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Inequality of renewable energy generation across OECD countries: A note

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ABSTRACT

This study recommends the use of Theil's second measure to investigate international renewable energy generation disparities. This index permits disparities to be broken down within and between groups of countries in a reliable style. An analysis of OECD countries for 1980–2011 shows some basic points: first, drop in renewable energy generation disparities is attributable both to within-group and between-group inequality components; second, between-group inequalities are presently the key contributor to the inequality; and, further investigation on within-group inequalities divulges the significant explanatory role played by North American, European, and Asian and Oceanian countries.

1. Introduction

The energy security issues being faced by the world brings forth the need to introduce renewable energy systems. Technological innovations are playing a major role in making this form of energy affordable to the citizens across the world [29,6]. However, looking at the OECD countries, it can be seen that the diffusion of technology across the member countries has not been taken place effectively, and the evidences are manifold. First, the technical efficiency of renewable energy does not show any parity for the OECD countries [8]. Second, rising CO_2 emission level in some of the OECD countries show the prominent use of fossil fuel based energy [25], and it is owing to the disparity in the level of energy intensity, which can be seen in the works of Alcantara and Duro [1]. Third, Foxon et al. [24] shows the regulatory and policy level inefficiencies and barriers preventing the UK and other OECD nations to implement long term renewable energy production and initiatives for trading of excess energy. Fourth, if we look at the renewable energy generation statistics as a percentage of total energy generation in the OECD countries, then a large amount of deviation can be seen. In 2011, when Iceland was holding 83.80 per cent of energy as renewable energy, comparatively bigger nations like the UK and the US were holding 4.10 and 6.10 per cent, respectively. When these four evidential statements were combined, it became prominent that there lies a certain amount of inequality in renewable energy generation among the OECD countries. This issue has been addressed by Duro and Padilla [19], while discussing about the role of energy transformation in OECD countries. However, the extent of this inequality has not been addressed so far in the literature of energy economics.

Taking a cue from the studies by Sun [57], Duro and Padilla [16], Clarke-Sather et al. [9], Sinha [56], Duro et al. [21] and several others, promising research areas in discovering the inequalities across diverse groups of nations in diverse contexts have emerged, and consequently, these inequalities can also be broken down to sub-group levels using several methodological applications, like mean deviation (MD), Gini coefficient, and Kakwani Index. In view of the arguments put forward in the literature, we have carried out the inequality analysis using Theil's second measure [59]. Compared to other inequality measures, this index exhibits a disintegration of inequality components by sub-groups [1]. This particular characteristic allows us to look into the inequality lying within the subgroups of a particular group of countries, and therefore, we will be able to look into the possible technology diffusion scenarios among the nations.

Through this study, we intend to present the inequality scenario regarding renewable energy generation across OECD countries. Purpose of this study is to open up the discussion regarding this pertaining inequality, so that further studies can come out with policy interventions for addressing this issue. Therefore, we are interested only to demonstrate the inequality condition by means of Theil's second measure, and will not indulge ourselves into prescribing any kind of policy level decisions for handling or mitigating this issue. Our aim is to present a perspective before the readers, so that they can take up this work as a foundation for further research.

2. Literature review

By far, in the literature of energy and environmental economics, researchers have majorly focused on the measurement of inequality in energy intensity [1,18,19,57] and inequality in CO_2 emission intensity

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[47,9,14,15,20,46,56,21]. If these studies are analyzed, then it can be seen that apart from looking into the international disparities in energy intensities and CO_2 emissions, these studies have also tried to find out the reason underlying the existing disparities. When most of the nations are trying to reduce emission levels, the growth trajectory should also be taken care of. Therefore, shifting from non-renewable to renewable energy source turns out to be an essential solution, while the economic cost of this solution should also be taken into consideration.

When the question of the economic cost of pollution abatement and renewable energy generation comes into picture, the discussion can be carried out on the premise of Environmental Kuznets curve (EKC) hypothesis, which is based on the interaction between economic growth and environmental degradation, and how the economic growth pattern can affect environmental quality. According to Grossman [26], this effect can take place by means of three channels, namely scale effect, composition effect, and technique effect. When the economic growth sets pace, it exerts the scale effect on the environment. In order to fuel economic growth, demand of natural resources rises, and consequently, the direct and indirect consumption of natural resources is translated into the production process. Once the production process starts, substantial amount of industrial waste is generated and this by-product of industrial and economic growth poses serious threat to the environmental quality. Now, with the rise in income, the industrial structure of a nation starts undergoing a transformation, and therefore, the composition of the economy starts changing. This is where economic growth exerts the composition effect on the environmental quality, and this is when the effect of economic growth on environmental quality starts to be positive. During this phase, the secondary sector starts maturing and the industries shift towards cleaner technologies. This industrial transformation is reflected in the urbanization pattern, and the demand for cleaner environment starts increasing. This is the time when the industries start to incorporate technologies for increasing energy efficiency. This progress in the path of technological innovation is the way, by which economic growth exerts the technique effect on the environmental quality. During this phase, the tertiary sector (service sector) starts growing, and the economy gradually starts turning out to be knowledge-intensive, rather than capital-intensive. This is the time, when the economy starts investing more in the research and development based activities, substituting the obsolete and polluting technologies, and generating energy from alternate sources. Therefore, in this phase, the environmental quality gradually improves with the rise in economic growth. Now, in order to achieve the improvement in environmental quality, the nations are looking forward to introduce renewable energy, so that this form of energy can bring forth the economic growth can exert technical effect on the environmental quality.

According to the World Energy Outlook special report 2015, “Renewables become the leading source of electricity by 2030, as average annual investment in non-hydro renewables is 80% higher than levels seen since 2000”.[2] This growth can be attributed to a number of factors, such as, growing environmental pressure, ongoing and increasing oil price volatility, and excessive dependence on shrinking fossil fuels [10]. This urge of exploration of renewable energy sources majorly came into picture after the oil crisis in 1973. Thereafter, nations started putting forth a great deal of funding and effort in the R & D activities for finding out renewable energy sources, but the result was not significant. However, according to the study of Jacobsson and Johnson [30], this perception started changing since the late 80's, and they found that the renewable energy intensity was on a rising path.

While stating this, though the renewable energy generation was turning out to be more prominent across the nations, it was noticed that this energy generation process was not equitable in nature. If the different groups of nations are considered, then this disparity can be more visible. An indicative literature review on this aspect is shown in Appendix 1A, and it is visible that the member countries of OECD are experiencing disparity in renewable energy intensity. This disparity can be attributed to a number of factors, namely inefficient diffusion of technology, political incoherence, terms of trade, policy level inefficiencies etc. Now, looking at the inequality in carbon emissions for these countries, it can be seen that the disparity is prevalent across the subgroups of OECD nations [56]. This disparity lies due to the dependence on fossil fuel based energy consumption [1]. In the latest study by Pascual et al. [48], it also has been indicated that the carbon emission pattern has historically been characterized by the demand of fossil fuel, and in order to mitigate that, demand has to be shifted towards renewable energy sources.

While stating the issue of inequality in renewable energy generation, it should always be remembered that income inequality plays an important role in defining the renewable energy profile of any nation. With respect to the implementation cost aspect of the renewable energy projects, differences per capita income growth characterizes the disparities in renewable energy generation in the comparatively low income nations, and at the same time, per capita emission levels [19]. This statement has to be analyzed in a scenario, where inequality in energy intensity among OECD countries is falling, but the emission levels are rising. In such a scenario, it is not hard to assume that the technological diffusion is not turning out to be efficient across the member nations, and green energy initiatives are getting concentrated in a few nations [37]. In such a scenario, it is required to investigate about the state of inequality in renewable energy generation across the OECD member countries.

3. Methodological aspects

Among the literature of energy economics, the study by Sun [57] can be considered as one of the earliest studies on estimation of inequality in energy intensity using the unweighted MD approach. One of the major problems with this approach is that it considers a homogenous weightage across the sample cross-sections. Even the weighted MD approach can hardly provide any information regarding the between-group inequality measures. One of the major advantages of Theil's inequality measure is that it allows us to break up the inequality components into within-group and between-group estimates, which might not be achieved by using the other inequality measures, like Gini index and Kakwani Index. These issues have also been identified by Alcantara and Duro [1], Duro and Padilla [16,17,19,20], and Duro et al. [21]. A recent study by Lee [35] on regional inequalities of renewable energy resources in Korea was carried out by using Gini index. This study also was not able to provide any information on between-group inequality component, as we have already discussed. Keeping these issues in mind, we have decided to go for the Theil's inequality measure.

Taking a cue from the information entropy measure demonstrated by Shannon [54], Theil's index can take the following form of entropy:

$$E = -k \sum_1^n (p_i \log p_i) \quad (1)$$

where, p_i is the probability of finding renewable energy r_i of a nation among N number of nations, and the total renewable energy generation of the group of countries can be given by $N_{\bar{r}}$, $\bar{r}$ being the average renewable energy generation of the nations under consideration. Therefore, the Theil's index is given by:

$$E = \sum_1^n \left(\frac{r_i}{N_{\bar{r}}} \log \frac{N_{\bar{r}}}{r_i} \right) \quad (2)$$

If the homogeneity among the nations is considered, then $p_i = 1/N$.

[2] Energy and Climate Change: World Energy Outlook special report, Chapter 1, p. 12. (https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf).

Therefore, Eq. (2) can be represented as:

$$E = \frac{1}{N}\sum\nolimits_1^n \left(\log \frac{N_{\bar{r}}}{r_i}\right) \tag{3}$$

The limiting condition applied to Theil's basic measure brings out the Theil's second measure, and at the limit condition of the scalar multiplier s to e zero [55], we obtain the following form of entropy:

$$E = \lim_{s\to 0}\left[\frac{1}{N}\frac{1}{s(s-1)}\sum\nolimits_1^n \left\{\left(\frac{r_i}{N_{\bar{r}}}\right)^s - 1\right\}\right] = \frac{1}{N}\sum\nolimits_1^n \left(\frac{N_{\bar{r}}}{r_i}\right) \tag{4}$$

This form is generally referred to as the Atkinson's index [5,52], and this is also the form, which is by and large referred to as Theil's second measure. Given by the probabilistic functional form as mentioned by Theil [59], Theil's second measure can be ranged as (0, 1), where values zero can be signified as perfect equality, and one as perfect inequality. Disintegration of E in the subgroup inequality components can be carried out in the following manner:

$$E = E_{wg}+E_{bg} = \sum\nolimits_{1=1}^g p_g\left(\log \frac{\bar{r}}{r_i}\right) \tag{5}$$

where, E_{wg} refers to the within-group inequality, E_{bg} refers to the between-group inequality, and p_g stands for percentage renewable energy generation by group g.

4. Results

We have taken the data from the U.S. Energy Information Administration. Renewable energy generation is calculated from the electricity production from renewable sources includes hydropower, geothermal, solar, tides, wind, biomass, and bio-fuels. The countries included (n =28) are OECD members.

The main results are presented in Table 1 and Table 2. Table 1 provides us with the sub-group inequality decomposition results, and

Table 1
Inequalities in renewable energy generation across OECD countries.

Year	E_{bg}	E_{wg}	E	E_{bg} (%)	E_{wg} (%)
1980	0.79795	0.15459	0.95254	83.77	16.23
1981	0.71849	0.16516	0.88365	81.31	18.69
1982	0.69500	0.16747	0.86247	80.58	19.42
1983	0.68528	0.17008	0.85536	80.12	19.88
1984	0.61431	0.17900	0.79331	77.44	22.56
1985	0.67220	0.18101	0.85322	78.78	21.22
1986	0.23281	0.15565	0.38845	59.93	40.07
1987	0.35496	0.14744	0.50240	70.65	29.35
1988	0.49141	0.14619	0.63760	77.07	22.93
1989	0.44343	0.13191	0.57534	77.07	22.93
1990	0.44368	0.11952	0.56320	78.78	21.22
1991	0.46872	0.11884	0.58756	79.77	20.23
1992	0.42664	0.11600	0.54264	78.62	21.38
1993	0.38805	0.11571	0.50376	77.03	22.97
1994	0.24463	0.11512	0.35975	68.00	32.00
1995	0.34369	0.10586	0.44955	76.45	23.55
1996	0.24390	0.10221	0.34612	70.47	29.53
1997	0.27781	0.07947	0.35728	77.76	22.24
1998	0.27938	0.07393	0.35331	79.07	20.93
1999	0.23030	0.07681	0.30711	74.99	25.01
2000	0.23018	0.07740	0.30758	74.84	25.16
2001	0.22628	0.07370	0.29998	75.43	24.57
2002	0.17038	0.06956	0.23993	71.01	28.99
2003	0.18172	0.06256	0.24428	74.39	25.61
2004	0.19416	0.06320	0.25736	75.44	24.56
2005	0.19872	0.05574	0.25446	78.09	21.91
2006	0.15522	0.05322	0.20844	74.47	25.53
2007	0.17892	0.04747	0.22639	79.03	20.97
2008	0.13997	0.04613	0.18610	75.21	24.79
2009	0.13641	0.04571	0.18212	74.90	25.10
2010	0.11030	0.04152	0.15182	72.65	27.35
2011	0.08905	0.03648	0.12553	70.94	29.06

Table 2
Breakdown of the within-group inequality component.

Year	Asia & Oceania	Central & South America	Europe	North America
1980	0.17155	0.01879	0.36752	0.32808
1981	0.15993	0.01970	0.35920	0.31892
1982	0.16925	0.02020	0.34361	0.31224
1983	0.16487	0.02047	0.32058	0.30498
1984	0.17206	0.02021	0.30435	0.30297
1985	0.15674	0.02090	0.30141	0.30805
1986	0.14556	0.02155	0.30324	0.29394
1987	0.14762	0.02194	0.30393	0.29340
1988	0.14412	0.02200	0.28427	0.29500
1989	0.13534	0.02180	0.21709	0.25535
1990	0.13282	0.02575	0.18539	0.24565
1991	0.13856	0.02535	0.18464	0.23976
1992	0.13614	0.02535	0.17510	0.23731
1993	0.14078	0.02557	0.16806	0.21437
1994	0.14396	0.02656	0.16210	0.20985
1995	0.13665	0.02988	0.15877	0.20133
1996	0.12718	0.03034	0.14858	0.19603
1997	0.12269	0.03098	0.12489	0.13085
1998	0.12122	0.03194	0.11373	0.12125
1999	0.12041	0.03395	0.11745	0.12267
2000	0.11974	0.03666	0.11735	0.11554
2001	0.10791	0.03788	0.10870	0.11361
2002	0.10177	0.03963	0.10312	0.11076
2003	0.10005	0.04133	0.10091	0.10323
2004	0.09903	0.04446	0.09834	0.10905
2005	0.09689	0.04605	0.09756	0.09150
2006	0.09380	0.05087	0.09386	0.08795
2007	0.09023	0.05817	0.08673	0.08027
2008	0.08951	0.06296	0.06833	0.07856
2009	0.08610	0.05814	0.06710	0.07509
2010	0.08025	0.06225	0.06020	0.06435
2011	0.05447	0.06505	0.05974	0.06456

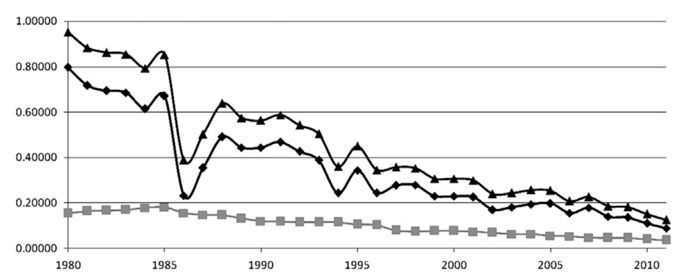

Fig. 1. Inequalities in renewable energy generation across OECD countries.

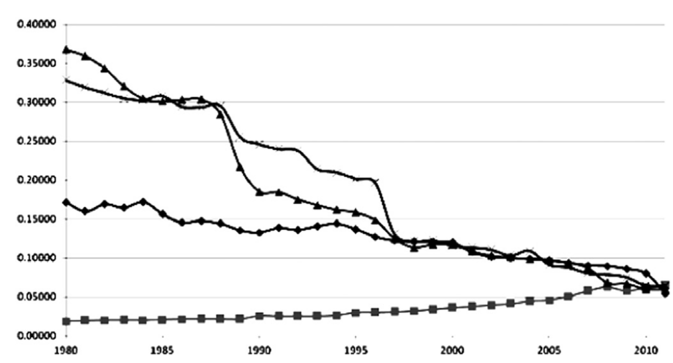

Fig. 2. Decomposition of within-group inequality components.

Table 2 demonstrates the contribution of each subgroup to within-group synthetic component. Fig. 1 and Fig. 2 depict graphical representations of patterns.

The analysis brings about a number of observations, as per the following:

First, the pattern of renewable energy generation inequalities among

OECD countries reveals a downward movement, with a plunge of 86.82% in the Theil index.

Second, the index has been divided into within-group and between-group inequality components, and both of these components jointly explain the fall in the inequalities. This is one part, where the literature has not focused, till date.

The rise in renewable energy generation and fall in the inequality in renewable energy generation in these nations is coexisting, and this is an observation coming out from the study. Without the Central and South American countries, this trend is visible for all the other groups. Since 1987, North American and European countries have been showing a steady decline in the inequality, whereas Asian and Oceanian countries have reached their peak in 1984, followed by a steady decline. This segment of the results suggest that the diffusion of renewable energy generation technology has been started among these nations, and this process might have further future policy implications regarding the sustainable development perspectives.

Third, the division of the inequality components shows that the between-group inequality component explains almost 75.75% of the overall inequality in renewable energy generation in OECD countries. From the policy perspective, this is a critical observation, as it designates the innovations in industrial sector, and thereby, providing us with the reason behind the diffusion of the renewable energy generation processes across the different geologically diversified groups. Though this aspect is not the focus of our study, further investigation on this aspect might highlight the strategies to be taken by the policymakers to extend the reach of renewable energy generation processes across these nations.

Apart from the Central and South American countries, rest of the groups demonstrated a steady decline in the renewable energy generation inequalities, and to mention in particular, the North American (18.83%) and European countries (17.83%).

5. Conclusion

Utilizing the Theil's inequality index, this study has found that over the period 1980–2011, OECD countries have demonstrated the fall in the inequalities in renewable energy generation while the overall inequality is decreasing, apart from of the pertaining to Central and South American countries. Besides, this index has exhibited two prime annotations: (a) the fall in inequality can be seen for both within-group and between-group inequality components, and (b) the contribution of between-group inequality component have been found to be higher in comparison with the within-group inequality component. The findings obtained from this study might signify two prospective areas of research on pollution abatement and renewable energy generation strategies: (a) the groups considered in this study show a sign of convergence in renewable energy generation process, which is determined by the institutional frameworks of these groups of nations, and (b) the existing level of inequality also explains the disproportionate rise in the demand of renewable energy, which is justified by the disproportionate industrial growth and lack of diffusion in technologies. Along with this, the fluctuations seen in the crude oil price movements in European, Asian and Oceanian nations can cause rise in inequality in energy intensity [1], and existence of this causal association might bring about the inequality in renewable energy generation, as well. Keeping the other findings of this study in mind, researchers should also look into this aspect, as this scenario might be faced in these nations in coming years.

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Appendix 1A. Review of the literature on renewable energy generation in OECD countries

Sample countries	*Authors*	*Result*
Australia	[32]	• Proportion of renewable energy is declining • Level of greenhouse gas emission is rising • R & D expenditure is declining
Austria	[36]	• Strong export profile in solar heating and bio-pellets • Domestic industry is expanding
Belgium	[27]	• Electricity from biological waste contributes to electricity generation • Wind energy generation is on the rise • Hydro power generation is falling
Canada	[33]	• Hydrokinetic energy generation is rising • Both in-land water bodies and oceans are being utilized
Chile	[4]	• Low willingness-to-pay for wind energy is making the power generation costly • Hydroelectric and thermoelectric energy are still to gain prominence
Denmark	[38]	• Gradual increase in wind energy, biomass, and waste energy for last thirty five years • Exploration is majorly driven by shrinking volume of natural resources
Finland	[36]	• Export profile is still at a nascent stage • Innovation policies are targeted at new energy initiatives • Lack of public support for domestic expansion
France	[11]	• Higher initial costs are major hurdle in implementing wind energy projects • Front-end loaded policy design is facing challenges
Germany	[62]	• Installation capacity of wind energy is rising • Present potential is not adequate to replace fossil fuel
Greece	[61]	• Financial viability of wind energy projects is catalyzing growth of wind energy projects • Legal constraints for introducing new energy sources
Ireland	[10]	• High dependence on fossil fuel imports • Policy level decisions are made for growing renewable energy generation capacity • Increasing fossil fuel price is worsening balance of payment condition

Italy	[7] [40]	• High public spending required to cover up the supply costs • Inadequate willingness to pay for renewable energy
Japan	[43] [13] [2]	• High willingness to pay for green energy • High negative elasticity of CO_2 emission w.r.t. renewable energy consumption
South Korea	[50] [58]	• High annual growth rate of renewable energy generation and consumption • Deregulation of energy market catalyzed the innovation of renewable energy sourcing
Luxembourg	[49]	• Low incentive in R & D investment • Non-existent tradable permits • Taxation is high
Mexico	[39]	• Social acceptance of renewable energy is high • Public-private partnership in innovation process is still in a nascent stage
Netherlands	[34]	• Co-firing of biomass and waste is rising • Tax benefit for firms using green energy • Exponential growth in the sale of green energy
New Zealand	[45]	• Microalgal biomass harvesting for emission reduction • Lipid extraction from algae and conversion into biodiesel • Regulatory support for boosting the renewable energy generation
Norway	[36]	• Strong export profile in photovoltaic cells • Public investment to reduce capital risk • Private investment is also on the rise
Portugal	[12]	• Constant rise is wave energy generation • Rising product cost is making the projects less profitable
Puerto Rico	[3]	• Strong wind energy generation profile • Emergence of energy production system from grass and sugarcane
Spain	[51]	• Government support for building up renewable energy generation architecture • Growth in employment in renewable energy sector • High willingness to pay
Sweden	[30]	• Increased use of renewable energy in households • Long standing political commitment towards renewable energy system development • Growing public expenditure in technological diffusion
Switzerland	[11] [22] [53]	• Financial viability of renewable energy projects is a major concern • Achieving the desirable capacity is constrained by financial problems
Turkey	[23] [31] [44] [60]	• Limited fossil fuel reserve is catalyzing renewable energy generation processes • Exponential growth in all phases of green energy • Growth in green energy generation is majorly to commensurate energy security issues
United Kingdom	[42]	• Policy level obstacles regarding cost-limiting in renewable energy generation process • Benefitting large organizations and excluding small organizations restricted diffusion and deployment • Misguided policy level decisions affecting achievement of full capacity
United States	[41]	• Dependence on imported energy • High investment on nuclear energy • High price volatility of commercial energy in domestic market
Virgin Islands	[28]	• 100% dependence on fossil fuel based energy • Sustainable renewable energy systems not in place • High implementation cost is

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