] over the time period of 1990-2019. The countries are segregated into four income categories, i.e., low, lower middle, higher middle, and high (World Bank, 2020). Data for population, gross domestic product (constant 2010 US$ in PPP terms), and total labor force have been collected from World Development Indicators (World Bank, 2019), and the data for total energy consumption (in TWh) have been collected from International Energy Agency. The list of countries considered in the study is provided in Appendix 1.

4. Results and discussion

The trend of average access to energy is demonstrated in Figure 1, and it is bifurcated across four different income groups. The global average has increased over the study period of 1990-2019, and this increase has been found to be steady during the period. However, the rising global trend is not visible across all the income groups. While the global average has shown an increase of 17.92%, the high-income group has demonstrated a rise of 22.17%. The average of the remaining three income groups are below the global average, and the upper middle-income group has shown a rise of 15.72%, while the lower middle-income group and low-income group have shown the decline of 6.24% and 8.61%, respectively. This prevailing trend gives an indication that there is a possibility of inequality in the distribution of access to energy in these four groups of countries.

Place for Figure 1

Following the trend depiction and based on the assumption of prevailing disparity among these nations, the first phase of decomposition has been carried out, and the decomposition outcome has been demonstrated in Figure 2. The inequality in access to energy at a global scale has been found to be increasing during the study period, and the Theil index has shown an increase of 116.34%. It might be due to the disproportionate labor productivity and labour force participation, which are possibly caused by the gradual replacement of labours with capital intensive technologies. Apart from the countries pertaining to the lower middle-income group, all the remaining three groups have shown rise in the inequality in access to energy. While the increase in inequality is only 4.41% for the high-oncome group countries, the higher middle-income and low-income group countries have shown the rise in inequality by 21.70% and 46.39%, respectively. However, it is quite likely that the rise in the global inequality in access to energy might also be caused by the inequality prevailing within the groups itself. Alongside this, it is also necessary to understand the persisting dynamics behind the movement of this inequality, i.e., the possible factors driving the trend of this inequality. In order to understand both these aspects, it is required to further decompose this inequality measure.

Place for Figure 2

4.1. Decomposition of inequality indices - inequality in energy intensity

[2] Based on availability of data, the country selection is made.

The trend of average energy intensity is demonstrated in Figure 3, and it is bifurcated across four different income groups. The global average has decreased over the study period of 1990-2019. During 1991-1994, the global average has shown an increase, and except the spike in 1999 and a small rise during 2015-2017, the decreasing trend has been nearly persistent. This global trend is almost similar across all the income groups. However, the magnitude of the decline varies across the groups. While the global average during the study period has been 0.536, the same for the high-income group has been 0.270. The average of the remaining three income groups are above the global average, and the respective average energy intensity of the upper middle-income, lower middle-income, and low-income groups have been 0.573, 0.755, and 0.964. In terms of decline, both high- and low-income groups of countries have shown the decline below global average, whereas lower middle- and upper middle-income groups of countries have shown the decline above global average. This divergence in the average magnitude and disparity in prevailing trend gives an indication that the distribution of energy intensity might demonstrate inequality in these four groups of countries. In order to analyze this possibility, the global inequality in energy intensity has been calculated, and subsequently, the inequality measures for the four groups of countries are also calculated.

Place for Figure 3

The inequality in energy intensity has been calculated following Theil index, and the movement of the inequality is depicted in Figure 4. It shows that the global inequality in energy intensity has demonstrated a rise, and this rise has been nearly 109.45%. This indicates that the regional disparity in the energy intensity has gone up during the study period. While the energy intensity is demonstrating a decline at a global level, rise in the inequality might demonstrate the presence of inter-regional and intra-regional differences during the study period. After 2009, the inequality has shown a sharp rise, and that growth trajectory prevailed till the end of study period. Following the economic downturn in 2008-09, the decline in energy consumption and economic output was experienced across the globe. However, the economic pressure was felt more on the countries pertaining to the lower income categories, as well as the developing and emerging economies. The major reason behind this situation was that the economic growth of these countries is characteristically dependent on economic growth of the developed countries via several channels, and therefore, economic downturn in the developed economies (high-income category) might have a multiplier effect on the economic growth of the countries pertaining to other income categories (IMF, 2009; World Bank, 2010). Because of the shrinkage in the economic output, it was not immediately possible for these countries to expand their R&D budget in energy research, which was feasible for the high-income countries. Therefore, after 2009, the energy consumption pattern in the developed economies started undergoing a transformation towards promoting renewable energy solutions, and their energy intensity started improving. For example, the *EU 2009 Renewable Energy Directive* was aimed at increasing the share of renewable energy solutions in their energy portfolio, as well as to improve the energy efficiency (see EU, 2009). At the same time, the USA also increased their energy research budget by nearly 100%, and one of the major reasons behind this increase in energy budget was to promote energy innovation for ascertaining energy efficiency by lowering energy intensity (Newell, 2011; IEA, 2020). However, such prompt policy actions were not possible for the other groups of countries. Because of the dependence on export-driven external demand, these countries faced the economic downturn, and hence, it was not possible for them to take any prompt action for bringing forth energy innovation. As a result, based on the abundance of natural resources, they tried to achieve economic growth, which was given more priority by the policymakers. For the lower middle- and upper middle-income groups of countries, this scenario can be expressed as a classic example of the "*Middle-Income Trap*", which delayed the technological adaptation (Arezki et al., 2019).

Place for Figure 4

While explaining the inequality prevailing among the different income groups, the inequality might also prevail within the individual income groups, and in order to analyze this scenario, the Theil index has been decomposed to bring out the within-group component of the inequality in energy intensity. The inequality components for the four income groups are depicted in Figure 5. The inequality in energy intensity has shown the lowest decline of 40% in case of the high-income countries, whereas the low-income countries have shown a rise in the inequality by nearly 171%. The lower middle- and upper middle-income groups of countries have shown decline in inequality by 69.5% and 51.5%, respectively. However, the within- and between-group decomposition of the inequality component shows that the contribution of within-group inequality component has been more than the between-group inequality component till 2002, and after that the trend has been reversed (see Appendix 2). This gives an indication that the prevalence of inequality in energy intensity started to reduce after Intergovernmental Panel on Climate Change (IPCC) started emphasizing more on technology transfer since 2002 (Philibert, 2004). Moreover, following the 2002 repartition, Global Environment Facility (GEF) started emphasizing more on the involvement of private players in financing the energy efficiency projects (Philibert, 2004). These policy initiatives helped the countries to ease the cross-border technology transfer. However, at the implementation level, the high-income group of countries enjoyed the most of the economic benefits, while the transitional and developing economies were deprived (Heller and Shukla, 2003). This led to the rise in between group inequality since 2002. Moreover, the characteristic political instability in the low-income countries hindered the technology transfer and opening the energy market for private players. This gradually enhanced the within-group inequality for the low-income group of countries. For example, the political instability in Ethiopia, economic vulnerability of Tajikistan, and the Syrian civil war are some of the cases, which have a significant impact in driving this inequality for the low-income group of countries.

Place for Figure 5

In a nutshell, it can be stated that the inequality in energy intensity between the countries started increasing because of the (a) advantageous economic position of the high-income countries in attracting the potential financing opportunities, whereas countries from other income groups were deprived, (b) following the economic slowdown in 2008, the lower middle- and upper middle-income group of countries started falling in the *Middle-Income Trap* for restoring their economic growth, by means of their pool of natural resources, and (c) the inherent political instability contributed towards the rising inequality in energy intensity in the low-income group of countries. While the high-, upper middle-, and lower middle-income groups of countries are showing a possibility of convergence in this inequality, it might not be possible for the low-income countries. Saying this, from the perspective of Sustainable Development Goals (SDGs), it might be inferred that when the high-income countries are making a fair progression towards attaining a sustainable energy future, the progression of the lower middle- and upper middle-income countries are moderate, and the low-income countries are drifting away from the sustainable energy future. It might be a concern for the policymakers of the low-income countries, as their present energy-led growth trajectory might make a hinderance in attaining the objective of SDG 7, i.e., affordable and clean energy.

4.2. Decomposition of inequality indices - inequality in labor productivity

The trend of average labor productivity is demonstrated in Figure 6, and it is bifurcated across four different income groups. The global average has increased over the study period of 1990-2019. During 1990-2002, the global average has shown a stagnant increase, and after 2002, the global average has shown a steady rise. Like the previous indicators, the trend seen at the global level is almost similar across all the income groups. However, the magnitude of the rise varies across the groups. While the global average during the study period has been $24,068.94, the same for the high-income group has been $52,042.44, which is more than two times of the global average. The average of the remaining three income groups are below the global average, and the respective average labor productivity of the upper middle-income, lower middle-income, and low-income groups have been $11,145.63, $3,572.55, and $1,875.97. In terms of growth rate, low-income group of countries have shown the rise above global average, the growth rate for high-income countries have been almost similar to the growth rate of global average, whereas low and upper middle-income groups of countries have shown the rise below global average. This divergence in the average magnitude and disparity in prevailing trend gives an indication that the distribution of labor productivity might demonstrate inequality in these four groups of countries. In order to analyze this possibility, the global inequality in labor productivity has been calculated, and subsequently, the inequality measures for the four groups of countries are also calculated.

Place for Figure 6

The inequality in labor productivity has been calculated following Theil index, and movement of the inequality is depicted in Figure 7. It shows that the global inequality in labor productivity has demonstrated a rise, and this rise has been nearly 120.95%. This indicates that the regional disparity in the labor productivity has gone up during the study period. Along with a regionally disproportionate rise in labor productivity at the global level, rise in the inequality might demonstrate the presence of inter-regional and intra-regional differences during the study period. The inequality increased till 2005, then it demonstrated a decline till 2012, and then it started increasing again. The labor market encountered a demand shock during the economic slowdown during 2005. The economic pressure was experienced in the countries across all the income categories. The introduction of Euro and its strong position against the US Dollars were gradually proving out to be unprofitable for the European countries, as their exports started shrinking (United Nations, 2005). Following the great Telecoms crash, weakened position of the developed nations in the international trade market created a slump in the demand of labors. This slump was felt outside the nations also, as the emerging Information Technology-based service industry in the developing economies was highly dependent on the outsourced projects from the developed nations (UNCTAD, 2013). The connectivity among the nations by means of trade spillovers helped the negative impact of economic slowdown to spread in other nations. Moreover, before the market could have recovered, the economic downturn of 2008-09 took place, and the pressure on the global labor market continued. Saying this, it also needs to be remembered that the pace of recovery has been different across the income groups, and the capacity to innovate and presence in the international trade market vary largely across the four income categories (United Nations, 2017). The developed nations were able to optimize the utilization of resources by the artificial intelligence and automation-based technologies, which started gaining prominence in 2011-12 (Marr, 2018). This is also the time, when the Fourth Industrial Revolution has started to gain momentum, and the developed nations started building on the intelligent manufacturing strategies (Li et al., 2017). With an aim of achieving increasing returns to scale, these technologies started replacing labors, which has created a slack in the labor demand from the developing and low developed economies. Rising demand for highly skilled labors in the newly emerging job opportunities gradually started crowding out the labors with low or backdated skillset, and as a result, overall labor market started shrinking, without having an impact on the output generation (Zhu et al., 2020). As a result, in mathematical terms, as per the definition provided by ILO (2019), the labor productivity will demonstrate a rise, without having any impact on the output generation. Therefore, following the *Capital-Labor Substitution* principle of Arrow et al. (1961), substitution of labor with capital invested in technology will indicate a higher labor productivity, as the total number of employed persons in the economy will be reduced, keeping the total output constant. Hence, without having proper skill-development facilities or adequate educational infrastructure in place, the low-skilled labors will be replaced by the technological innovation, and therefore, with the rise in technological innovations in 2012, the inequality in labor productivity started increasing.

Place for Figure 7

While explaining the inequality prevailing among the different income groups, the inequality might also prevail within the individual income groups, and in order to analyze this scenario, the Theil index has been decomposed to bring out the within-group component of the inequality in labor productivity. The inequality components for the four income groups are depicted in Figure 8. The inequality in energy intensity has shown the lowest increase of 106% in case of the low-income countries, whereas the high-income countries have shown a rise in the inequality by nearly 184%. The lower middle- and upper middle-income groups of countries have shown decline in inequality by 115.44% and 174.67%, respectively. However, the within- and between-group decomposition of the inequality component shows that the contribution of within-group inequality component has been more than the between-group inequality component, almost across the entire study period (see Appendix 3). The gap between these two components has shown a cyclical movement, and the gap has nearly shrunk to zero in various phases. It is interesting to observe that the reduction in the gap between these two components occurred in those phases, whenever there has been any economic slowdown at the global level. For example, the first phase can be traced back to the incident of Economic Crisis in early 1990s, which majorly lasted till 1993 (Walsh, 1993). Similarly, the second phase can be traced back to the economic slowdown, that was probably caused by the collapse of dotcom bubble, and the attack on the World Trade Centre on September 11, 2001 (Emin, 2016). Moving on, the third and fourth phases can be traced back to the Subprime Mortgage crisis, followed by the economic recession, which affected the global economic scenario almost till 2010 (Dymski, 2010). It was followed by the Black Monday 2011 incident, which was characterized by the global stock market crash (Kastner, 2019). Before the world could have recovered from this sudden shock in the financial market, United States debt-ceiling crisis of 2013 took place (Nippani and Smith, 2014). This incident had a severe impact on the global employment scenario, and therefore, it affected the productivity of the labors. Owing to the technological capability of the high-income countries, it was comparatively easier for them to recover from the economic losses and start creating jobs, which was difficult for the low- and middle-income countries. For low- and lower middle-income countries, dependence of the service industry on developed nations for income and employment generation reduced the productivity of labor, as technological progression in the developed economies gradually started replacing the labors from the low- and lower middle-income countries. For example, under the lower middle-income group of countries, India has added the most to the within-group inequality component. Continuous dependence on the USA for service-oriented jobs (Pant, 2018), lack of investment in the manufacturing sector (Basu, 2018), and inadequate infrastructure for boosting the entrepreneurship (Doshi et al., 2019) can be attributed as the lowered labor productivity in

India. While saying this, the political instability of the low-income countries can be considered as a potential barrier to the rise in entrepreneurship opportunities, which has decreased the labor productivity in these countries. Gradually declining movement of labor force between the countries across several income groups has attributed to the between-group inequality component. On the other hand, while the trade relation among the high-income countries has shown improvement, it has been limited to technology transfer, which has consequently added to the unemployment problem in these nations (Galati and Bigliardi, 2019). Therefore, the disparity in labor productivity has been more prevalent in the high-income countries, as this showcases the prevalent policy myopia in these nations (Francis, 2015). Similarly, the uneven technological adaptation and capital-labor substitution in the upper middle-income countries has added to the rise in the disparity in labor productivity (Naudé and Nagler, 2016). Coexistence of these scenarios has added to the within-group inequality component.

Place for Figure 8

In a nutshell, it can be stated that the inequality in labor productivity between the countries started increasing majorly because of the (a) adaptation of technologies as a substitute of labor, (b) lack of encouragement for entrepreneurship initiatives in low- and lower middle-income countries, and (c) the inherent political instability in the low-income group of countries. None of the group of countries is demonstrating the likelihood of convergence in terms of inequality in labor productivity, rather a divergence from the present scenario can be expected. In view of this discussion, it might be inferred that the technological adaptation in the nations around the world might not prove to be sustainable in the long-run, as the circular flow of the economy might be violated owing to the exclusion of the labor force and concentration of wealth in the hands of few. It might be a concern for the policymakers, as this prevalent growth trajectory might make a hinderance in attaining the objective of SDG 8, i.e., decent work and economic growth, and continuation of this situation might lead to the non-attainment of SDG 10, reduced inequalities.

4.3. Decomposition of inequality indices - inequality in labor force participation

Like the previous two cases, the trend of average labor force participation is demonstrated in Figure 9, and it is bifurcated across four different income groups. The global average has increased over the study period of 1990-2019. During 1990-2008, the global average has shown a steady increase, and after 2008, the inequality started increasing at a lower growth rate. Like the previous two indicators, the trend seen at the global level is almost similar across all the income groups. However, the magnitude of the rise varies across the groups. While the global average during the study period has been 0.438, the same for the high-income group has been 0.491. The average of the remaining three income groups are below the global average, and the respective average labor force participation of the upper middle-income, lower middle-income, and low-income groups have been 0.421, 0.403, and 0.365. In terms of growth rate, upper middle-income group of countries have shown the rise above global average, the growth rate for high-income countries have been almost similar to the growth rate of global average, whereas low and lower middle-income groups of countries have shown the rise below global average. This divergence in the average magnitude and disparity in prevailing trend gives an indication that the distribution of labor force participation might demonstrate inequality in these four groups of countries. In order to analyze this possibility, the global inequality in labor force participation has been calculated, and subsequently, the inequality measures for the four groups of countries are also calculated.

Place for Figure 9

The inequality in labor force participation has been calculated following Theil index, and movement of the inequality is depicted in Figure 10. It shows that the global inequality in labor force participation has demonstrated a rise, and this rise has been nearly 121.31%. This indicates that the regional disparity in the labor force participation has gone up during the study period. Along with a regionally disproportionate rise in labor force participation at the global level, rise in the inequality might demonstrate the possible presence of inter-regional and intra-regional differences during the study period. The inequality increased till 1998, then after a decline in 1999, and then it started increasing again. This situation might be reflected back to the global labor market reform through *Declaration on Fundamental Principles and Rights at Work* (ILO, 1998). During the International Labour Conference 1998, this declaration paved a way to enhance the labor standards in the organizations, while ascertaining an improved work environment by means of collective bargaining, eradication of involuntary labor, abolition of workplace discrimination, and outlawing child labor. These directives gave the labors around the world an incentive to join the workforce, and consequently, global inequality in the labor force participation came down in 1999. However, a series of consecutive economic slowdowns, starting from the collapse of dotcom bubble, and the gradual improvement in the digital automation technologies started to replace human labor in the workplace. Lack of inadequate educational infrastructure and training facilities, and wage shrinkage started disincentivizing the labor force participation in several countries. For low-income countries, Fabrizio et al. (2017) have attributed this scenario to lack of proper governance structure, inadequate inter-sectoral labor mobility and financial investment, and poor infrastructural development, which said to have hindered the labor force participation, and led to higher income inequality. In a consecutive study, Cole (2018) has described the consequence of this situation in terms of distribution of power and respect for civil liberties by socioeconomic position. Therefore, it can be assumed that the vicious circle of poverty might have been led by the bidirectional association between poor labor force participation and higher income inequality, and its negative impact in terms of hindering the structural transformation of the economy towards being knowledge-driven has worsened the position of the low-income countries in the labor market (Lachler and Walker, 2018). The disparity has also its impacts on the skill development scenario, and owing to this, the number of high-skilled labors in the low-income countries started to reduce. However, because of the infrastructural capability of the middle- and high-income countries, this situation in the labor market did not worsen to this extent, and moderate to high governmental support for entrepreneurship activities helped to reinstate the balance in the job market. In spite of this, the connectedness between the countries by economic spillovers through exchange of labors started to reduce because of rapid technological innovation brought forth by Industry 4.0, which has been relying mostly on automation.

Place for Figure 10

Like the previous two inequality indicators, the inequality might also prevail within individual income groups, and the Theil index has been decomposed to bring out within-group component of the inequality in labor force participation. The inequality components for the four income groups are depicted in Figure 11. The inequality in labor force participation has shown the lowest increase of 6.19% in case of the high-income countries, whereas the lower middle-income countries have shown a rise in the inequality by nearly 54.25%. The upper middle- and low-income groups of countries have shown rise in inequality by 46.17% and 20.03%, respectively. However, within- and between-group decomposition of the inequality component shows that the contribution of within-group inequality component has been more than the between-group inequality component till 1993, and after that the trend has been reversed (see Appendix 4). Along with the line of the economic slowdowns, the cross-border mobility of labors started to reduce, as the policymakers in the respective countries are more concerned about creating employment for own citizens. Moreover, the rapid technological advancements also started to reduce the demand of labors, which has been catalyzed further through the easing of cross-border technology transfer. While saying this, it is also necessary to note that at the beginning of the study period, the prevailing inequality in the low-income countries was already highest among the four income groups, and the poor skill development scenario in these countries has resulted in limited cross-border movement of labors. With graduation of time, the situation has only worsened in the countries, and the political instability of these nations added to the worsening of the situation. However, situation of skill development in the middle-income countries is comparatively better, but the focus of skill development in these nations is largely peripheral, and therefore, the labors from these nations can be replaced by the technologies. This situation can be traced back to the classic case of "*Middle-Income Trap*", which holds these nations back from investing in high value-added industries (Doner and Schneider, 2020). Hence, with graduation of time, skillsets of the labors are not upgraded in accordance with the technological progression, and in due course, unemployment increases in these nations. This psychological barrier of maintaining the status quo proved to be costly for these nations, as with graduation of time, the inequality in labor force participation in these countries increased, owing to the fact that the majority of the labor force in these nations started losing their global competitiveness. Existence of these scenarios added to the between-group inequality component more than the within-group inequality component.

Place for Figure 11

In a nutshell, it can be stated that the inequality in labor force participation among the countries started increasing majorly because of the (a) adaptation of technologies as a substitute of labor, (b) lack of skill development facilitates in low-income countries, and (c) psychological barrier of "*Middle-Income Trap*" in the middle-income countries. None of the group of countries is demonstrating the likelihood of convergence in terms of inequality in labor force participation. In view of this discussion, it might be inferred that the technological adaptation around the world might not prove to be sustainable in the long-run, as it shrinks the labor market. Absence of adequate skill development facilities might worsen the situation. It might be a concern for the policymakers, as this prevalent growth trajectory might make a hinderance in attaining the objective of SDG 8, i.e., decent work and economic growth, and continuation of this situation might lead to the non-attainment of SDG 10, reduced inequalities.

4.4. Association between the decomposed inequality components

By far, the components of inequality in access to energy have been decomposed and analyzed. If these three components are analyzed together, we can find certain insights, which might have academic and policy-level significance. Because of the inadequate skill development facility, the labors across the world might face issues in acquiring high-skilled jobs, which require high end technological applications. As the pace of skill development is slower than the pace of technological progression, labors will be replaced gradually, and their average wage will also start shrinking. However, with few high-skilled labors, the technological advancements will be able to produce the same level of output, and therefore the labor productivity will rise. In such a situation, technological advancement will exert a *Substitution Effect* on the labor productivity. Now, with the few high-skilled labors available in the job market, rise in labor productivity will gradually create income inequality, as the wealth will start to concentrate on the hands of few high-skilled labors. This is the phase, when rise in the income inequality will gradually put demand side pressure on the economy, as disproportionate distribution of income will exert a pressure on the demand of products, and GDP growth in several countries might start slowing down. With gradually falling demand in the goods and services market, and shrinkage in wealth in the hands of labor, the demand for energy will start coming down. As a result, the energy intensity might start coming down. During this phase, it might be said the labor productivity might have an *Income Effect* on the energy intensity. Now this reduction in energy intensity might have a possible impact on the income generation process, which might have a consequential impact on the skill development of the labors. This impact might create a *Vicious Circle of Energy Poverty* through the feedback impact on labor force participation. This entire sequence of events has been depicted in Appendix 5. From the perspective of attaining the SDG objectives, these associations might prove to be critical for the policymakers.

4.5. Policy implications

Owing to the rise in the inequality in access to energy, it is likely that the countries might fall into the trap of *Vicious Circle of Energy Poverty*, and it might impede the prospect of skill development across the nations. As the technological innovation is inevitable, it can be assumed that with the graduation of time, a greater number of labors might be excluded from the workforce, and the job market will shrink further. Although the nations will enjoy a short-run economic benefit by utilizing the labor-replacing technologies, it might be difficult for the nations to sustain the economic growth, as the social order might be disturbed because of the rising unemployment scenario. In such a context, attainment of SDG 7 might prove to be difficult, as non-attainment of SDG 8 and SDG 10 might turn out to be potential predicaments on the way (Sinha et al., 2020 a, b, c). This is where the policy intervention might be necessary to avoid such an issue, which might harm the developmental trajectory of the nations.

As the technological progression is embraced by the nations, the policymakers need to ensure that it should not replace labors. In order to reduce the level of unemployment, policymakers need to ensure that the replacement of labors for a firm should not go beyond a threshold limit, which could be defined by a certain percentage of the labor force (Cheng et al., 2021). Though the firms are profit-oriented, it should be remembered that they are a vital part of the circular economy, and hence, they also need to ensure the social welfare of the economy. Saying this, it is also evident that it might not be possible for the firms to take up this responsibility without the support of the policymakers. The government should also augment the action of firms by initiating adequate skill development facilities for the surplus labor, so that they can be employed in other sectors. However, in keeping with the pace of technological development, skill development initiatives by government might not be sufficient, as non-adaptation of latest technologies might reduce the competitiveness of the firms in the international market, and this might have a negative consequence on the economic growth pattern. In order to adhere to the mandates of SDG 7, the policymakers might ponder upon boosting the renewable energy generation sector, so that the surplus labor can be employed in those firms. As reliance on technological adaptation might reduce the scope of cross-border movement of labors, the nations need to develop domestic capabilities to absorb the labor force (Balsalobre et al., 2021; Sinha et al., 2021). Employment of the surplus labors in the newly formed firms will help the nations to make certain progression towards attainment of the objectives of SDG 8. Encouragement of the entrepreneurship activities towards renewable energy generation may not only ensure the energy security of the nations, but also long-run employment of the surplus labor, subject to proper and adequate skill development facilities provided by the policymakers and strict adherence to the labor-replacement policy (Ahmad et al., 2021). This initiative will help the nation to reduce the skewed distribution of income by encouraging labor force participation, while the continuous skill development by the government will enhance the productivity of the labors. It will help the nations to make certain progress towards attaining the objectives of SDG 10, and in this pursuit, attainment of the objectives of SDG 8 might act as a driver.

Now, while having this core policy framework in place, it is required to have a tangential policy framework, which will help the core policy framework to sustain (Shahbaz et al., 2019; Zafar et al., 2020). The tangential policy framework needs to focus more on the aspect of education and skill development, so that the future generation of labor force might be well-acquainted with the latest developments in the field of technology, with a special focus on the sustenance of energy generation. Therefore, the policymakers might need to bring forth modernization in the educational curriculum, so that the skill development process can reach the grassroots level. Moreover, this initiative will also help these nations to achieve the full potential of renewable energy. By ensuring quality education, i.e., by means of attaining the objectives of SDG 4, the nations can ascertain the attainment of the objectives of SDG 7.

5. Conclusions

The study focused on the assessment of the global energy poverty scenario by analyzing the global inequality in access to energy over 1990-2019, and using Kaya-Theil decomposition approach, the inequality has been bifurcated into three components, i.e., inequality in energy intensity, inequality in labor productivity, and inequality in labor force participation. The study considered four income groups, and it was found that rise in inequality in access to energy has been found both at the global level, as well as for all the four groups. The three components of inequality also have shown rise during the study period.

5.1. Theoretical contribution

The present study touches upon the dynamics of energy poverty from the perspective of interaction between inequalities in energy and labor market. In doing so, the study looks into the energy poverty issue from the demand side perspective, while the literature has majorly looked into the supply side dynamics of the problem. In this study, an attempt is made to analyze how the inequality in energy intensity has a spillover effect on the inequality in the labor market, followed by the feedback effect of inequality in the labor market on the inequality in energy intensity. These inequality components are divulged by decomposing the inequality in access to energy, which is characteristically energy poverty. The catalyzing role of ongoing technological innovations in improving energy efficiency and replacing labors might create a social imbalance through creating unequal wealth accumulation, and this will be reflected in the unequal access to the energy sources. The inequality in the labor market might widen the income gap, which might negatively impact the economic output in the long run by further widening the inequality in energy intensity. As a result, the incidents of energy poverty might rise. This interaction between the energy and labor market might create the *Vicious Circle of Energy Poverty*. In the literature of energy economics, this is by far the first study to analyze the energy poverty from this dimension. This result might help the policymakers in addressing the issue of energy poverty in a more holistic way. While the existing policy measures deal with improving the access to energy, this study outcomes have shown how the solutions should take into account the labor market aspects. Largely, the prevailing policy measures assume that addressing the energy poverty issue might lead to improvement in the livelihood standard. The study outcomes have questioned that measure and have shown that access to income via access to jobs might solve the global problem of energy poverty Theoretically, this study can open the avenues for the empirical research in identifying the linkage between these two markets, and how the causal associations between these two markets can shape the energy poverty. Moreover, the nature of the income and substitution effects across various countries can be analyzed to gain more insights about the possible nature of energy poverty, and thereby, suitable policy designs can be suggested.

5.2. Limitations and future directions

Limitation of the present study lies in the consideration of labor market only, while analyzing the energy poverty scenario. The study could have been enriched by considering the aspects of innovation, as it could have brought forth additional insights on the energy poverty scenario. Saying this, it is also needed to remember that this study puts forth a baseline mechanism to approach the issue of energy poverty, and the policy framework suggested in the study can be taken as a reference to build the policy frameworks suitable for the contextual setting of the nation. Future research on this direction can be carried out by considering the energy innovation aspects, so that the policy implications can be further strengthened.

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